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RUNNING HEAD: REDUCED MIND-WANDERING IN MILD COGNITIVE
IMPAIRMENT

Reduced mind-wandering in Mild Cognitive Impairment: Testing the spontaneous retrieval
deficit hypothesis

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Abstract

Objective: Research on early cognitive markers of Alzheimer's disease (AD) is primarily focused on declarative episodic memory tests that involve deliberate and effortful/strategic processes at retrieval. The present study tested the Spontaneous Retrieval Deficit Hypothesis, which predicts that people with amnesic Mild Cognitive Impairment (aMCI), who are at increased risk of developing AD, are particularly impaired on tasks that rely on spontaneous retrieval processes.

Method: Twenty-three participants with aMCI and 25 healthy controls (HC) completed an easy vigilance task and thought probes (reporting what was going through their mind), which were categorized as spontaneous thoughts about the past (i.e., involuntary memories), current situation, and future (i.e., spontaneous prospection).

Results: Participants with aMCI reported significantly fewer spontaneous thoughts or mind-wandering than HC. This effect was driven by significantly fewer involuntary memories, while groups did not differ in the number of current and future thoughts.

Conclusions: Findings provide strong support for the Spontaneous Retrieval Deficit Hypothesis. Implications for research on mind-wandering and the default network, early cognitive markers of the disease, and our theoretical understanding of the nature of cognitive deficits in Alzheimer's disease are discussed.

Keywords: Alzheimer's disease, Mild Cognitive Impairment, early cognitive marker, mind-wandering, involuntary memories

Public significance statement: Neuropsychological tests for diagnosing people with Mild Cognitive Impairment who are at increased risk of developing Alzheimer's disease, involve effortful encoding/retrieval processes. We provide novel evidence of significant disruptions in tasks based on spontaneous retrieval (mind-wandering) in Mild Cognitive Impairment, which may improve the early diagnosis and the current understanding of Alzheimer's disease.

Reduced mind-wandering in Mild Cognitive Impairment: Testing the spontaneous retrieval deficit hypothesis

In daily life, people spend large proportion of their time on thinking about issues that are not related to the tasks at hand (Kane et al., 2007; Killingsworth & Gillbert, 2010). These task-unrelated thoughts or mind-wandering can vary greatly in their content and time orientation. For example, while attending a boring meeting, one's thoughts may drift to thinking about a previous holiday (past), problems with car engine (present) or one's intention to collect laundry after work (future). One thing that these diverse thoughts share is that they are not preceded by deliberate attempts to think about them, the thoughts simply 'pop' into mind, and may result in a shift of attention from external world to one's inner musings (Smallwood & Schooler, 2006; 2015). Although some theories regard these spontaneous task-unrelated thoughts as failures of cognitive control (McVay & Kane, 2010), others emphasize possible adaptive functions of mind-wandering (e.g., learning from past mistakes, planning the future, having creative insights), at times when one is engaged in undemanding activities (Baird, Smallwood, & Schooler, 2011; Baird et al., 2012; Mooneyham & Schooler, 2013).

Such internal spontaneous mental activity has been increasingly linked to the brain's default network, which consists of several anatomically and functionally interconnected brain areas that show increased co-activations in passive task states, deactivations during cognitively demanding tasks, and stable patterns of resting state functional connectivity (Andrews-Hanna, Reidler, Huang & Buckner, 2010; Buckner et al., 2008; Christoff, 2012). Functional activations in these regions appear to converge on key hubs along the brain's midline (the anterior Medial Prefrontal Cortex, Posterior Cingulate Cortex, and the Inferior Parietal Lobule) that facilitate the transfer of information between different parts of the network. The Posterior Cingulate Cortex (PCC), in particular, appears to play a key integrative role in the default network, by showing functional correlations with all other

regions of the network (Fransson & Marrelec, 2008). Its strong reciprocal anatomic and functional connections with the hippocampus (via the entorhinal cortex), may also explain its involvement in self-referential tasks, such as remembering past episodes and constructing future mental projections (Buckner et al., 2008; Spreng & Grady 2009) that often form the content of task-unrelated thoughts (Andrews-Hanna et al., 2010; O’Callaghan et al. 2015).

Research on the default network and mind-wandering can provide important insights into the precise brain mechanisms involved in the spontaneous occurrence of task-unrelated thoughts (Andrews-Hanna, Irving, Fox, Spreng & Christoff, in press; Smallwood, 2013). For example, Ellamil et al.’s study (2016) on highly trained meditation practitioners showed the involvement of key posterior parts of the default network, such as the medial temporal lobe, the PCC and the right Inferior Parietal Lobule, just before participants reported the occurrence of spontaneous task-unrelated thoughts while trying to concentrate on breathing in the scanner. In contrast, activations in anterior parts of the default network (e.g., medial and lateral prefrontal cortex) were observed while participants were having the thought in mind.

