Neurophysiological markers of prospective- and working-memory in typical ageing and Mild Cognitive Impairment

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Highlights

- Poorer conceptual prospective memory (PM[1]) and working memory (WM[2]) performance in mild cognitively impaired older adults (MCI[3]).
- MCI had deficits in P2 and parietal positivity amplitudes and reorientation negativity (RON[4]) latency.
- Older adults and MCI had delayed parietal positivity, reduced RON, raised N300 and frontal positivity amplitudes.

Abstract

Objective: Prospective memory (PM) —the memory of delayed intentions— is impacted by age-related cognitive decline. The current event-related potential study investigates neural mechanisms underpinning typical and atypical (Mild Cognitive Impairment, MCI) age-related decline in PM.

Methods: Young adults (YA, n=30, age=24.7, female n=13), healthy older adults (OA, n=39, age=72.87, female n=24) and older adults with MCI (n=27, age=77.54, female n=12) performed two event-based PM tasks (perceptual, conceptual) superimposed on an ongoing working memory task. Electroencephalographic data was recorded from 128 electrodes. Groups were compared for P2 (higher order perceptual processing), N300/frontal positivity (cue detection), the parietal positivity (retrieval), reorienting negativity (RON; attention shifting).

Results: Participants with MCI had poorer performance (ongoing working memory task, conceptual PM), lower P2 amplitudes, and delayed RON (particularly for perceptual PM) than YA and OA. MCI

[1] PM = prospective memory
[2] WM = working memory
[3] MCI = mild cognitive impairment
[4] RON = reorientation negativity

had lower parietal positivity relative to YA only. YA had earlier latencies for the parietal positivity than MCI and OA, and lower amplitudes for N300 (than OA) and frontal positivity (than OA and MCI).

Conclusions: Impaired attention and working memory may underpin PM deficits in MCI.

Significance: This is the first study to document the role of RON in PM and to investigate neurophysiological mechanisms underpinning PM in MCI.

1. Introduction

Mild cognitive impairment (MCI) is an intermediary state between typical ageing and dementia (Petersen et al., 1999). Older adults who meet diagnostic criteria for MCI are ten times more likely to develop dementia-related diseases (approximately 10–15% risk), such as Alzheimer's disease, than those without MCI (approximately 1–2% risk; Petersen et al., 2009). Cognitive domains such as episodic memory, executive function, attention, language and working memory have been intensively investigated (Dubois, 2009; Saunders and Summers, 2011; Brandt et al., 2009; Klekociuk et al., 2014). Blanco-Campal et al., (2009) suggest prospective memory as a sensitive early indicator of memory failure in MCI of suspected Alzheimer's disease aetiology, and subsequent work has begun to identify associated neurocognitive mechanisms (Costa et al., 2010).

Prospective memory (PM, the memory of delayed intentions) refers to the self-initiated execution of a planned action, contingent on contextual recognition of a retrieval cue at an appropriate time (McDaniel and Einstein, 2007). PM constitutes a large part of everyday memory (Kliegel et al., 2008; Boelen et al., 2011; e.g., remembering to take prescribed medications at the correct time) and everyday memory failures (Kliegel and Martin, 2003; e.g., forgetting to turn off the stove). The ubiquity of these actions underlies basic personal day-to-day functioning and is, therefore, an essential precursor for independent living. Impairment in PM can be more distressing than that of retrospective memory (Smith et al., 2000), and is often the first patient-reported complaint to family members and/or health professionals (Brandimonte et al., 2014). Thus, PM has clinical relevance, particularly as regards atypical ageing (Kliegel et al., 2011).

In event-based PM tasks, performance is usually facilitated by the visual appearance of the retrieval cue, prompting the response (McDaniel & Einstein, 2007). Compared to healthy controls, individuals with MCI consistently demonstrate poorer PM performance in event-based tasks (Thompson et al., 2017). Manipulation of the PM task design (e.g., specificity/saliency) increases the sensitivity and specificity in discriminating between typically ageing adults and those experiencing MCI compared to 'traditional' declarative memory tests (Blanco-Campal et al., 2009).

Compared to other neuroimaging methods, electroencephalographic (EEG) techniques, such as event-related potentials (ERPs) offer superior temporal resolution and have identified several components associated with PM performance (West, 2011). The N300, a negative deflection with a maximum amplitude parietooccipitally between 300–500ms post-onset, is thought to reflect cue identification (West, 2011). It is coupled with the midline frontal positivity component, implicated in task switching (i.e., from the ongoing to the PM task; West, 2011). The recognition of a delayed intention is reflected in a late positivity complex, with a centroparietal maxima extending across 400–1200ms post-stimulus-onset (West et al., 2001; West and Krompinger, 2005). One subcomponent of the late positivity complex, known as the parietal positivity (PP[5], 400–800ms) purportedly reflects intention retrieval.

Most PM ERP studies have manipulated the visual features of event-based PM cues (e.g., Scolaro et al., 2014; Cona et al., 2015). Some studies have begun to explore conceptually relevant PM tasks, such as semantic categories of words (Wang et al., 2013; Wilson et al., 2013; Cousens et al., 2015; Cruz et al., 2016). Perceptual features have been found to elicit strong N300 and prospective positivity responses in young adults. However, for conceptual PM stimuli in some instances, the N300 is found to be delayed (Cruz et al., 2016) or absent (Cousens et al., 2015).

[5] PP = parietal positivity

Two theoretically relevant, but under-investigated, components to PM and MCI are the P2 and reorientation negativity (RON). Some researchers suggest that the P2 (150–275ms) reflects selective attention (Lijffijt et al., 2009; Wongupparaj et al., 2018) or is related to familiarity (Doyle et al., 1996; Rugg and Nieto-Vegas, 1999) and the feeling of knowing in episodic memory tasks (Irak et al., 2019a; Irak et al., 2019b). While it remains unclear what the P2 reflects, the research does allude toward representing top-down semantic stimulus evaluation (Paynter et al., 2009; Irak et al., 2019b) and a peri-perceptual sense of familiarity (Doborjeh et al., 2018). P2 amplitudes may be preserved in older adults during semantic working memory (Kuo et al., 2014) but amplitude reductions and latency delays are found in older adults with MCI (Fix et al., 2015; López et al., 2016; Li et al., 2016; Lister et al., 2016). Given the documented early impairments of semantic memory in older adults with MCI (Pineault et al., 2018) and semantic encoding (Olichney et al., 2011), one would expect that a conceptual event-based PM paradigm would be particularly sensitive to functional changes in P2 due to MCI.

RON reflects two distinct functional processes of attentional reorientation after distraction: the re-focusing toward task-relevant information within working memory, and a general attentional reorientation/preparation for the next stimulus (Schröger et al., 2000). The RON remains uninvestigated in MCI but is impaired in schizophrenia, Parkinson's disease and traumatic brain injury (review: Justo-Guillén et al., 2019). Reduced amplitudes and prolonged latencies have been observed in older adults during an inhibitory control task, which was interpreted as a general slowing of cognitive processes (Cona et al., 2013). This indicates that reorientation capabilities may be susceptible to age-related cognitive decline. Given that behavioural studies demonstrate impaired task-switching in MCI (Belleville et al., 2008; Schmitter-Edgecombe and Sanders, 2009), RON should be investigated as an underpinning mechanism. The requirement to switch between the ongoing working memory task and the PM task in experimental PM studies would be expected to elicit a RON ERP. However, to date, no studies have examined RON after a successful PM response. The importance of examining this component in the current study is twofold: firstly, to determine the presence of RON following a PM response; and secondly, to investigate the effect of typical and atypical (MCI) ageing on RON.

Few ERP studies have investigated PM as a function of typical ageing and no research has explored PM ERPs in atypical ageing. Studies employing perceptually based PM cues report reduced N300 (West and Covell, 2001) and PP amplitudes (Zöllig et al., 2007; Mattli et al., 2011) in older relative to younger adults. Older adults may therefore have impaired PM cue detection and recall abilities. However, other research has not found amplitude differences in cue detection (Zöllig et al., 2007) and intention retrieval ERPs (West et al., 2003). Clarity would be gained from investigating the N300, frontal positivity and PP components of PM in older adults through variations in PM task type. By using similar tasks that vary PM cue characteristics, different facets of PM can be tested (Cousens et al., 2015; Cruz et al., 2016). Not all real-world PM cues will be predominately perceptual in nature and may vary in their salience and relation to the encoded intention (Cousens et al., 2015). Therefore, by examining both perceptual and conceptual PM cues, PM differences can be better understood between aged populations, young adults and those experiencing cognitive impairments.

The current study aims to investigate the neurophysiological differences in PM in healthy older adults (OA) and older adults with MCI (MCI). A semantic working memory task (the *n*-back task) acted as the ongoing task, with two types of embedded PM cue: perceptual and conceptual. Given the known behavioural impairments across PM cue types in OA and participants with MCI, examining performance in, and neurophysiological correlates of different PM tasks will further our understanding of PM in typical and atypical ageing.

2. Methods

2.1 Participants

Thirty right-handed young adults (YA; 13 females, mean age = 24.7 years, SD = 3.43) were recruited from the Nottinghamshire area, UK. Inclusion criteria required participants to have: normal or corrected to normal vision; be 18–35 years of age, no history of dyslexia, no history of drug abuse (including alcohol), no history or current diagnosis of psychiatric or neurological disorder or medication that may impact EEG recordings. In addition, thirty-nine right-handed typically ageing older adults (OA; 24 females, mean age = 72.87, SD = 4.18) were recruited through an internal database of older adult study volunteers. Inclusion criteria for the participation: fluent in English; >= 65 years of age; no paranoid of paraphrenic illness; no expression of memory impairments. Twenty-seven right-handed older adults with a confirmed diagnosis of MCI (MCI; 12 females, mean age = 77.54; SD = 6.49) were recruited through the study matching service: Join Dementia Research (JDR) and through a referral from Memory Assessment Clinics within the Nottinghamshire area. Participants referred by JDR or the memory assessment clinics had been diagnosed based on scores between 15–25 on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), 60–94 on the Addenbrookes Cognitive Examination III (ACEIII; Hsieh et al., 2013) or 18–26 on the Mini Mental State Examination (MMSE; Vertesi et al., 2001), depending on which measures each clinic used. Participants' exclusion for both older adult groups included: definite or probable Alzheimer's disease (as defined at the clinic); definite or probable dementia/dementia-related disease (as defined at the clinic); previous history of epilepsy/stroke; any evidence of clouding of consciousness; a history of drug abuse or dependence (including alcohol). All participants were required to abstain from alcohol for 24 hours, and from caffeine and nicotine for 3 hours prior to the study. Participants provided written informed consent. The study approval was issued by the Health Research Authority, UK (REC reference: 17/EM/1010).