The main assumption of the present investigation is that studying mind-wandering can also shed new light on the nature of key cognitive deficits in abnormal aging, which may significantly improve the early diagnosis and prediction of Alzheimer’s disease (AD). Given that one of the main brain pathologies of AD, beta-amyloid depositions accumulate in the key hubs of the default network (see below), the main hypothesis tested in this paper is that spontaneous mind-wandering would be significantly disrupted or reduced in people at prodromal and very early stages of AD (*cf.* Gyurkovics, Balota & Jackson, 2017). This novel prediction contradicts theories of cognitive aging and a large body of evidence, which shows that aging mostly disrupts more difficult tasks that rely on deliberate control processes, while performance on tasks involving spontaneous retrieval is relatively spared (Craig & Grady, 2002; Maillet & Schacter, 2016a).

Early cognitive markers of AD and Mild Cognitive Impairment

Dementia research is increasingly focused on identifying individuals at risk of developing AD, such as people with Mild Cognitive Impairment (MCI) who can benefit most from the early disease management, which could delay or even prevent the progression to AD (Sperling, Mormino, & Johnson, 2014; Sperling et al., 2011). The MCI has several subcategories, the most prevalent being amnesic MCI (aMCI). It manifests in a deficit in episodic memory tests, in addition to subjective memory complaints, but does not meet the criteria for AD diagnosis due to a patient's preserved daily functioning (Petersen, 2004). The episodic memory deficit may either be an isolated one (single domain aMCI) or accompanied by deficits in other cognitive domains (multiple domain aMCI). Individuals with aMCI have increased yearly conversion rates to AD (10-15%) and are more likely than normally aging adults to have brain pathology characteristic of AD (Albert et al., 2011; Sperling et al., 2011), such as the accumulation of (i) tau protein in the nerve cells of the entorhinal cortex and the hippocampus (Braak & Braak, 1997; Jack & Petersen, 2000; Nickl-Jockschat et al., 2012), and (ii) beta-amyloid plaques in the key hubs of the default network (PCC, lateral parietal and medial prefrontal regions) (Morris, 2005; Musiek & Holtzman, 2015).

There is no universal agreement about which particular cognitive processes or tests have the best diagnostic sensitivity and specificity in accurately discriminating healthy older adults from aMCI (Gainotti, Quaranta, Vita, & Marra, 2014; Ozer, Young, Champ, & Burke, 2016). The dominant view is that long-term episodic memory tasks are the best available tests for detecting cognitive decline in MCI and AD (Bastin & Salmon, 2014; Gainotti et al., 2014). It is assumed that impaired performance on these tasks maps onto the first signs of tau pathology in the entorhinal cortex and the hippocampus. However, the medial temporal lobe, including the hippocampus, serves multiple functions, not only episodic memory (Hannula & Ranganath, 2008; Lee et al., 2008; Moscovitch, Gabeza, Winocur & Nadel, 2016). In

addition, this account downplays the key role of beta-amyloid pathology in MCI that is accompanied by functional/metabolic disruptions and structural changes in the posterior parts of the default network, especially in the PCC/Retrosplenial Cortex (Buckner et al., 2005; Greicius et al., 2004), which may be comparable to or even stronger than the medial temporal lobe atrophy caused by tau protein accumulation (e.g., Nestor, Fryer, Smielewski, & Hodges, 2003; Pengas, Hodges, Watson, & Nestor, 2010). For example, several studies have found that amyloid depositions may be related to subsequent neurodegeneration in medial temporal lobes and surrounding areas at later stages of MCI (Fagan et al., 2009; Mormino et al., 2008).

Therefore, we have recently proposed a new hypothesis of *spontaneous retrieval deficits* in aMCI, which argues that currently used tests of episodic memory and executive functions may not be optimal for early detection of aMCI (Niedźwieńska, Kvavilashvili, Ashaye & Neckar, 2017). Almost all of these tests rely on deliberate and effortful strategies at encoding and retrieval, which are mediated by areas in anterior and dorsolateral pre-frontal cortex, in both normal and cognitively impaired adults (e.g., Lekeu et al., 2003). Given that these control subsystems of the brain are compromised at later stages of AD (Braak & Braak, 1991; 1997), it is highly likely that currently used neuropsychological tests are not sensitive enough to detect very subtle changes in the medial temporal lobes and the default network due to partial compensation in performance via the prefrontal cortex activity (e.g., see Grady et al., 2003). Consequently, the spontaneous retrieval deficit hypothesis predicts that cognitive tasks that rely less on frontal lobe functioning and are mediated primarily by key regions related to tau and beta-amyloid pathologies in the brain, such as the hippocampus and the posterior parts of the default network (e.g., PCC), should be more effective in discriminating aMCI patients from healthy controls than tests of episodic memory and executive functions.

Evidence for the spontaneous retrieval deficit hypothesis

Spontaneous mind-wandering would be a prime example of such tasks, given its

reliance on posterior parts of the default network, which are thought to mediate the associative cognitive processes that bring conscious mental representations to mind without deliberately trying to think about them (Ellamil et al., 2016; Moscovitch et al., 2016; Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011).¹ Another cognitive task that may satisfy these criteria is event-based prospective memory that involves remembering an intended action in response to an event cue while being engaged in an unrelated activity, for example, taking a pill with a meal or passing a message to a colleague at work (McDaniel & Einstein, 2007). In line with the results of Ellamil et al. (2016) on mind-wandering, a recent meta-analysis showed that focal event-based tasks, that rely predominantly on spontaneous retrieval, involved activations in the PCC, and ventral parietal regions, while activations in nonfocal tasks, mediated by more strategic monitoring processes, involved the left lateral anterior prefrontal cortex (BA 10) (Cona, Bisiacchi, Sartori, & Scarpazza, 2016).²

In line with this dissociation in brain mechanisms of focal and nonfocal prospective memory, McDaniel et al. (2011) showed that in comparison to healthy controls, patients with very mild AD were disproportionately more impaired in an easy focal event-based task, than more difficult nonfocal task requiring strategic monitoring. This significant group by task interaction has been replicated in two studies with aMCI participants, providing initial support for the spontaneous retrieval deficit hypothesis (Chi et al., 2014; Niedzwieńska, et al., 2017).

To the best of our knowledge, there are no published studies on mind-wandering in patients with aMCI. This could be partly due to relatively demanding nature of the currently used tasks of mind-wandering (*cf.* O'Callaghan et al. 2015). For example, the often-used Sustained Attention to Response Task (SART) requires participants to respond to highly frequent targets (digits 1 to 9) and withhold responses to infrequent non-targets (e.g., the digit 3), while being randomly probed whether they are on-task or off-task. The proportion of probes with reported mind-wandering can be relatively low even in young participants,

(McVay & Kane, 2009; Smallwood, O'Connor, Sudberry, Haskell, & Ballantyne, 2004), and recent findings indicate that a fairly large proportion of thoughts rated as off-task (i.e., 34% - 41%) are actually deliberate task-unrelated thoughts that participants intentionally engage in for various reasons (e.g., boredom) (Seli, Cheyne, Xu, Purdon, & Smilek, 2015; Seli, Risko & Smilek, 2016). Consequently, using the standard version of the SART for assessing the spontaneous retrieval deficit hypothesis may be problematic given the strong emphasis of this hypothesis on the reduction in spontaneous rather than intentional mind-wandering in aMCI.

The present study

We investigated the spontaneous mind-wandering in people with aMCI and healthy older adults using a novel vigilance task that has been successfully used in young adults to study spontaneous task-unrelated thoughts about past, present and future (Plimpton, Patel & Kvavilashvili, 2015). In Plimpton et al. (2015), high levels of mind-wandering were induced by having participants detect infrequent target slides with vertical lines in a long sequence of non-target slides with horizontal lines, and exposing participants to irrelevant cue phrases on each slide. Mind-wandering was assessed by random probes in which participants described their current thought and indicated whether the thought was spontaneous or deliberate. In the present study, several changes were made to enable testing older participants with aMCI: (i) the presentation time of each slide was increased, (ii) target vertical lines were made more salient, and (iii) irrelevant cue words were presented on 1/3 of the slides to reduce the overall cognitive load (see Method). With these changes, it was expected that aMCI participants would not differ from healthy controls in the number of detected targets, which would be close to ceiling in both groups. However, in line with the spontaneous retrieval deficit hypothesis, it was expected that aMCI participants would report significantly fewer spontaneous task-unrelated thoughts than healthy controls.

The two groups were also compared in terms of the temporal focus of task-unrelated

thoughts. Plimpton et al. (2015) found that young participants reported significantly more thoughts about the past (i.e., involuntary autobiographical memories) than thoughts about the present or the future. In contrast, studies using the SART, have reported the prevalence of future-oriented thoughts (e.g., Baird et al., 2011; Smallwood et al., 2011). Plimpton et al. (2015) suggested that the presence of meaningful stimuli (irrelevant cue words) in their vigilance task was essential for eliciting spontaneous bottom-up retrieval processes resulting in the recall of past memories, while in the SART and other similar tasks with no meaningful stimuli, people would be more likely to engage in future thinking (see Maillet, Seli & Schacter, 2017; Vannucci, Pelagatti, & Marchetti, 2017). If such automatic bottom-up retrieval processes in response to meaningful environmental cues are disrupted in aMCI patients due to their brain pathology in posterior parts of the default network and medial temporal lobes, then the reduction of mind-wandering in aMCI should be particularly pronounced for their thoughts about past events than thoughts about the future or the present.