2.1.1 Dementia Screening

Prior to participation in the study, all participants completed the Hopkins Verbal Learning Test-Revised (HVLT-R; Benedict et al., 1998). This was employed to ensure that older adults with MCI were not likely to have Alzheimer's disease and to ensure the healthy older adults were not likely to be experiencing MCI. This was possible with the HVLT-R due to higher sensitivity and specificity of differentiating between MCI and healthy controls compared to other cognitive tests such as the Mini-Mental State Examination (MMSE; de Jager et al., 2003). Particularly, evidence demonstrates that the HVLT total recall has the highest sensitivity and specificity compared to all other cognitive screenings tests for differentiating between MCI and dementia (de Jager et al., 2009). The optimal cut-off for MCI and dementia classification were based on the Hogervorst et al. (2014) HVLT literature review. Additionally, all participants completed the shortened version of the Geriatric Depression Scale (GDS; Sheikh and Yesavage, 1986) as a measure of depression, which has good diagnostic sensitivity and specificity in adults over 18 years old (Guerin et al., 2018). This was collected to ensure that older adults with MCI did not differ from the healthy older adults and did not meet the criteria for depression, which may potentially confound behavioural and neurophysiological responses.

2.2 Procedure

Data were recorded in a quiet room with a stable temperature (~20°C). After explaining the study procedure, the participants provided informed consent. Participants were then sat approximately 60cm away from a 19" (48.26cm)- diagonal colour LCD monitor (1,600 x 900 resolution: 60Hz refresh rate on a Windows Operating System). EEG equipment was then attached to the participant before impedance checks were made.

Participants were required to complete two PM tasks. These differed in their salience but maintained the same cognitive demands on working memory and intention retrieval. Stimuli between the ongoing-only task and PM tasks were kept the same. Different instructions were given for each PM task, thereby altering the nature of the encoded PM intention. As with similar studies (Chen et al., 2009; Cona et al., 2012), the ongoing-only working memory task was completed first (see Figure 1a) to minimise potential long-lasting interference effects of the PM instructions. This has been considered due to the noted effect of strategic monitoring engagement even when PM intentions were no longer required (Marsh et al., 2006; West et al., 2007). The two PM tasks built upon the ongoing task with the PM cues embedded within the stream of stimuli comprising the ongoing task (see Figure 1b). For both PM tasks, therefore, participants completed the PM task and the ongoing task simultaneously. The PM instructions were given at the start of the PM tasks followed by a delay, where participants were presented with at least 12 stimuli of the ongoing task before the first PM cue appeared. In line with past research (Cruz et al., 2016), only 10% of all stimuli presented were PM stimuli. This allows participants to re-engage with the ongoing stimuli task and better simulate real-life PM events, i.e., remembering to perform an action after a delay.

2.2.1 Ongoing Task

A 1-back word categorisation task was used as the ongoing task (Figure 1a). Participants made continuous semantic judgements of whether the word presented on a computer screen is of the same semantic category as a preceding word. Participants were shown a list of 10 categories and told that within each of these categories there are 10 words. Participants were instructed to press a button on a response box with their right index finger if the word was semantically related to the previous word (i.e., the category repeated from previous word) and to refrain from responding if the word was unrelated to the previous word (i.e., the category is non-repeated from previous word). The instructions included examples and a short practice block which provided feedback on whether the participant was correct or incorrect. Categories were created from the updated and expanded version of the Battig and Montague (1969) Category Norms (Van Overschelde et al., 2004) using the top 10 words from each category. The ongoing task was comprised of 300 stimuli with a 25% chance of a word belonging to the same semantic category as the previous category. Each word was presented for 500ms with a 2 seconds stimulus onset asynchrony between words. No feedback was given to the participant during the ongoing task. The 1-back targets (stimuli requiring a response during the ongoing task) will be referred to as a 1-back_{target}. The 1-back non-targets (stimuli that do not require a response during the ongoing task) will be referred to as $1\text{-back}_{nontargets}$. 'Ongoing' encompasses both $1\text{-back}_{targets}$ and $1\text{-back}_{nontargets}$. In order to minimise fatigue, short optional break-blocks were offered after every 30 stimuli, which varied in duration from 20 seconds and up to 3 minutes. All words were presented in lowercase.

2.2.2 Prospective Memory Task

The PM task is an adapted version of Cruz's (2016) PM paradigm incorporating two PM conditions: feature-based (referred to as *perceptual* within the literature and throughout the rest of the current study) and conceptual PM (illustrated in Figure 1b). Repeating the procedure of the ongoing task

(Figure 1a), participants were first presented with a list of 10 categories. Words (10 words from each category; 100 in total) were quasi-randomly presented. To mitigate practice effects, the experiments were programmed to not repeat a previously presented set of categories. Participants were instructed to press a labelled button on the response box with their right index finger if the word on the screen was from the same semantic category as the word before it. Participants were then instructed on the secondary PM task, which was based on either i) stimulus features (perceptual PM) or ii) semantics (conceptual PM).

For the perceptual PM condition ($PM_{percept}$), participants were told to remember to press the labelled button on the response box with their left index finger if they noticed the word appearing in capital letters, for example, the word 'SWORD'. For the conceptual PM condition ($PM_{concept}$), participants were told to remember to press the labelled button on the response box with their left index finger if they read the word of a four-footed animal, for example, the word 'lion'. The instructions included examples and a short practice block, which provided feedback informing the participants whether their response was correct or incorrect. The order of presentation of the PM tasks was counterbalanced to mitigate fatigue effects (tasks 2/3 in Figure 1b). Each PM task contained 600 stimuli, with breaks offered every 30 stimuli. PM cues occurred no more than 10% of the time and were presented pseudo-randomly to allow participants to re-engage with the ongoing task and to remove the chance of a PM cue repeating. As such, in each PM task there were approximately 60 stimuli trials. During the task no feedback was given after the participant's response.

[Please insert Figure 1 about here]

2.3 Electrophysiological Recording

Electroencephalographic activity was measured on the surface of the scalp using an active-electrode, 128 channel Active Two Acquisition system (BioSemi, Amsterdam, Netherlands) sampling at 2048Hz and digitised at 24-bits. Referencing was performed online using CMS/DRL feedback loop with a low pass filter (5th order since response with a -3dB at 1/5th sampling rate). During the electrode application, offsets were examined to ensure they were <20µV. Seven additional Ag/AgCl electrodes were placed around the face to help with artifact detection. Data were collected using ActiView V6.05 (National Instruments, TX, USA) on a Windows PC. A response box was used to record the participant's responses. Digital response and event markers were inserted into the recording data via a parallel port.

2.4 Depression and Behavioural Performance Analysis

To evaluate differences in the GDS between YA, OA and MCI a one-way ANOVA was performed. To assess the behavioural differences between the groups in response to PM stimuli, two mixed measures ANOVAs were conducted. To ensure that participants were not fatigued during the tasks, the behavioural responses were split into three equal time epochs. Reaction time and percentage of correct responses were analysed using a 3 (*Stimuli*: 1-$back_{target}$, $PM_{percept}$, $PM_{concept}$) x 3 (*Epoch*: 1^{st}, 2^{nd}, 3^{rd}) x 3 (*Group*: YA, OA, MCI) mixed measures ANOVA. Only data from successful responses to stimuli were analysed for reaction time due to the small number of incorrect responses.

2.5 EEG data Processing and Analysis

EEG data analysis and preprocessing were performed in MATLAB R2015a (The Mathworks, Inc) using custom-written scripts and the EEGLAB plugin (Delorme & Makeig, 2004). Data was imported

referenced to linked mastoids and downsampled to 256Hz. Following recommendations by Tanner, Morgan-Short and Luck (2015) a high-pass finite impulse (FIR) filter was applied at 0.01Hz and a low-pass FIR filter at 35Hz. Line noise was removed using the cleanline function before a visual inspection was performed to reject bad channels. Following an ICA (runica) decomposition, independent components were visually inspected, and ocular and muscular artifacts were rejected from the data based on their scalp topographies and activity spectra. Next, the stimulus triggers were recoded to incorrect and correct responses before epochs were extracted. ERP Epochs were 1000ms with a 200ms pre-stimulus baseline.

A virtual electrode method (Krusemark et al., 2008; Rousselet et al., 2010; Baker et al., 2018) was employed to generate maximal value ERPs of a defined electrode cluster. This method enables individual differences to be considered and minimises multiple comparisons from an area of interest. Clusters were informed through the consideration of previous EEG research of PM (West, 2011; Zöllig et al., 2012; Scolaro et al., 2014; Cruz et al., 2016) for the ongoing, $PM_{percept}$ and $PM_{concept}$ task conditions. The 128 channels were clustered into 18 clusters (Figure 2; Appendix A for a table of the clusters). $1\text{-back}_{nontarget}$ stimulus ERP amplitudes from the ongoing task were also extracted and analysed to explore passive working memory processes.

[Please insert figure 2 about here]

Peak detection was performed using custom-written scripts in Matlab 2015a on each waveform using the EEGLAB toolbox (Delorme and Makeig, 2004). P2 was defined as the maximum positive peak at midline frontal and central clusters and bilateral frontal, frontocentral and central clusters between 160–220ms. N300 was defined as the most negative peak at midline parietal and occipital clusters and bilateral inferior parietal and occipital clusters between 300–500ms. Frontal positivity was defined as the most positive peak at midline frontal and central and bilateral frontal and frontocentral clusters between 300–500ms. The PP was defined as the greatest positive amplitude between 400–800ms. RON was defined as being the most negative peak between 400–750ms over bilateral frontotemporal clusters. Latencies were measured at maximum peak and amplitude was measured as baseline-peak.

Statistical analyses were performed using Jefferys's Amazing Statistics Program (JASP; 0.10.1). The following analyses were used to test for group differences in P2, N300, frontal positivity, PP effect and RON. Each component was analysed independently and was further divided between midline and bilateral analyses in the following mixed measures ANOVAs. For all components, ANOVAs included *Stimuli* (1-back_{target}, $1\text{-back}_{nontarget}$, $PM_{percept}$, $PM_{concept}$) x *Group* (YA, OA, MCI) as variables. In addition, ANOVAs of bilateral measures included *Hemisphere* (left, right) and *Cluster*. Level in the *Cluster* variable varied depending on the component: P2 and frontal positivity (frontal, frontocentral, central), N300 (parietal, occipital), PP (central, parietal), RON (frontotemporal). Separate ANOVAs were performed for amplitudes and latencies. Lower-order ANOVAs were used to explore significant interactions. Simple linear contrasts with Bonferroni corrections (Cabin and Mitchell, 2000) were used for post-hoc analyses of *Group* and are separated in the results with a pipe (|). Greenhouse-Geisser was used to correct for violations of sphericity. Only ERP data from correct responses were analysed.

3. Results

Three participants with MCI were removed due to indications of probable dementia as indicated by the HVLT. One YA participant was removed due to poor EEG data (approximately 50% of electrodes had offsets > 20μV). One participant from the OA and one from the MCI group were removed as they

did not complete all conditions. Thus, the number of participants used in the final analysis were: YA = 29; OA = 36; MCI = 23.