Method

Participants

A total of 25 healthy older adults and 25 aMCI participants were recruited. The study was approved by the National Research Ethics Service Committee - Cambridgeshire and Hertfordshire. For all participants, exclusion criteria included: (a) head/brain injuries, (b) history of cerebrovascular disease, (c) history of alcohol or substance dependence, (d) medical, neurological, or psychiatric disorders resulting in cognitive dysfunctions, (e) age less than 60 years. Fluency in English and adequate vision and hearing were also required. Exclusion criteria were assessed in the initial phone screening. Participants who passed the screening, completed a battery of experimental and standardized neuropsychological tests.

MCI participants. The MCI participants were referred from local mental health services (memory clinics). They all had MCI diagnosis via multidisciplinary diagnostic

consensus (i.e., neurological, psychiatric, neuropsychological, and functional assessment). The clinical diagnosis was confirmed using the inclusion criteria that satisfied the diagnostic criteria of aMCI (Petersen, 2004; Winblad et al., 2004): (a) presence of a subjective memory complaint (i.e., sought professional assessment due to concerns about memory decline); (b) objective memory impairment evidenced by a score at or below 1.5 *SD* of the mean of age-matched peers on at least one test of the neuropsychological screening battery assessing episodic memory (see the Neuropsychological evaluation section); (c) not meeting the Diagnostic and Statistical Manual of Mental Disorders' (DSM-5) criteria for dementia (American Psychiatric Association, 2013), (d) preserved general cognitive function as confirmed by a normal score on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) (normality cut-off score: 24; Measso, Cavarzeran, Zappala, & Lebowitz, 1993); (e) maintained activities of daily living or slight impairment in instrumental activities of daily living, as confirmed by no more than one item showing deterioration in the Lawton Instrumental Activities of Daily Living scale (IADL; Lawton & Brody, 1969); (f) absence of severe depression, as confirmed by a score below 20 on the Geriatric Depression Scale 30 (GDS30; Yesavage et al., 1983).

To have a homogeneous sample of single domain aMCI, we excluded two participants with multiple domain aMCI. In addition to their deficit in episodic memory, they scored 1.5 standard deviations or more below age-appropriate means on at least one of the tests of short-term memory, attention and executive functions from the neuropsychological test battery (Petersen, 2004). The final sample thus consisted of 23 participants with single domain aMCI (memory impairment only) and 25 healthy controls. Although at a group level, single domain aMCI participants scored reliably lower than healthy controls on almost all measures of attention and executive functions (see the Neuropsychological evaluation section), none of

them scored at 1.5 standard deviations or below (compared to the published norms) unlike the two participants with multiple domain aMCI.

Healthy controls (HC). HC were recruited through lunch and social clubs for older adults and a database of the older adult volunteers maintained by the second author. Inclusion criteria for the HC group were: (a) absence of a subjective memory complaint (i.e., had not sought professional assessment due to concerns about memory performance); (b) a score within or above 1.5 *SD* of the mean of age-matched peers on each test of the neuropsychological screening battery assessing episodic memory; (c) a score ≥ 27 on the MMSE; (d) no impairment in instrumental activities of daily living, as confirmed by a maximum score on the Lawton IADL; (e) absence of severe depression, as confirmed by a score of below 20 on the GDS30.

Table 1 shows demographic details of the final sample. A series of independent samples *t* tests and a chi-square test (for gender) revealed no significant differences between aMCI and HC on the demographic variables (*ds* between .08 and .44), except for MMSE scores, which were higher in HC than in aMCI individuals, $t(46) = 4.20, p < .001, d = 1.19$.

Measures

Neuropsychological evaluation. The episodic memory tests included the Hopkins Verbal Learning Test– Revised (HVLT-R; Brandt & Benedict, 2001), consisting of three Immediate Recall and one Delayed Recall tests, and several tests from the Wechsler Memory Scale–3rd edition (Wechsler et al., 1998): Logical Memory Subtest (Immediate Recall and Delayed Recall); Verbal Paired Associates (Immediate Recall and Delayed Recall); two tests of short-term memory (Digit Span Forward and Digit Span Backward). The attention and executive function tests included Verbal Fluency Test: Letter Fluency (Spreen & Strauss, 1998), and Category Fluency (Rosen, 1980), and the Trail Making Test (TMT): Part A and B (Reitan, 1958). A series of independent samples *t* tests (aMCI vs. HC) were conducted on the

mean scores of all the tests from the battery. Significant group differences were obtained for all the tests, except for the Digit Span Forward, with HC group outperforming the aMCI group (see Table 2). In line with the criteria for single domain aMCI classification, the effect sizes for episodic memory tests were markedly higher than for the tests measuring attention and executive functions.