3.1 Depression Results

No participants were excluded as none met the criteria for depression. There was a significant effect of *Group* ($F_{2,90} = 6.66$, $p = 0.002$, $\eta_p^2 = 0.13$), which was due to YA reporting significantly greater levels of depression than OA ($p = 0.001$). There was no significant difference between the OA and MCI group ($p = 0.22$), suggesting that differences between OA and MCI are likely not due to depression.

3.2 Behavioural Results

3.2.1 Correct Responses

Percentage of correct response results are illustrated in Figure 3(a); descriptions can be found in Table 1. There was a significant effect of *Stimuli* ($F_{1.85,166.38} = 82.76$, $p < 0.001$, $\eta_p^2 = 0.50$). For all groups $PM_{concept}$ performance was significantly worse relative to $PM_{percept}$ (all *ps* < 0.05).

Additionally, there was a significant main effect of *Group* ($F_{2,89} = 8.54$, $p < 0.001$, $\eta_p^2 = 0.16$) and a *Stimuli*Group* interaction ($F_{4,178} = 3.60$, $p = 0.008$, $\eta_p^2 = 0.08$), which was due to significant effects of *Group* for ongoing ($F_{2,89} = 14.30$, $p < 0.001$, $\eta_p^2 = 0.24$) and $PM_{concept}$ ($F_{2,89} = 4.08$, $p = 0.020$, $\eta_p^2 = 0.08$) but not $PM_{percept}$ stimuli. MCI performed worse for ongoing stimuli relative to OA and YA (*ps* < 0.001) and worse for $PM_{concept}$ relative to OA ($p = 0.16$). There were no main or interaction effects of *Epoch* suggesting that participants were not fatigued by the tasks.

3.2.2 Reaction Time

Reaction time results are illustrated in Figure 3(b); descriptions can be found in Table 2. There was a significant effect of *Stimuli* ($F_{1.87,166.06} = 32.17$, $p < 0.001$, $\eta_p^2 = 0.26$), such that that it required a significantly greater amount of time to correctly respond to $PM_{concept}$ stimuli relative to $PM_{percept}$ ($p < 0.001$) and 1-$back_{target}$ stimuli ($p < 0.001$). Additionally, the $PM_{percept}$ stimuli was responded to faster than 1-$back_{target}$ stimuli ($p = 0.017$).

There was also a significant interaction of *Stimuli*Epoch* ($F_{2.00,177.62} = 4.15$, $p = 0.014$, $\eta_p^2 = 0.04$), where relative to the first 1st epoch, response times were faster in the 2nd and 3rd epochs for $PM_{concept}$ stimuli (*ps* < 0.002). This further supports the notion that participants were not fatigued during the study but may suggest practice effects. There were no other significant effects.

[Please insert Figure 3 about here]

3.3 Electrophysiology

ERP descriptions can be found in Appendix B.

Peak amplitudes have the advantage of accounting for individual differences in component onset and peak latency (Luck, 2014), however, mean amplitudes are resilient to random fluctuations (noise) in the amplitude. As such, the PP and RON peak amplitude analyses were repeated with mean amplitudes (defined as the mean over their respective epochs) to account for their broad, less well-defined peaks.

3.3.1 Effects of atypical ageing: MCI-specific deficits

Frontocentral P2

A summary of all significant P2 *Group* effects and interactions can be found in Table 3. There was a significant *Cluster*Group* interaction over bilateral P2 amplitudes ($F_{2,87}$ = 3.28, p = 0.033, η_p^2 = 0.09; visualised in Figure 4). The MCI groups showed significantly lower amplitudes at frontocentral clusters, relative to the OA and YA across all conditions (all ps < 0.05).

There was a significant *Stimuli*Group* interaction at the midline frontocentral cluster for P2 amplitudes ($F_{5.14,221.04}$ = 5.37, p < 0.001, η_p^2 = 0.14). This was due to a *Stimuli* effect for YA ($F_{3,54}$ = 5.34, p = 0.003, η_p^2 = 0.23; 1-back$_{target}$ > 1-back$_{nontarget}$ | PM$_{percept}$ > 1-back$_{nontarget}$, ps < 0.05) and for OA ($F_{3,75}$ = 4.27, p = 0.008, η_p^2 = 0.15; 1-back$_{target}$ > 1-back$_{nontarget}$ & PM$_{percept}$, ps < 0.05), which was not found for MCI.

There was a significant *Hemisphere*Group* interaction for lateral P2 latencies ($F_{2,87}$ = 3.55, p = 0.034, η_p^2 = 0.10). The MCI group showed significantly delayed right hemisphere responses relative to the left hemisphere ($F_{1,22}$ = 7.39, p = 0.019, η_p^2 = 0.38).

[Please insert Figure 4 about here]

RON latency

Results of the significant *Group* analyses for the lateral reorientation negativity are visualised in Figure 5 and are summarised in Table 4. A *Stimuli*Group interaction* was due to a significant effect of *Group* in response to PM$_{percept}$ stimuli ($F_{2,87}$ = 12.78, p < 0.001, η_p^2 = 0.24; YA < OA, p = 0.008; YA < MCI, p < 0.001; OA < MCI, p = 0.019). Furthermore, there was a significant effect of *Stimuli* in YA ($F_{3,84}$ = 16.77, p < 0.001, η_p^2 = 0.41; PM$_{concept}$ > PM$_{percept}$, p < 0.001; PM$_{concept}$ > 1-back$_{nontarget}$ stimuli, p = 0.022) and in OA ($F_{3,111}$ = 3.31, p = 0.024, η_p^2 = 0.11; PM$_{concept}$ < 1-back$_{nontarget}$, p = 0.022), which was not found for MCI group.

[Please insert Figure 5 about here]

Parietal positivity amplitude

In the lateral clusters there was a significant *Stimuli*Hemisphere*Group* interaction ($F_{5.15,224.18}$ = 4.12, p = 0.001, η_p^2 = 0.10), due to a significant *Stimuli*Group* interaction in the right hemisphere ($F_{4.83,209.89}$ = 3.68, p = 0.004, η_p^2 = 0.09) for PM$_{percept}$ stimuli (YA > MCI, p = 0.005), which was not seen in the left. Additionally, the three-way interaction is explained by a *Stimuli*Hemisphere* interaction ($F_{3,84}$ = 5.49, p = 0.005, η_p^2 = 0.17) for PM$_{percept}$ in YA (right > left, p = 0.024) and 1-back$_{target}$ in OA ($F_{2.54,93.73}$ = 15.75, p < 0.001, η_p^2 = 0.33; right > left, p < 0.001), which was not found in the MCI group. All significant *Group* effects for the PP are summarised in Table 5.

To confirm the group effects that may be potentially disrupted by unstable ERP latencies due to affected cognition, mean amplitude analyses for the parietal positivity are presented in the footnote[6].

[6] In lateral clusters there was a significant *Stimuli*Hemisphere*Group* interaction ($F_{5.47,240.55}$ = 7.00, p < 0.001, η_p^2 = 0.17), due to a significant *Stimuli*Group* interaction in the left hemisphere ($F_{4.91,216.10}$ = 18.75, p < 0.001, η_p^2 = 0.35) for PM$_{percept}$

3.3.2 Effects of typical ageing: how do MCI and OA differ from YA?

Parietal positivity amplitude

Figure 6 shows averaged ERPs at the midline parietal cluster for each *Stimulus* as a function of *Group*. At midline clusters there was a significant *Stimuli*Group* interaction ($F_{4.87,211.97} = 4.87$, $p < 0.001$, $\eta_p^2 = 0.12$). Further analysis showed that YA showed significantly greater PP amplitudes for $PM_{percept}$ relative to both OA and MCI groups (*ps* < 0.001). Additionally, YA displayed significantly greater amplitudes for 1-$back_{target}$ and 1-$back_{nontarget}$ stimuli relative to individuals with MCI (*ps* < 0.05). Additionally, there was a significant *Cluster*Group* interaction ($F_{2,87} = 4.21$, $p = 0.019$, $\eta_p^2 = 0.11$), that was due to a significant effect of *Group* at the parietal cluster (YA > OA and MCI groups, *ps* < 0.001) and at central clusters (YA > MCI, $p = 0.041$).

Mean amplitude analysis is presented in the footnote[7].

Parietal positivity latency

The significant *Cluster*Group* interaction at midline clusters ($F_{2,87} = 4.81$, $p = 0.011$, $\eta_p^2 = 0.12$) was due to a significant effect of *Group* at the parietal cluster (YA < OA, $p = 0.035$; YA < MCI, $p < 0.001$; OA < MCI, $p = 0.064$ (trend)). There was also a *Stimuli*Group* interaction ($F_{2.68,181.98} = 3.31$, $p = 0.006$, $\eta_p^2 = 0.09$), due to an effect of *Stimuli* for 1-$back_{target}$ (YA < OA, $p = 0.039$) and 1-$back_{nontarget}$ (YA < OA, $p = 0.036$). This was not found for the PM conditions.

The significant *Stimuli*Group* interaction at lateral clusters ($F_{5.40,186.26} = 2.66$, $p = 0.07$, $\eta_p^2 = 0.07$), was due to an effect of *Group* for $PM_{percept}$ stimuli ($F_{2,87} = 10.01$, $p < 0.001$, $\eta_p^2 = 0.20$; YA < OA, $p = 0.025$). A significant effect of *Group* was found for $PM_{concept}$ stimuli ($F_{2,87} = 3.24$, $p = 0.044$, $\eta_p^2 = 0.14$) but did not remain significant after Bonferroni corrections were applied.

[Please insert figure 6 about here]

RON amplitude

(YA > OA & MCI, *ps* < 0.001) and $PM_{concept}$ (YA > OA & MCI, *ps* < 0.02) and a *Stimuli*Group* interaction in the right hemisphere ($F_{5.48,241.00} = 8.41$, $p < 0.001$, $\eta_p^2 = 0.19$) for $PM_{percept}$ (YA > OA, $p = 0.008$). Additionally, the three-way interaction is explained by a *Stimuli*Hemisphere* interaction ($F_{2.89,93.97} = 2.11$, $p = 0.015$, $\eta_p^2 = 0.14$) for 1-$back_{target}$ and both PM stimuli in OA (right > left, *ps* < 0.001). A similar effect was found for MCI but only in the PM stimuli (right > left, *ps* < 0.01).

[7] At midline clusters there was a significant effect of *Group* ($F_{2,87} = 8.96$, $p < 0.001$, $\eta_p^2 = 0.21$), where YA had larger amplitudes relative to OA and MCI (*ps* = 0.002). There was also a significant three-way *Stimuli*Cluster*Group* ($F_{5.50,236.47} = 2.87$, $p = 0.045$, $\eta_p^2 = 0.06$), which was due to a *Cluster*Group* interaction for the 1-$back_{nontarget}$ ($F_{2,87} = 4.31$, $p = 0.017$, $\eta_p^2 = 0.10$) in the parietal cluster (YA > MCI, $p = 0.015$). Additionally, the three-way interaction was explained by a *Stimuli*Group* interaction in the central cluster ($F_{5.45,239.74} = 18.39$, $p < 0.001$, $\eta_p^2 = 0.10$) for $PM_{percept}$ stimuli (YA > OA & MCI, *ps* < 0.001) and in the parietal cluster ($F_{5.38,236.62} = 9.72$, $p < 0.001$, $\eta_p^2 = 0.22$) for 1-$back_{target}$, 1-$back_{nontarget}$ (YA > MCI, $p = 0.033$ & $p = 0.015$, respectively), $PM_{percept}$ (YA > OA & MCI, *ps* < 0.001) and $PM_{concept}$ (YA > OA, $p = 0.013$). In OA there was a *Stimuli*Cluster* interaction ($F_{2.66,100.96} = 5.65$, $p = 0.001$, $\eta_p^2 = 0.16$) due to greater parietal 1-$back_{target}$ amplitudes relative to the midline central cluster ($p = 0.031$) and greater $PM_{concept}$ amplitudes in central clusters relative to 1-$back_{nontarget}$ ($p = 0.015$).

The significant *Stimuli*Group* interaction ($F_{4.72,205.20}$ = 6.93, p = 0.001, η_p^2 = 0.17) demonstrated an effect of *Group* for $PM_{percept}$ ($F_{2,87}$ = 12.78, p < 0.001, η_p^2 = 0.24) and $PM_{concept}$ stimuli ($F_{2,87}$ = 10.49, p < 0.001, η_p^2 = 0.21; YA > both OA and MCI, all *ps* < 0.001) in the lateral frontotemporal clusters. Moreover, there was a significant *Hemisphere*Group* interaction ($F_{2,87}$ = 6.72, p = 0.002, η_p^2 = 0.17), due to an effect of *Group* ($F_{2,87}$ = 9.70, p < 0.001, η_p^2 = 0.22) over the right (but not left) hemisphere: YA > OA (p < 0.001) and MCI (p = 0.001). Additionally, there was a significant effect of *Hemisphere* in OA and MCI (left > right; OA, $F_{1,37}$ = 22.51, p < 0.001; MCI, $F_{1,22}$ = 13.85, p = 0.002).

Given that RON is broad waveform and that the current study is the first to investigate RON in MCI, findings for the RON were confirmed using mean amplitude and are presented in the footnote[8].

N300 latency

A summary of all significant N300 amplitude and latency *Group* effects are presented in Table 6. The midline analysis of N300 latencies demonstrated a significant *Stimuli*Group* interaction ($F_{6,261}$ = 3.58, p = 0.002, η_p^2 = 0.09), which was due to a significant *Group* effect for $1\text{-back}_{nontarget}$ stimuli ($F_{2,87}$ = 6.17, p = 0.003), where YA evoked an N300 response earlier than OA (p = 0.002). Additionally, a *Group* effect for $PM_{percept}$ stimuli was found ($F_{2,87}$ = 10.01, p < 0.001), where YA evoked an N300 responses earlier than OA (p < 0.001) and MCI (p = 0.004).

Over bilateral clusters a significant *Cluster*Group* interaction ($F_{2,87}$ = 7.05, p = 0.002, η_p^2 = 0.16) was due to a significant effect of *Group* at occipital clusters ($F_{2,87}$ = 3.87, p = 0.025, η_p^2 = 0.10; YA < OA, p = 0.026).

Moreover, there was a significant three-way *Stimuli*Hemisphere*Group* interaction in the lateral clusters ($F_{6,261}$ = 9.21, p = 0.012, η_p^2 = 0.07). This interaction effect was due to a significant *Stimuli*Hemisphere* interaction for YA ($F_{3,84}$ = 6.41, p < 0.001, η_p^2 = 0.32). For YA, left N300 latency was significantly earlier for 1-back_{target} than $1\text{-back}_{nontarget}$ (p = 0.032) and $PM_{percept}$ (p = 0.009); right N300 latency was earlier for $PM_{percept}$ than 1-back_{target} (p < 0.001), $1\text{-back}_{nontarget}$ (p = 0.025) and $PM_{concept}$ (p = 0.002). Additionally, there was a significant *Stimuli*Hemisphere* interaction in OA ($F_{3,99}$ = 3.20, p = 0.027, η_p^2 = 0.09), such that left N300 latency in response to $1\text{-back}_{nontarget}$ was later than 1-back_{target} (p = 0.006), whilst right N300 latency in response to $1\text{-back}_{nontarget}$ was delayed, relative to both 1-back_{target} (p < 0.001) and $PM_{percept}$ (p = 0.010). Furthermore, there was a significant *Hemisphere*Group* interaction ($F_{2,87}$ = 7.05, p = 0.002, η_p^2 = 0.15), which was due to an earlier left N300 latency for 1-back_{target} in YA ($F_{1,28}$ = 20.57, p < 0.001).

3.3.3 Compensatory effects of ageing.

[8] The significant effect of *Group* ($F_{2,87}$ = 4.13, p = 0.020, η_p^2 = 0.11) was due to more negative amplitudes in YA relative to MCI (p = 0.027). The significant *Stimuli*Group* ($F_{4.81}$ = 3.79, p = 0.034, η_p^2 = 0.06) demonstrated an effect of *Group* for $PM_{percept}$ ($F_{2,87}$ = 9.24, p < 0.001, η_p^2 = 0.19) where YA had significantly more negative amplitudes than OA and MCI (*ps* < 0.001) in the right frontotemporal cluster with a trending effect for $PM_{concept}$ ($F_{2,87}$ = 2.80, p = 0.068, η_p^2 = 0.07). Effects of *Stimuli* were only found in the YA ($F_{3,81}$ = 7.69, p < 0.001, η_p^2 = 0.24: $PM_{percept}$ > 1-back_{target}, p = 0.002; $PM_{percept}$ > $1\text{-back}_{nontarget}$, p < 0.001; $PM_{percept}$ > $PM_{concept}$, p = 0.011).

There was a significant *Hemisphere*Group* interaction ($F_{2,87}$ = 3.24, p = 0.046, η_p^2 = 0.09) due to an effect of *Group* ($F_{2,87}$ = 6.64, p = 0.002, η_p^2 = 0.16) over the right (but not left) hemisphere: YA > OA (p = 0.006) and MCI (p = 0.008). Additionally, there was a significant effect of *Hemisphere* in OA (left > right; OA, $F_{1,37}$ = 15.24, p < 0.001, η_p^2 = 0.35), which was not found in YA or MCI (*ps* > 0.05).

N300 amplitude

At midline clusters the N300 amplitudes demonstrated a significant main effect of *Group* at midline clusters ($F_{2,87}$ = 4.95, p = 0.010, η_p^2 = 0.12; YA < OA, p = 0.010).

At lateral clusters there was a significant three-way interaction of *Stimuli*Cluster*Group* at lateral posterior clusters ($F_{5.01,215.24}$ = 3.05, p = 0.011, η_p^2 = 0.08). Further analysis revealed that over bilateral inferior parietal clusters ($F_{4.86,211.37}$ = 4.28, p = 0.001, η_p^2 = 0.11), the OA evoked significantly greater amplitudes compared to the YA for 1-back$_{nontarget}$ (p < 0.001) and PM$_{concept}$ stimuli (p = 0.017). Descriptively, MCI evoked more negative amplitudes for both the 1-back$_{nontarget}$ and PM$_{concept}$ stimuli relative to YA but were not significantly different to YA or OA (ps > 0.05).

Frontal positivity amplitude

A summary of all *Group* effects is presented in Table 7. Midline frontal positivity showed a significant *Stimuli*Group* interaction ($F_{5.07,217.04}$ = 2.59, p = 0.027, η_p^2 = 0.07), due to significantly greater amplitudes in OA and MCI, compared to YA, for 1-back$_{target}$ ($F_{2,87}$ = 7.20, p = 0.001, η_p^2 = 0.15), 1-back$_{nontarget}$ ($F_{2,87}$ = 16.22, p < 0.001, η_p^2 = 0.29) and PM$_{concept}$ ($F_{2,87}$ = 9.12, p < 0.002, η_p^2 = 0.18) stimuli (all ps < 0.001 for OA and ps < 0.02 for MCI), but not for PM$_{percept}$. Similarly, for bilateral frontal positivity, a significant *Group* effect was found (OA > YA, p < 0.001; MCI > YA, p = 0.025).

4. Discussion

The current study is the first, to the author's knowledge, to use ERPs to examine neurophysiological mechanisms underpinning atypical age-associated decline in PM. It is also the first to investigate RON in PM. Participants, particularly, the MCI group, performed worse in the conceptual PM task than other tasks. Participants with MCI had poorer performance (ongoing working memory and conceptual PM relative to healthy older adults), lower bilateral frontocentral P2 amplitudes, delayed RON than both other groups and lower PP amplitudes (relative to young adults only). Furthermore, PM tasks appear to elicit greater RON amplitudes than ongoing tasks in young adults (also shown for conceptual PM tasks with older adults). However, this effect was absent in those with MCI. RON latency in older adults was earlier than for those with MCI and delayed compared to young adults for non-repeat ongoing stimuli and perceptual PM stimuli.

Regarding typical ageing, compared to young adults, both healthy older adults and MCI groups had lower amplitudes and delayed latencies for the PP, and higher amplitudes for N300 and frontal positivity. Lower RON amplitudes and a left hemisphere bias (i.e., greater RON amplitudes relative to ongoing stimuli were only found over the left hemisphere) were seen in both older (compared to younger) adult groups. For perceptual PM stimuli, both older adult groups had reduced PP amplitudes at midline clusters (and left hemisphere in mean amplitude analyses) and a longer latency at midline and bilateral regions. However, the hypothesised reduction in N300 amplitudes in older groups was not supported.

4.1 Mild cognitive impairment specific deficits

The current study reveals poorer accuracy but not reaction time in those with MCI compared to other groups for the ongoing working memory task, suggesting an impairment in semantic working memory.

This could reflect a speed-accuracy trade-off for those with MCI (Lassen-Greene et al., 2017). However, without evaluating differences between correct and incorrect responses, a speed-accuracy trade-off remains speculative. The absence of group differences in salient perceptual-based PM, which relies more on spontaneous retrieval (Knight et al., 2011), may reflect intact spontaneous recall of PM in MCI. However, the impairment for those with MCI in the conceptual PM task suggests active monitoring for PM stimuli may be affected in line with PM tasks requiring strategic monitoring (Karantzoulis et al., 2009; Niedzwienska et al., 2017).

In line with previous studies (Li et al., 2016; Waninger et al., 2018), the current results demonstrate attenuated frontocentral P2 amplitudes in older adults with MCI compared to healthy older and younger adults. Recent studies have linked the P2 to a peri-perceptual sense of familiarity (Doborjeh et al., 2018) and the feeling of knowing in episodic memory tasks (Irak et al., 2019a; Irak et al., 2019b). Given the similarity between episodic and PM tasks (Brewer and Marsh, 2010), one might also assume that reduced P2 amplitudes reflect a decrease in familiarity and feelings of knowing in the presented stimulus, supporting evidence of familiarity deficits as an early cognitive impairment marker (Anderson et al., 2021).