Experimental Materials

Vigilance task. Participants completed a computer-based vigilance task, which was originally developed by Schlagman and Kvavilashvili (2008), and modified by Plimpton et al. (2015). The task consisted of a 600-slide presentation, which mostly depicted arrangements of horizontal lines (non-target stimuli), but participants were asked to press the spacebar when arrangements of vertical lines (target stimuli) appeared. These target stimuli appeared 11 times throughout the presentation with a minimum of 32 slides between each target. All the slides were 28.5 x 16.5 cm in size and 200 slides featured centrally oriented cue-words or phrases in 18-point Arial font. There were 67 positive (e.g., *dinner with friends*), 66 negative (e.g., *root canal treatment*) and 67 neutral cue-words (e.g., *local newspaper*) that had been previously rated for valence by independent coders and received at least 75% agreement (Schlagman & Kvavilashvili, 2008). Slides were presented in a fixed random order.

The vigilance task used by Plimpton et al. (2015) was modified to better suit older adults and be equally undemanding for healthy and cognitively impaired participants. First, the presentation time of each slide was increased from 1500 to 3000 ms. Second, target slides with vertical lines were made more salient by presenting vertical lines in red color and all the non-target slides with horizontal lines in black color. Third, the available pool of 600 cue words from Plimpton et al. (2015), that could act as potential triggers for spontaneous thoughts, was reduced to 200 so that cue words were presented on only 1/3 of the slides.³ Cue words were randomly deleted in each of the positive, negative and neutral category with the

exception that no more than four slides without words appeared in succession and cue words never appeared on the 11 target slides.

Thought Probe Questionnaire. The slide presentation stopped at 12 fixed points with the following message on the screen: “Please stop and report your concentration and thoughts now”. At each stop participants completed the first page of a 2-page questionnaire, adapted from Plimpton et al. (2015). To simplify the recording process for older participants, the experimenter read out each question and manually recorded participants’ responses.

Participants first gave a brief description of their thoughts at the moment they were stopped, and indicated if the thought occurred spontaneously or whether they deliberately decided to think about it. If spontaneous, they also indicated whether the thought had been triggered by the environment, by their own thoughts, or if there was no trigger. If a trigger was identified, they were asked to describe it. Finally, participants rated how much they were concentrating on the task when stopped (1=*Not at all*, 5=*Fully concentrating*).

After finishing the vigilance task, participants were shown each of their 12 thought descriptions and asked questions from the second page of the questionnaire. First, they were asked to categorise their thoughts as a past memory, future event or current situation. If they chose a memory or future thought, they also estimated how far in the past it had occurred, or how far in the future they were projecting. Participants also rated the thought for pleasantness (1=*Very unpleasant*, 3=*Neutral*, 5=*Very pleasant*) and how often they had experienced the thought before (1=*Never*, 3=*A few times*, 5=*Many times*).

Procedure

Participants were tested individually, by the first author at the participant’s home. The neuropsychological test battery was completed in Session 1 as part of a larger study on aMCI (see Niedzwieńska et al., 2017). Experimental tests were completed in Session 2, which took place within three to six months from Session 1. To ensure that the cognitive and mental

health status of participants had not changed since Session 1, the MMSE and the Geriatric Depression Scale 30 were administered at both sessions. Each session lasted about two hours.

In Session 2, participants were informed that the study was about fluctuations in concentration and thoughts during monotonous tasks and the vigilance task was briefly explained. Participants had to press the spacebar when they saw a slide with vertical lines, but do nothing when seeing slides depicting horizontal lines. They were also told to ignore the words or phrases that appeared on some of the slides as their task was to detect vertical lines while participants in another condition had to detect certain words. This was followed by a short practice trial with three target and 37 non-target slides that did not contain any thought probes. Participants were then informed that the main vigilance task would be much longer and that the slide presentation would occasionally stop, at which point they would be prompted to report their concentration level and thoughts at the exact moment they were stopped. Finally, participants were briefly informed about the types of off-task thinking they could experience during the vigilance task (thoughts about the past, present or the future) and explained the difference between spontaneous thoughts (*thoughts that pop into your mind spontaneously*) and deliberate thoughts (*something you have deliberately chosen to think about*).

When participants started the vigilance task and the first stop trial appeared, the experimenter asked the questions from the first page of the thought questionnaire. This was repeated with each stop trial. Once the task was finished, they were shown their thought descriptions, one by one, and asked questions from the second page of the questionnaire.

Results

Unless otherwise specified, the alpha level adopted for determining significance of the results was set at 0.05. The effect size was measured by partial eta squared, η_p^2 (small .01, medium .06, large .16) or Cohen's d (small .20, medium .50, large .80) (Cohen, 1977).

Performance on Vigilance Task

Performance on the vigilance task was at ceiling in both groups with only three aMCI participants and one HC missing one target out of 11 targets presented. There were no significant group differences in the number of detected targets or mean ratings of concentration, but participants with aMCI were significantly slower at responding to targets than HC (see Table 3).