The current results suggest typical age-associated changes in PM RON latency are accelerated in MCI. Cona et al., (2013) attribute an age-related latency delay in the RON to a specific deficit in attentional shifting and not to a general slowing of processes with advancing age. This supports previous research of age-related RON delays (Correa-Jaraba et al., 2016) and extends them to also occur following PM cues. In MCI, this decline was particularly exaggerated for perceptual PM cues. Thus, reorienting back to an ongoing task following a perceptual PM cue may be particularly sensitive to atypical ageing. Such results are the first to highlight the potential of the RON during PM as an early biomarker of cognitive decline. Moreover, the results here support fMRI evidence implicating attention networks and the right inferior frontal cortex during task-switching as a preclinical marker of Alzheimer's disease (Gordon et al., 2015; Oh et al., 2016). Further research should draw a RON comparison between MCI and dementia-related diseases in PM.

4.2 Neurophysiological age-related deficits

As hypothesised, both aged participant groups had evoked attenuated PP ERPs relative to younger adults, providing further support for reduced intention retrieval responses in older adults (West and Bowry, 2005; Zöllig, 2007). However, unlike previous studies, PP attenuation was present without behavioural group differences. This may be due to the dedifferentiation of neuronal source distinctiveness where blurring of localised activity causes detected amplitudes to be more dispersed throughout the cortex resulting in lower amplitudes (Koen and Rugg, 2019). Importantly, we did not find further attenuation of the PP for the MCI group suggesting that intention retrieval may remain unaffected in older adults experiencing cognitive decline. These results were confirmed in the mean amplitude analysis but also demonstrated that the younger adults have greater amplitude responses relative to both older adult groups in response to both PM stimuli in the left hemisphere.

The results indicate earlier PP responses for younger adults compared to both older adult groups. Those with MCI were trending towards slower PP responses relative to healthy older adults. This may not have reached significance due to the heterogeneity of the MCI sample and the possible inclusion of MCI subtypes. The earlier PP latencies of the younger adults without faster reaction times may suggest differences in neural strategies as previously demonstrated in task-switching studies (Gáal and Czigler, 2015).

The current study suggests age-related lateralisation of RON responses. The lateralisation of the RON with age concurs with findings from a visual inhibitory control task (Cona et al., 2013) showing greater RON amplitudes for younger adults compared to older adults over the right (but not left) frontotemporal scalp regions during detect trials. Together, the results from Cona et al. (2013) and the current study suggest lateralisation of the structures responsible for reorienting attention, although the mean amplitudes suggest that this may be compromised in individuals with MCI. Source localisation data implicate frontotemporal scalp regions in the RON (Schröger et al., 2000). Thus, whilst asymmetry may decline anteriorly with age in some experiments (Cabeza, 2002), exaggerated lateralisation in frontotemporal structures underpinning orientation of attention may occur.

4.3 Neurophysiology age-related compensation

In line with previous studies (Wilson et al., 2013; Hering et al., 2016), the N300 and frontal positivity did not show age-related amplitude attenuation. Instead, the N300 demonstrated greater amplitudes in the older relative to younger adults as seen in childhood (Sumich et al., 2012) and Schizophrenia (Sumich et al., 2013). No differences were found between the healthy older adults and older adults with MCI, implying that PM cue detection is retained in MCI and likely does not contribute to the reported PM deficits in MCI.

N300 amplitude attenuations are reportedly due to an inability to recruit preparatory attentional processes, which was supported by reported behavioural deficits (Smith and Bayen, 2006). However, as behavioural deficits were not found in the current study, the N300 may not reflect recruitment of preparatory attentional processes but instead indicate the recruitment of different neural strategies (West and Bowry, 2005). This is supported by increased frontal positivity in the older relative to younger adults, which has similarly been found during simple working memory tasks (Tays et al., 2011). Older adults may be recruiting frontal networks to a greater extent to support the maintenance of intentions as proposed in a recent fMRI study (Peira et al., 2016).

The earlier N300 responses of the younger relative to older adults found here without earlier reaction times further supports the notion that older adults are relying on different neural mechanism for successful PM cue detection (Hering et al., 2016). Some latency effects (e.g., RON and N300) were in opposite directions between the younger and older adults and were absent in the older adults with MCI. It remains unclear why the latencies of ERPs are different between younger and older adults; further research is required to understand these differences.

4.4 Limitations and future studies

As this study is the first to document the RON in both PM and MCI, future research should further explore this effect in different PM task designs and replicate this effect in MCI and early Alzheimer's disease. In addition, RON differences between conceptual and perceptual stimuli may be due to the focality of the PM task. Although salient, the perceptual PM stimuli may be considered non-focal. This is because the semantic features are not processed as part of the ongoing task, whereas the conceptual PM stimuli can be considered focal due to being evaluated with the semantic features. Thus, reorienting attention might have been easier for participants for conceptual PM cues. Future research should vary the focality of PM cues when evaluating the RON in PM.

It is to be noted that subtypes of MCI were not recorded, which due to the heterogeneity of MCI (Panza et al., 2007) may have masked other potential neurophysiological differences between groups. Recently, structural brain differences have been found between those with amnestic and non-

amnestic MCI (Csukly et al., 2016). Based on the poorer retrospective memory scores of those with amnestic relative to non-amnestic MCI, one might expect that the ERPs associated with intention retrieval (i.e., the parietal positivity) would be significantly reduced relative to those with amnestic MCI. It was not possible to separate MCI subtypes in the current study, but the authors reinforce the need for further research to examine the neurophysiology of PM in subtypes of MCI. Furthermore, instrumental activities of daily living (iADLs) were not recorded to support classification of individuals with MCI within the current study. This poses a limitation as iADL impairments are not only related to an increased risk of dementia (Cloutier et al., 2013) but also forms a defining diagnostic characteristic between dementia and MCI (Altieri et al., 2021).

It should also be noted that the results of the current study may not extend beyond a laboratory setting. Often within laboratory settings older adults perform worse relative to young adults (Henry et al., 2004). However, when comparing younger and older adults in 'real-world' PM tasks, older adults often perform on a par with or even outperform the younger adults (Niedźwieńska et al., 2020; Schnitzspahn et al., 2016). It is unclear to what extent this PM paradox extends to those with MCI although it would be of interest to replicate the results here in a format that better reflects daily living PM (e.g., virtual reality).

4.5 Summary

To conclude, participants with MCI were associated with poorer behavioural performance in the ongoing working memory and conceptual PM task. Neurophysiological evidence demonstrated reduced frontocentral P2 amplitudes for older adults with MCI, possibly reflecting deficits in networks associated with familiarity. Behavioural differences between young and healthy older adults were not found. Nevertheless, their neurophysiological responses suggest different neural strategies related to PM cue detection and intention retrieval. Finally, neurophysiological evidence indicates the presence of a RON following PM stimulus retrieval, which was markedly decreased in older adults over the right hemisphere. Furthermore, latency delays of the RON indicate attention shifting deficits in older adults and an increased delay may serve as an early biomarker of cognitive decline.

Conflict of Interest Statement

None of the authors has potential conflicts of interest to be disclosed.

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Contribution of authors

- Mark Crook-Rumsey conducted the literature search, participated in the design of the methods, experimental design, collected data, conducted preprocessing and data analysis and interpretation, authored and reviewed drafts of the paper, prepared figures/or tables, approved the final draft and submitted the manuscript.
- Christina J. Howard participated in the design of the method, experimental design, statistical analysis interpretation, authored and reviewed drafts of the paper, approved the final draft.
- Florentina Hadjiefthyvoulou participated in the statistical interpretation, authored and reviewed drafts of the paper, approved the final draft.

- Alexander Sumich conducted the literature search, participated in the design of the methods, experimental design, conducted data analysis and interpretation, reviewed drafts of the paper, approved the final draft.

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Tables

Table 1.

Means and Standard Deviations of Behavioural Responses for the Percentage of Correct Responses.

Stimuli	YA			OA			MCI		
Epoch	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
1-back$_{target}$	80.46 (12.54)	80.52 (14.55)	80.95 (11.27)	75.19 (15.81)	78.00 (10.91)	82.03 (12.09)	61.47 (16.95)	67.71 (15.06)	63.60 (21.83)
PM$_{percept}$	97.77 (3.23)	98.12 (3.07)	98.22 (4.52)	98.06 (4.25)	97.95 (3.47)	96.19 (12.86)	95.04 (18.70)	94.09 (20.87)	94.02 (20.71)
PM$_{concept}$	83.19 (13.25)	84.51 (14.65)	90.03 (8.60)	90.90 (9.67)	90.95 (12.77)	89.37 (15.22)	79.60 (20.38)	80.69 (21.08)	79.18 (27.49)

Standard deviations are given in parentheses. YA = young adult, OA = older adult, MCI = older adult with mild cognitive impairment. 1-back$_{target}$ = stimuli requiring response. 1-back$_{nontarget}$ = stimuli not requiring a response. PM$_{percept}$ = perceptual prospective memory stimuli. PM$_{concept}$ = conceptual prospective memory stimuli.

Table 2.

Means and Standard Deviations of Behavioural Responses for Reaction Time in Milliseconds.

Stimuli	YA			OA			MCI		
Epoch	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
1-back$_{target}$	0.77 (1.45)	0.76 (0.13)	0.76 (0.14)	0.77 (0.13)	0.77 (0.12)	0.78 (0.17)	0.77 (0.29)	0.77 (0.29)	0.83 (0.52)
PM$_{percept}$	0.73 (0.10)	0.71 (0.08)	0.70 (0.10)	0.70 (0.14)	0.70 (0.19)	0.69 (0.19)	0.68 (0.30)	0.67 (0.29)	0.68 (0.29)
PM$_{concept}$	0.98 (0.13)	0.92 (0.11)	0.89 (0.13)	0.92 (0.32)	0.87 (0.30)	0.86 (0.30)	0.97 (0.34)	0.93 (0.34)	0.93 (0.38)

Standard deviations are given in parentheses. YA = young adult, OA = older adult, MCI = older adult with mild cognitive impairment. 1-back$_{target}$ = stimuli requiring response. 1-back$_{nontarget}$ = stimuli not requiring a response. PM$_{percept}$ = perceptual prospective memory stimuli. PM$_{concept}$ = conceptual prospective memory stimuli.

Table 3.

Summary of Significant Group Effects for P2 ERP Amplitudes and P2 ERP Latencies.

Midline P2 ERP amplitude	Lower	F	DF	*p*	η_p^2	Post-Hoc Tests
Stimuli*Group		5.37	5.14,221.04	<0.001	0.14	
	YA	5.34	3,54	0.003	0.23	1-back$_{target}$ > 1-back$_{nontarget}$ | PM$_{percept}$ > 1-back$_{nontarget}$ & PM$_{concept}$
	OA	4.27	3,75	0.008	0.15	1-back$_{target}$ > 1-back$_{nontarget}$ & PM$_{percept}$
Lateral P2 ERP amplitude						
Cluster*Group		4.79	2.83,113.26	0.005	0.14	
	FC	3.28	2,87	0.033	0.09	MCI < OA & YA
Lateral P2 latencies						
Hemisphere* Group		3.55	2,87	0.034	0.10	
	MCI	7.39	1,22	0.019	0.38	R > L

YA = young adults. OA = healthy older adults. MCI = older adults with MCI. 1-back$_{target}$ = stimuli requiring response. 1-back$_{nontarget}$ = stimuli not requiring a response. PM$_{percept}$ = perceptual prospective memory stimuli. PM$_{concept}$ = conceptual prospective memory stimuli. FC = Frontocentral. R = Right hemisphere. L = Left hemisphere. | = separator between post-hoc tests.

Table 4.

Summary of Significant Group Effects for Reorientation Negativity (RON) ERP Amplitudes and RON ERP Latencies.

Lateral reorientation negativity ERP amplitude	Lower	F	DF	*p*	η_p^2	Post-Hoc Tests
Group		4.06	2,87	0.022	0.12	
Stimuli*Group		6.93	4.72,205.20	0.001	0.17	
	$PM_{percept}$	12.78	2,87	<0.001	0.24	YA > OA & MCI
	$PM_{concept}$	10.49	2,87	<0.001	0.21	YA > OA & MCI
	YA	16.77	3,84	<0.001	0.41	$PM_{percept}$ & $PM_{concept}$ > 1-$back_{target}$ & 1-$back_{nontarget}$
	OA	3.31	3,111	0.024	0.11	$PM_{concept}$ > 1-$back_{target}$
Hemisphere*Group		6.72	2,87	0.002	0.17	
	R	9.70	2,87	<0.001	0.22	YA > OA & MCI
	OA	22.51	1,37	<0.001	0.45	L > R
	MCI	13.85	1,22	0.002	0.50	L > R
Lateral reorientation negativity latencies						
Group		9.89	2,87	<0.001	0.23	
Stimuli*Group		3.90	6,261	0.001	0.11	
	1-$back_{nontarget}$	9.13	1,87	<0.001	0.18	YA < OA & MCI
	$PM_{percept}$	14.75	2,87	<0.001	0.27	YA < OA < MCI
	YA	7.07	3,84	<0.001	0.23	$PM_{concept}$ > $PM_{percept}$ & 1-$back_{nontarget}$
	OA	3.87	3,111	0.012	0.12	$PM_{concept}$ < 1-$back_{nontarget}$

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-$back_{target}$ = stimuli requiring a response. 1-$back_{nontarget}$ = stimuli not requiring a response. $PM_{percept}$ = perceptual prospective memory stimuli. $PM_{concept}$ = conceptual prospective memory stimuli. L = left hemisphere. R = right hemisphere. | = separator between post-hoc tests.

Table 5.

Summary of Significant Group Effects for Parietal Positivity ERP Amplitudes and Parietal Positivity ERP Latencies.

Midline parietal positivity ERP amplitude	lower	F	DF	*p*-	η_p^2	Post-Hoc Tests
Group		8.82	2,87	<0.001	0.20	
Stimuli*Group		4.87	4.87,211.97	<0.001	0.12	
	1-back_{target}	2,87	3.442	0.037	0.08	YA > MCI
	$1\text{-back}_{nontarget}$	2,87	4.82	0.011	0.11	YA > MCI
	$PM_{percept}$	2,87	12.46	<0.001	0.23	YA > OA & MCI
Cluster*Group		4.21	2,87	0.019	0.11	
	C	3.27	2,87	0.044	0.43	YA > MCI
	P	10.42	2,87	<0.001	0.22	YA > OA & MCI
Lateral parietal positivity ERP amplitude						
Stimuli*Hemisphere*Group		4.12	5.15,224.18	0.001	0.10	
Stimuli*Group	R	3.68	4.83,209.89	0.004	0.09	$PM_{percept}$: YA > MCI
Stimuli*Hemisphere	YA	5.49	3,84	0.005	0.17	$PM_{percept}$: R > L
	OA	15.75	2.54,93.73	<0.001	0.33	1-back_{target}: R > L
Midline parietal positivity latencies						
Group		3.56	2,87	0.034	0.10	
Stimuli*Group		3.31	2.68,181.98	0.006	0.09	
	1-back_{target}	3.75	2,87	0.028		YA < OA & MCI
	$1\text{-back}_{nontarget}$	3.48	2,87	0.036		YA < OA & MCI
Cluster*Group		4.81	2,87	0.011	0.12	
	P	7.59	2,87	0.001	0.09	YA < OA & MCI[†]
Lateral parietal positivity latencies						
Stimuli*Group		2.66	5.40,186.26	0.021	0.07	
	$PM_{percept}$	10.01	2,87	<0.001	0.20	YA < OA & MCI
	$PM_{concept}$	3.24	2,87	0.044	0.72	x

[†] Trending (p = 0.064) after corrections. x = no significant effects after DF corrections. YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back_{target} = stimuli requiring a response. $1\text{-back}_{nontarget}$ = stimuli not requiring a response. $PM_{percept}$ = perceptual prospective memory stimuli. $PM_{concept}$ = conceptual PM stimuli. P = parietal. C = central. R = right hemisphere. L = left hemisphere. | = separator between post-hoc tests.

Table 6.

Summary of Significant Group Effects for N300 ERP Amplitudes and N300 ERP Latencies.

Midline N300 ERP amplitude	Lower	F	DF	*p*	η_p^2	Post-Hoc Tests
Group		4.95	2,87	0.010	0.12	YA < OA
Lateral N300 ERP amplitude						
Stimuli*Group		2.94	4.70,202.25	0.015	0.08	
	1-back$_{target}$	5.16	2,87	0.008	0.11	YA < OA & MCI
	1-back$_{nontarget}$	11.79	2,87	<0.001	0.23	YA < OA & MCI
	PM$_{concept}$	4.99	2,87	0.009	0.11	YA < OA
Stimuli*Cluster*Group		3.05	5.01,215.24	0.011	0.08	
Stimuli*Group	IP	4.28	4.86,211.37	0.001	0.11	1-back$_{nontarget}$: YA < OA | PM$_{concept}$: YA < OA
Stimuli*Cluster	Young	7.06	2.23,60.96	<0.001	0.21	IP < OC & P | IP: PM$_{percept}$ > 1-back$_{nontarget}$ & 1-back$_{target}$ & PM$_{concept}$ | OC: PM$_{concept}$ > 1-back$_{target}$ & 1-back$_{nontarget}$
Cluster*Group	PM$_{percept}$	3.64	2,87	0.031	0.08	x
Midline N300 latencies						
Group		7.59	2,87	0.001	0.17	
Stimuli*Group		3.58	6,261	0.002	0.09	1-back$_{nontarget}$: YA < OA| PM$_{percept}$: YA < OA & MCI
Lateral N300 latencies						
Cluster*Group		7.05	2,87	0.002	0.16	
	OC	3.87	2,87	0.025	0.10	YA < OA
Stimuli*Hemisphere*Group		9.21	6,261	0.012	0.07	
Stimuli*Hemisphere	YA	6.41	3,84	<0.001	0.32	L: 1-back$_{target}$ < 1-back$_{nontarget}$ & PM$_{percept}$ | R: PM$_{percept}$ < 1-back$_{target}$ & 1-back$_{nontarget}$ & PM$_{concept}$
	OA	3.20	3,99	0.027	0.09	L: 1-back$_{nontarget}$ > 1-back$_{target}$ | R: 1-back$_{nontarget}$ > 1-back$_{target}$ & PM$_{percept}$ |PM$_{concept}$ > PM$_{percept}$
Hemisphere*Group	1-back$_{target}$	7.05	2,87	0.002	0.15	x

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back$_{target}$ = stimuli requiring a response. 1-back$_{nontarget}$ = stimuli not requiring a response. PM$_{percept}$ = perceptual PM stimuli. PM$_{concept}$ = conceptual PM stimuli. OC = occipital. IP = inferior parietal. P = parietal. R = right hemisphere. L = Left hemisphere. | = separator between post-hoc tests.

Table 7.

Summary of Significant Group Effects for Frontal Positivity ERP Amplitudes and Frontal Positivity ERP Latencies.

Midline frontal positivity amplitude	Lower	F	DF	*p*	η_p^2	Post-Hoc Tests
Group		10.76	2,87	<0.001	0.23	
Stimuli*Group		2.59	5.07,217.04	0.027	0.07	
	1-back_{target}	7.20	2,87	0.001	0.15	OA & MCI > YA
	$1\text{-back}_{nontarget}$	16.22	2,87	<0.001	0.29	OA & MCI > YA
	$PM_{concept}$	9.12	2,87	<0.001	0.18	OA & MCI > YA
Lateral frontal positivity amplitude						
Group		12.48	2,87	<0.001	0.27	OA & MCI > YA

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. F = frontal. FC = frontocentral. L = left hemisphere. R = right hemisphere. 1-back_{target} = stimuli requiring a response. $1\text{-back}_{nontarget}$ = stimuli not requiring a response. $PM_{concept}$ = conceptual PM stimuli. | = separator between post-hoc tests.

Appendix A

Table A.

Electrode Cluster Definitions.

Cluster	Electrode locations							
Left frontal	AF7	AFF5	AFF5h	FP1	AF3	AFF3h		
Right frontal	AFF4h	AF4	FP2	AFF6h	AFF6	AF8		
Mid frontal	AFFz	Fz	FFCz	FCz				
Left frontocentral	FC5h	FC3	FC3h	FFC5h	F3	FFC3h	FC1	F1
Right frontocentral	FC4h	FC4	FC6h	FFC4h	F4	FFC6h	FC2	F2
Left central	C3h	C3	C5h	C5	T7h			
Mid central	Cz	CCPz	CPz	C2h	CCP2h	C1h	CCP1h	
Right central	C4h	C4	C6h	C6	T8h			
Left frontotemporal	T7	FT7	F7					
Right frontotemporal	F8	FT8	T8					
Left parietal	CPP3h	P3	CCP1	CP5	CP5h	CP3	CPP5h	
Mid parietal	CPPz	Pz	PPOz	POz				
Right parietal	CPP3h	P4	CPP6h	CP6	CP6h	CP4	CCP2	
Left inferior parietal	TP7	TP7h	P5	P7	P9			
Right inferior parietal	P10	P8	P6	TP8	TP8h			
Left occipital	PPO5	PO7	PO9	PO11	O1	POO5	PO3h	
Mid occipital	POOz	Oz	OIz	Iz				
Right occipital	O2	POO6	PO4h	PPO6	PO8	PO10	PO12	

Electrodes in relation to the 10-5 system.