Type of Recorded Thoughts

All thought descriptions, provided by participants at 12 stop trials, were coded by the first and second authors (independently and being blind to participant group) into the following three categories: 1) task-related thoughts, 2) task-unrelated thoughts, and 3) no thoughts. The majority of task-related thoughts (85%) referred to the so-called task-related interference (TRI), rather than thoughts about detecting vertical lines (*cf.* Plimpton et al., 2015). These consisted of any references to aspects of the vigilance task (e.g., *I was thinking what it means that lines have different lengths and whether it means anything at all*), any mention of the phrases on the screen (e.g., *I was looking at words and I was thinking I would not have to remember these*), or any reference to a state/emotion that arose in response to the vigilance task (e.g., *I was getting bored*). In contrast, task-unrelated thoughts were those which did not contain any explicit reference to the vigilance task and referred to either past (e.g., *I was thinking about my honeymoon. We went to Spain and saw a bull fight there*), present (e.g., *I was thinking people do not really have engagement parties these days*) or future (e.g., *we are going to see my grandson tomorrow who is in the army*). The ‘no thoughts’ category was chosen when the participant said explicitly that they did not think about anything (e.g., *I was not thinking anything, no thoughts*) or that they were just doing the task (e.g., *nothing really, just concentrating*). Inter-rater reliability between the coders was excellent ($Kappa=.99$, $SE=.01$).

In the HC group, the coding resulted in 19 probes with ‘no thoughts’ (6%), 62 task-related thoughts (21%), and 219 task-unrelated thoughts (73%). In the aMCI group, there were 53 probes classed as ‘no thoughts’ (19%), 101 task-related thoughts (37%) and 122 task-unrelated thoughts (44%). In the task-unrelated thought category, only three thoughts in the HC group and five thoughts in the aMCI group were rated by participants as deliberate thoughts. The exclusion of these thought probes resulted in 216 and 117 spontaneous task-unrelated thoughts in HC and aMCI participants, respectively. The majority of spontaneous task-unrelated thoughts were reported to have identifiable external triggers in both aMCI (86%) and in HC (92%). Among thoughts with external triggers, the majority were triggered by incidental word-cues encountered in the vigilance task (86% in aMCI and 92% in HC).

To assess the hypothesis that aMCI participants would report significantly fewer spontaneous task-unrelated thoughts than HC, the mean number of thought probes in each of the three thought category were entered into a group (HC vs. aMCI) by 3 thought type (task-related vs. spontaneous task-unrelated vs. no thoughts) mixed ANOVA with the repeated measure on the second factor. There was a significant main effect of thought type $F(1.56, 71.59) = 40.03, p < .0001, \eta_p^2 = 0.47$, with the number of task-unrelated thoughts being significantly higher than task-related thoughts, which were significantly more frequent than instances of ‘no thoughts’ ($p_s < .0001$). However, this main effect was qualified by a significant group by thought type interaction, $F(1.56, 71.59) = 12.79, p < .0001, \eta_p^2 = 0.22$.

Tests of simple main effects showed that while the HC group reported higher number of task-unrelated thoughts ($M = 8.64, SD = 3.03$) than aMCI participants ($M = 5.09, SD = 2.83$) ($F(1,46) = 17.59, p < .001, \eta_p^2 = 0.28$), the pattern was reversed for the remaining two types of thoughts (see Figure 1). Thus, the mean number of task-related thoughts was significantly higher in aMCI participants ($M = 4.39, SD = 2.33$) than in the HC group ($M = 2.48, SD = 2.52$) ($F(1,46) = 7.41, p = .009, \eta_p^2 = 0.14$). Similarly, the aMCI group reported

higher number of instances of ‘no thoughts’ ($M = 2.30$, $SD = 2.14$) than the HC group ($M = .76$, $SD = 1.27$) ($F(1,46) = 9.43$, $p = .004$, $\eta_p^2 = 0.17$).

Temporal Location of Spontaneous Task-Unrelated Thoughts

After completing the vigilance task, participants categorized their thought descriptions as thoughts referring to their past, present or future. The mean numbers of spontaneous task-unrelated thoughts in each temporal category were entered into a 2 (group: aMCI, HC) x 3 (temporal focus of thought: past, present, future) mixed ANOVA with repeated measures on the second factor.⁴ Overall, HC reported spontaneous thoughts more often than aMCI participants, $F(1,43) = 21.68$, $p < .0001$, $\eta_p^2 = 0.34$. The main effect of temporal focus of thought was also significant, $F(1.55,66.68) = 41.95$, $p < .00001$, $\eta_p^2 = 0.49$. However, these effects were qualified by a significant group by temporal focus interaction, $F(1.55,66.68) = 10.82$, $p < .0001$, $\eta_p^2 = .20$ (see Figure 2). Tests of simple main effects showed that the HC group reported significantly more spontaneous thoughts about past memories ($M = 6.21$, $SD = 2.77$) than participants with aMCI ($M = 2.90$, $SD = 1.97$), $F(1, 43) = 20.71$, $p < .0001$, $\eta_p^2 = .33$, but there were no significant differences between the two groups in the frequency of either current thoughts ($M_{HC} = 1.29$, $SD_{HC} = 1.16$; $M_{aMCI} = 1.00$, $SD_{aMCI} = .95$) or future thoughts ($M_{HC} = 1.50$, $SD_{HC} = 1.45$; $M_{aMCI} = 1.67$, $SD_{aMCI} = 1.62$) ($F_s < 1$).