Appendix B

Table B.1

Means and Standard Deviations of P2 Amplitudes across Stimuli, Hemisphere, Cluster and Group

			YA		OA		MCI	
Stimuli	Cluster	Hemisphere	M (μv)	SD	M (μv)	SD	M (μv)	SD
1-back$_{target}$	Frontal	Midline	4.08	2.33	4.31	1.54	3.12	1.34
		Left	3.14	2.06	4.25	2.33	2.98	2.32
		Right	3.15	1.71	4.43	2.32	3.23	2.25
	Frontocentral	Left	4.13	1.52	4.35	1.49	3.47	1.18
		Right	3.90	1.41	4.30	1.58	3.13	1.29
	Central	Midline	3.97	1.27	3.85	1.77	3.11	0.99
		Left	2.68	1.06	3.10	1.95	2.78	1.05
		Right	2.75	1.38	2.81	1.41	2.65	1.16
1-back$_{nontarget}$	Frontal	Midline	3.58	1.32	3.70	1.73	2.91	1.40
		Left	2.82	1.52	346	2.36	2.99	2.32
		Right	2.58	1.53	3.65	2.13	3.11	1.57
	Frontocentral	Left	3.85	1.17	3.74	1.63	2.46	1.07
		Right	3.54	1.67	3.87	1.80	2.80	0.93
	Central	Midline	2.55	1.21	3.04	1.36	2.68	1.29
		Left	2.54	0.84	2.80	1.56	2.15	1.05
		Right	2.55	1.21	3.04	1.36	2.68	1.29
Ongoing + PM$_{percept}$	Frontal	Midline	3.58	1.46	3.82	1.57	2.67	1.39
		Left	2.56	1.47	3.14	1.59	3.66	3.83
		Right	2.60	1.47	3.25	1.27	3.40	3.65
	Frontocentral	Left	3.70	1.19	4.16	1.45	2.83	1.29

		Right	3.52	1.31	4.06	1.45	2.83	1.08
	Central	Midline	3.07	1.26	3.88	1.81	2.71	1.08
		Left	2.65	1.11	3.50	1.87	2.31	1.03
		Right	2.54	1.25	3.50	2.01	2.58	1.09
Ongoing + $PM_{concept}$	Frontal	Midline	3.58	1.37	3.74	1.81	2.56	0.88
		Left	2.90	1.62	350	2.19	2.42	1.24
		Right	2.69	1.52	3.41	2.37	2.66	1.37
	Frontocentral	Left	3.79	1.21	3.82	1.59	2.75	0.94
		Right	3.57	1.22	3.95	1.61	2.90	0.79
	Central	Midline	2.98	1.22	3.54	1.55	3.04	1.90
		Left	2.51	0.88	3.11	1.58	2.20	0.78
		Right	2.59	1.03	3.20	1.22	2.59	0.76

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back_{target} = stimuli requiring a response. $1\text{-back}_{nontarget}$ = stimuli not requiring a response. $PM_{percept}$ = perceptual PM stimuli. $PM_{concept}$ = conceptual PM stimuli.

Table B.2

Means and Standard Deviations of Reorientation Negativity Latencies across Stimuli, Hemisphere, Cluster and Group

		YA		OA		MCI	
Stimuli	**Hemisphere**	**M (ms)**	**SD**	**M (ms)**	**SD**	**M (ms)**	**SD**
1-back_{target}	Left	607.22	106.12	626.13	104.61	652.17	104.43
	Right	560.61	111.01	616.78	110.28	619.91	117.46
$1\text{-back}_{nontarget}$	Left	606.27	97.10	668.59	92.16	710.94	81.50
	Right	586.34	128.76	657.48	125.86	676.80	112.55
$PM_{percept}$	Left	547.28	93.93	620.89	77.13	678.67	102.31
	Right	558.32	108.00	603.21	106.20	670.18	106.00
$PM_{concept}$	Left	642.24	56.58	603.00	108.92	660.33	97.10

	Right	636.99	93.53	616.98	113.87	660.33	114.16

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back$_{target}$ = stimuli requiring a response. 1-back$_{nontarget}$ = stimuli not requiring a response. PM$_{percept}$ = perceptual PM stimuli. PM$_{concept}$ = conceptual PM stimuli.

Table B.3

Means and Standard Deviations of Reorientation Negativity Amplitudes across Stimuli, Hemisphere, Cluster and Group

		YA		OA		MCI	
Stimuli	**Hemisphere**	**M (μv)**	**SD**	**M (μv)**	**SD**	**M (μv)**	**SD**
1-back$_{target}$	Left	-1.95	2.69	-2.40	2.38	-2.68	2.96
	Right	-2.15	2.67	-0.63	2.73	-0.63	3.01
1-back$_{nontarget}$	Left	-1.64	1.30	-2.66	2.33	-2.34	3.87
	Right	-1.93	1.89	-1.95	2.28	-1.12	4.26
PM$_{percept}$	Left	-4.02	3.14	-2.52	3.33	-2.51	1.49
	Right	-4.82	3.09	-0.59	2.66	-0.22	1.79
PM$_{concept}$	Left	-3.18	2.73	-2.19	2.09	-4.47	1.71
	Right	-3.51	2.95	-0.57	2.10	-0.02	1.99

Table B.4

Means and Standard Deviations of Parietal Positivity Amplitudes across Stimuli, Hemisphere, Cluster and Group

			YA		OA		MCI	
Stimuli	**Cluster**	**Hemisphere**	**M (μv)**	**SD**	**M (μv)**	**SD**	**M (μv)**	**SD**
1-back$_{target}$	Parietal	Midline	4.68	2.29	3.77	2.63	2.59	6.64
		Left	3.61	1.67	2.89	2.05	2.60	1.74
		Right	3.85	1.69	3.99	1.90	3.54	2.13
	Central	Midline	3.28	1.54	2.85	1.96	2.48	2.22
		Left	1.78	1.37	1.25	1.90	2.45	2.41
		Right	2.58	1.41	3.22	1.66	2.92	1.57

1-back$_{nontarget}$	Parietal	Midline	4.22	2.25	2.73	2.02	216	2.35
		Left	3.15	1.51	2.81	1.91	2.10	1.04
		Right	3.10	1.56	2.77	1.64	2.07	1.70
	Central	Midline	2.73	1.42	2.95	1.91	1.83	1.83
		Left	1.91	1.44	2.33	1.56	2.41	2.72
		Right	1.65	1.24	2.01	1.47	1.41	1.01
PM$_{percept}$	Parietal	Midline	8.35	4.30	4.40	3.14	4.13	2.21
		Left	5.47	2.60	5.01	2.72	4.27	1.99
		Right	6.67	2.44	5.00	2.64	4.09	2.49
	Central	Midline	6.93	2.61	4.87	2.93	4.00	3.66
		Left	3.68	2.11	3.69	2.23	3.57	2.40
		Right	4.16	1.80	3.74	2.13	3.04	1.73
PM$_{concept}$	Parietal	Midline	5.14	2.95	3.18	2.45	3.18	2.90
		Left	3.59	1.71	3.87	2.79	3.35	1.84
		Right	4.02	1.95	3.18	2.42	3.50	2.16
	Central	Midline	4.09	2.22	3.72	2.36	3.08	3.45
		Left	2.78	1.90	3.46	2.60	2.85	1.57
		Right	2.28	1.43	2.95	2.58	2.83	2.20

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back$_{target}$ = stimuli requiring a response. 1-back$_{nontarget}$ = stimuli not requiring a response. PM$_{percept}$ = perceptual PM stimuli. PM$_{concept}$ = conceptual PM stimuli.

Table B.5

Means and Standard Deviations of Parietal Positivity Latencies across Stimuli, Hemisphere, Cluster and Group

			YA		OA		MCI	
Stimuli	Cluster	Hemisphere	M (ms)	SD	M (ms)	SD	M (ms)	SD
1-back$_{target}$	Parietal	Midline	552.46	82.38	593.75	72.32	606.99	81.70

		Left	569.75	81.49	613.49	46.37	593.01	76.92
		Right	564.04	79.34	598.07	59.91	597.87	71.80
	Central	Midline	564.87	73.74	591.80	77.61	566.84	94.14
		Left	560.97	86.18	545.74	76.08	525.61	83.33
		Right	557.62	75.81	565.07	87.91	585.73	56.67
1-back$_{nontarget}$	Parietal	Midline	555.80	78.98	606.63	73.36	615.67	75.75
		Left	558.73	90.93	598.99	68.81	571.62	86.80
		Right	565.99	79.19	604.34	69.92	594.62	61.96
	Central	Midline	718.61	124.34	740.45	100.16	777.34	103.17
		Left	849.19	199.67	795.13	116.91	814.35	122.16
		Right	808.45	117.63	790.09	115.44	797.29	128.62
PM$_{percept}$	Parietal	Midline	646.82	40.31	699.44	96.19	708.40	96.90
		Left	791.99	121.44	752.50	119.42	791.99	121.44
		Right	643.32	63.02	725.69	127.32	768.56	134.66
	Central	Midline	653.42	75.88	715.93	113.34	768.56	127.39
		Left	793.64	131.91	808.16	133.28	850.59	132.36
		Right	753.23	136.39	785.05	137.74	832.03	132.35
PM$_{concept}$	Parietal	Midline	712.28	104.32	776.32	112.14	780.66	104.57
		Left	798.36	118.42	803.42	122.79	833.79	115.47
		Right	765.89	134.62	814.76	129.10	857.42	95.61
	Central	Midline	753.64	138.93	771.22	112.34	834.38	125.25
		Left	825.97	124.22	862.12	108.21	883.01	128.69
		Right	837.15	145.70	802.94	143.84	864.45	133.24

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back$_{target}$ = stimuli requiring a response. 1-back$_{nontarget}$ = stimuli not requiring a response. PM$_{percept}$ = perceptual PM stimuli. PM$_{concept}$ = conceptual PM stimuli.

Table B.6

Means and Standard Deviations of N300 Amplitudes across Stimuli, Hemisphere, Cluster and Group

			YA		OA		MCI	
Stimuli	Cluster	Hemisphere	M (μv)	SD	M (μv)	SD	M (μv)	SD
1-back$_{target}$	Occipital	Midline	-0.01	2.43	-1.35	2.13	-1.30	2.44
		Left	1.21	2.15	-0.14	2.02	-0.46	2.10
		Right	1.36	2.39	0.13	2.02	-0.08	2.58
	Inferior parietal	Left	-0.47	1.61	-1.39	2.41	-0.98	1.94
		Right	0.11	2.11	-0.40	2.10	-0.68	1.30
	Parietal	Midline	1.62	1.77	0.83	1.98	0.003	1.98
		Left	0.97	1.36	0.13	1.54	0.71	1.51
		Right	1.53	1.46	1.20	1.34	0.80	1.17
1-back$_{nontarget}$	Occipital	Midline	0.28	2.14	-1.85	2.80	-1.36	2.42
		Left	1.61	2.22	-0.33	1.93	0.08	1.87
		Right	1.53	2.20	-0.56	2.11	0.07	1.77
	Inferior parietal	Left	0.62	1.54	-1.31	1.47	-0.53	1.50
		Right	0.38	2.10	-0.81	2.40	-0.59	1.35
	Parietal	Midline	1.36	1.58	0.70	1.59	0.29	2.00
		Left	0.97	1.28	0.76	1.40	0.72	0.99
		Right	1.22	1.47	0.97	1.33	0.50	1.19
Ongoing + PM$_{percept}$	Occipital	Midline	-1.16	3.03	-2.95	2.93	-2.17	3.79
		Left	0.73	3.03	-1.04	2.84	-0.33	2.95
		Right	0.26	3.10	-0.83	2.56	-0.47	2.11
	Inferior parietal	Left	-1.58	223	-1.82	2.02	-0.87	1.42

		Right	-1.46	2.86	-1.53	2.05	-0.48	1.65
	Parietal	Midline	2.20	2.73	0.36	1.91	0.62	2.01
		Left	1.10	1.90	0.88	1.79	0.76	1.73
		Right	1.80	1.60	1.26	1.74	0.68	2.12
Ongoing + $PM_{concept}$	Occipital	Midline	-0.99	2.11	-2.76	3.21	-1.78	2.23
		Left	0.42	2.45	-0.79	2.13	-0.06	1.70
		Right	0.57	2.42	-0.70	2.52	0.05	1.75
	Inferior parietal	Left	0.11	1.84	-0.96	1.99	-1.10	1.83
		Right	-0.26	2.19	-1.21	2.12	-0.73	1.61
	Parietal	Midline	0.87	1.74	0.67	1.72	0.56	1.65
		Left	0.53	1.20	0.74	1.35	0.66	1.62
		Right	0.93	1.22	0.79	1.36	1.51	1.61

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back_{target} = stimuli requiring a response. $1\text{-back}_{nontarget}$ = stimuli not requiring a response. $PM_{percept}$ = perceptual PM stimuli. $PM_{concept}$ = conceptual PM stimuli.

Table B.7

Means and Standard Deviations of N300 Latencies across Stimuli, Hemisphere, Cluster and Group

			YA		OA		MCI	
Stimuli	**Cluster**	**Hemisphere**	**M (ms)**	**SD**	**M (ms)**	**SD**	**M (ms)**	**SD**
1-back_{target}	Occipital	Midline	353.93	66.12	380.76	68.88	371.71	73.15
		Left	365.93	66.05	393.30	68.31	399.88	74.85
		Right	416.38	63.70	390.73	71.89	396.38	78.14
	Inferior parietal	Left	354.91	52.08	390.83	63.31	390.63	78.58
		Right	418.95	63.31	367.50	70.19	393.45	81.17
	parietal	Midline	352.40	66.02	366.37	60.44	395.56	74.76

		Left	345.29	53.89	408.10	57.32	415.50	72.41
		Right	389.79	63.12	378.08	61.92	401.52	69.95
1-back$_{nontarget}$	Occipital	Midline	365.37	77.21	428.15	69.82	400.29	83.80
		Left	394.67	77.45	434.83	62.19	431.74	72.56
		Right	417.82	70.23	445.72	70.25	432.36	68.51
	Inferior parietal	Left	376.95	79.44	402.86	64.29	380.96	75.03
		Right	429.83	69.53	411.80	74.81	412.76	78.27
	parietal	Midline	354.21	63.30	405.74	77.56	387.95	75.80
		Left	351.28	57.20	376.75	58.43	409.95	68.18
		Right	403.88	57.56	431.95	67.31	431.74	56.93
Ongoing PM$_{percept}$	+ Occipital	Midline	359.91	69.72	403.43	73.23	512.31	80.33
		Left	375.14	73.77	405.49	65.32	396.83	77.92
		Right	349.95	65.39	399.74	74.33	395.31	82.40
	Inferior parietal	Left	425.78	72.36	396.27	70.45	411.52	80.03
		Right	100.86	73.23	372.72	56.13	385.74	66.44
	parietal	Midline	335.94	46.02	409.40	72.31	392.58	77.51
		Left	350.49	44.07	376.74	56.05	384.18	68.97
		Right	344.02	33.33	382.92	59.36	362.89	54.42
Ongoing PM$_{concept}$	+ Occipital	Midline	401.23	84.72	436.47	70.05	399.02	87.60
		Left	390.63	77.38	422.08	74.02	412.11	79.75
		Right	420.80	75.10	433.80	71.80	409.77	80.53
	Inferior parietal	Left	37136	67.10	379.83	61.60	353.91	60.45
		Right	442.48	60.26	409.13	70.53	403.13	71.88
	parietal	Midline	401.27	84.72	436.47	70.05	399.02	87.60
		Left	390.63	77.83	422.08	74.02	412.11	79.45

		Right	420.80	75.10	433.80	71.80	409.77	80.53

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back$_{target}$ = stimuli requiring a response. 1-back$_{nontarget}$ = stimuli not requiring a response. PM$_{percept}$ = perceptual PM stimuli. PM$_{concept}$ = conceptual PM stimuli.

Table B.8

Means and Standard Deviations of Frontal Positivity Amplitudes across Stimuli, Hemisphere, Cluster and Group

			YA		OA		MCI	
Stimuli	Cluster	Hemisphere	M (μv)	SD	M (μv)	SD	M (μv)	SD
1-back$_{target}$	Frontal	Midline	1.76	2.14	3.85	2.40	2.97	1.84
		Left	1.23	3.32	3.74	3.15	3.42	2.45
		Right	2.16	2.84	4.68	2.28	4.20	1.96
	Frontocentral	Left	1.56	2.12	3.49	1.81	3.18	2.03
		Right	2.03	1.79	4.37	1.81	2.98	1.51
	Central	Midline	2.92	1.41	2.45	1.38	2.01	1.60
		Left	1.64	1.44	1.80	1.45	2.81	2.07
		Right	2.17	1.27	2.78	1.63	2.85	1.65
1-back$_{nontarget}$	Frontal	Midline	0.55	1.67	3.62	2.65	2.44	1.64
		Left	1.24	2.40	3.73	3.75	3.61	2.01
		Right	1.17	2.21	3.30	2.58	3.03	1.49
	Frontocentral	Left	1.26	1.53	3.68	2.42	2.78	1.80
		Right	0.92	155	3.53	1.99	2.20	1.53
	Central	Midline	2.27	1.48	2.57	1.74	1.68	1.56
		Left	1.85	1.42	2.17	1.37	2.56	2.39
		Right	1.49	1.21	2.05	1.43	1.55	1.04

Ongoing $PM_{percept}$	+	Frontal	Midline	3.57	2.26	5.21	3.06	3.86	2.86
			Left	1.62	2.78	4.33	2.27	3.91	3.05
			Right	2.25	2.60	4.73	2.35	4.19	3.79
		Frontocentral	Left	3.54	2.15	5.39	2.79	4.56	2.89
			Right	3.57	2.39	5.62	3.11	3.77	1.98
		Central	Midline	6.30	2.59	4.03	2.38	2.84	2.25
			Left	3.25	1.99	3.31	1.89	2.86	1.52
			Right	3.70	1.93	3.64	1.88	2.76	1.84
Ongoing $PM_{concept}$	+	Frontal	Midline	1.79	1.66	4.11	2.64	3.23	1.94
			Left	2.44	2.48	4.01	2.93	3.87	2.29
			Right	2.31	1.99	4.47	2.71	4.24	4.33
		Frontocentral	Left	2.42	1.70	4.52	2.23	3.47	1.61
			Right	2.05	1.67	4.65	2.84	2.96	1.92
		Central	Midline	2.60	1.90	3.16	2.02	2.92	2.78
			Left	2.45	1.87	3.12	2.26	2.61	1.21
			Right	2.07	1.45	3.01	2.26	2.90	2.05

YA = young adults. OA = healthy older adults. MCI = Older adults with MCI. 1-back_{target} = stimuli requiring a response. $1\text{-back}_{nontarget}$ = stimuli not requiring a response. $PM_{percept}$ = perceptual PM stimuli. $PM_{concept}$ = conceptual PM stimuli.

Figures

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Figure legends:

Figure 1. Experimental prospective memory (PM) paradigm. (a) The 1-back_{target} (ongoing-only) word categorisation task. Arrow directions indicate the evaluation of stimulus in relation to the previous word. Related words are those which are from the same category as the previous word and require a response. Unrelated words are those that did not belong to the same category as the previous word

and did not require a response. (b) The embedded prospective memory tasks. Examples of the perceptual and conceptual prospective memory cues are highlighted with grey bars.

Figure 2. Illustration of the prospective memory related ERP cluster definitions for the virtual electrode method. Green = P2 and Frontal Positivity. Red = parietal positivity. Blue = N300. Orange = reorientation negativity.

Figure 3. Interaction plots of percentage of correct responses and reaction time. (a) Percentage of correct responses to the ongoing-only task (1-back_{target}), perceptual prospective memory task ($PM_{percept}$) and conceptual prospective memory task ($PM_{concept}$) for young adults (YA), older adults (OA) and older adults with mild cognitive impairment (MCI). (b) Reaction time for correct responses to ongoing-only, perceptual prospective memory task and conceptual prospective memory task across the three-time epochs of the study. Error bars represent standard error.

Figure 4. Grand-averaged ERP amplitudes for the P2 at bilateral frontocentral cluster in response to repeated ongoing (1-back_{target}), non-repeated ongoing ($1\text{-back}_{nontarget}$), perceptual prospective memory ($PM_{percept}$) and conceptual prospective memory ($PM_{concept}$) stimuli in the left hemisphere and right hemisphere for young adults (YA), healthy older adults (OA) and older adults with MCI (MCI).

Figure 5. ERP amplitudes and latencies for the reorientation negativity (RON) at bilateral frontotemporal clusters. Left and right denote the hemisphere of the frontotemporal clusters. (a) Grand-averaged ERP waveforms in response to repeated ongoing (1-back_{target}), non-repeated ongoing ($1\text{-back}_{nontarget}$), perceptual PM ($PM_{percept}$) and conceptual PM ($PM_{concept}$) stimuli for young adults (YA), healthy older adults (OA) and older adults with mild cognitive impairment (MCI). Dashed boxes highlight the epoch for the RON component. (b) Bar charts of the latencies of the RON across the YA, OA and MCI groups. (c) Bar charts of amplitudes of the RON across the YA, OA and MCI groups. Significant effects are highlighted with curly braces. * = $p < 0.05$; ** $p < 0.01$; *** = $p < 0.001$. Error bars represent standard error.

Figure 6. ERP amplitudes and latencies for the parietal positivity (PP) at the midline parietal cluster. (a) Grand-averaged ERP waveforms in response to repeated ongoing (1-back_{target}), non-repeated ongoing ($1\text{-back}_{nontarget}$), perceptual PM ($PM_{percept}$) and conceptual PM ($PM_{concept}$) stimuli for young adults (YA), healthy older adults (OA) and older adults with mild cognitive impairment (MCI). Dashed boxes highlight the epoch for the PP component. (b) Bar charts of the latencies of the PP across the YA, OA and MCI groups. (c) Bar charts of amplitudes of the PP across the YA, OA and MCI groups. Significant effects are highlighted with curly braces. * = $p < 0.05$; *** = $p < 0.001$. Error bars represent standard error.