Sensitivity and specificity analyses

To examine how well the vigilance task discriminated between HC and aMCI participants, we carried out the sensitivity and specificity analyses for the number of spontaneous task-unrelated thoughts and the number of involuntary memories. The sensitivity referred to the probability that an individual with aMCI would have a low number of spontaneous task-unrelated thoughts or involuntary memories during the vigilance task. The specificity referred to the probability that a healthy older adult would have a high number of

spontaneous task-unrelated thoughts or involuntary memories. The receiver operating characteristic curve (ROC) was analyzed with the program MedCalc (MedCalc Statistical Software, Version 17.9.7). The area under the curve (AUC) was found to be .819 ($p < .0001$) for spontaneous thoughts and .813 ($p < .0001$) for involuntary memories. The optimum specificities and sensitivities for spontaneous thoughts were 84% and 78%, respectively, and 64% and 96%, for involuntary memories, respectively. These results suggest good sensitivity and specificity of the vigilance task (as a measure of spontaneous thoughts) in discriminating individuals with aMCI from healthy older adults.

Additional Analyses

In Supplementary Materials we report analyses which examined cue valence as a function of thought temporality and aMCI status as well as thought characteristics as a function of aMCI status. Overall, similar results were obtained for aMCI participants and HC. In both groups, involuntary memories were more often triggered by negative and positive cues (compared to neutral ones), while spontaneous thoughts about the future were predominantly triggered by positive cues. No group differences were found for the pleasantness of spontaneous thoughts and the mean proportion of specific memories among involuntary memories. For both groups, the majority of future thoughts were projections into the immediate future whereas memories referred to very distant events.

Discussion

The aim of this study was to test the spontaneous retrieval deficit hypothesis (Niedźwieńska et al., 2017) by investigating, for the first time, the frequency and the temporal focus of spontaneous mind-wandering in participants with aMCI and a matched group of normally aging healthy older adults. The results showed that aMCI participants reported significantly fewer spontaneous task-unrelated thoughts or mind-wandering during the

vigilance task than HC, and this difference was driven by aMCI participants reporting significantly fewer involuntary memories about past events than HC, as groups did not differ in the number of spontaneous thoughts about the present or the future.

Most importantly, in line with findings on young adults using the same vigilance task paradigm, the majority of spontaneous task-unrelated thoughts were reported to have been triggered by irrelevant cue-words presented on the slides (Cole, Staugaard & Berntsen, 2016; Plimpton et al., 2015; Vannucci et al., 2015; 2017; Schlagman & Kvavilashvili, 2008). However, aMCI participants reported significantly fewer spontaneous thoughts about the past, suggesting that incidental cue words were less effective in automatically triggering memories in aMCI participants than in HC. This novel finding provides further support for the spontaneous retrieval deficit hypothesis predicting disproportionate disruption of bottom up cue-driven associative retrieval processes compared to deliberate retrieval processes in aMCI, as reported in the studies of focal and non-focal prospective memory (Chi et al., 2014; Niedźwieńska et al., 2017; McDaniel et al., 2011). The results have significant implications for research on mind-wandering and the default network, early cognitive markers of the disease, and our theoretical understanding of cognitive deficits in AD.

Effects of aMCI on spontaneous mind-wandering

Despite the large amount of research on the brain's default network in patients with aMCI and AD, there is noticeable absence of behavioral research on mind-wandering in patients with aMCI and AD. To our knowledge, there is only one published study on mind-wandering in patients with very mild AD and mild AD who had the global score of .05 and 1 on the Clinical Dementia Rating (CDR) scale, respectively (Gyurkovics, et al., 2017). Gyurkovics, et al. (2017) used the standard SART (i.e., responding to single digits, but withholding response to the digit 3) and found that participants with very mild and mild AD

reported significantly fewer task-unrelated thoughts in response to random thought probes than healthy older adults (with the score of 0 on the CDR).

However, relating this important finding to spontaneous retrieval deficits in aMCI may be problematic for the following reasons. First, AD patients performed worse on several indices of the SART than the HC group, indicating that the ongoing task was more difficult for them. Given that on-going task difficulty reduces mind-wandering rates even in young adults (e.g., Forster & Lavie, 2009; Smallwood et al., 2009), it is essential to assess mind-wandering under conditions in which group differences in ongoing task performance are reduced as much as possible (*cf.* O'Callaghan et al., 2015). Second, there is also some uncertainty about the comparability of diagnostic criteria for aMCI (Petersen, 2004) and the CDR-based classification used by Gyurkovics et al. (2017). Although individuals with an overall CDR rating of .05 are quite heterogeneous and represent a continuum between normal aging and mild AD that encompasses the spectrum of MCI, some studies have shown that the CDR score of .05 may tap into more severe end of MCI diagnosis (Woolf et al., 2016). Most importantly, participants in the Gyurkovics et al. (2017) study reported only whether their thoughts were on-task or off-task, which made it difficult to ascertain what proportion of task-unrelated thoughts involved truly spontaneous (i.e., unintended) rather than intentional mind-wandering (see Smallwood & Schooler, 2015; Seli, Risko, Smilek & Schacter, 2016).

Therefore, the results of the present study significantly extend the initial findings of Gyurkovics, et al. (2017) by specifically demonstrating substantial reductions in *spontaneous* (i.e., unintentional) mind-wandering in people with aMCI under the conditions that elicited equal performance in target detection in both groups of participants and allowed the examination of cues and the temporal focus of spontaneous task-unrelated thoughts (Plimpton et al., 2016). It is important that large group differences in the proportion of probes with reported spontaneous task-unrelated thoughts (73% in HC and 44% in aMCI) occurred in a

very slow-paced vigilance task (3 seconds per slide) that did not require any behavioral response on the majority (98%) of trials. In addition, infrequent targets (vertical lines) were perceptually salient by being presented in red color while all non-target stimuli (horizontal lines) were black. This arrangement resulted in ceiling performance in both groups and it is less likely that aMCI had to put more effort to achieve the same level of target detection as HC. Indeed, the reported levels of concentration did not differ between the groups (if anything, it was nominally lower in the aMCI than in the HC group) and informally participants reported that the task was not difficult at all.

The most novel and important finding was that aMCI participants reported less mind-wandering than HC due to their inability to experience spontaneous task-unrelated thoughts about past events in response to incidental cues. The finding that verbal cues were essential in triggering spontaneous task-unrelated thoughts about past memories more frequently than current or future thoughts is important because it is in line with recent results from studies on healthy young and older adults (Maillet & Schacter, 2016b; Maillet et al., 2017; Vannucci et al., 2017). These studies showed that participants were more likely to report past memories than future thoughts in undemanding ongoing tasks with verbal cues, while in ongoing tasks with no verbal cues, significantly more future thoughts were reported than past memories. It is interesting that this general pattern was present even in our aMCI participants who, despite their greatly reduced number of task-unrelated past thoughts, still reported significantly higher number of past memories than current thoughts ($p = .003$), while the difference between past memories and future thoughts was in the same direction, but did not reach statistical significance ($p = .087$) (see Figure 2).

Taken together, the findings appear to indicate that “environmental stimuli regularly trigger mind-wandering episodes” (p.56, Maillet et al., 2017), which calls for some re-conceptualization of mind-wandering as purely stimulus-independent (*cf.* Plimpton et al.,

2015). Accordingly, Maillet and Schacter (2016b) have made a useful distinction between stimulus-dependent and stimulus independent mind-wandering and have provided initial empirical evidence for potential differences between the two (see Maillet et al., 2017).⁵ Consequently, in the present study we have investigated the effects of aMCI status on stimulus-dependent (but spontaneous) mind-wandering, given that instances of stimulus-independent mind-wandering (i.e., instances of task-unrelated thoughts with no reported triggers) were relatively low in both groups. In contrast, Gyurkovics, et al. (2017) investigated stimulus-independent mind-wandering using the SART with numerical stimuli and also found significant reductions in off-task thoughts in patients with very early stages of AD, indicating that reduced mind-wandering may be the key characteristic of very early stages of AD irrespective of type of mind-wandering. However, future research needs to address an interesting question about whether stimulus-dependent mind-wandering is reduced more substantially than stimulus-independent mind-wandering in aMCI participants.

Reduced mind-wandering as an early cognitive marker of AD

A large body of research on early cognitive markers of AD indicates that currently available neuropsychological tests, used in clinical settings, may not be sufficiently sensitive to detecting subtle memory impairments in individuals with aMCI and especially those at pre-MCI stages who report some problems in their everyday cognitive functioning, but do not yet satisfy the diagnostic criteria for MCI (Ozer et al., 2016). Consequently, significant efforts are made to improve diagnostic accuracy by developing new memory and cognitive tasks based on research in cognitive neuroscience and experimental psychology (see Rentz et al., 2013).

Results of the present study indicate that people with aMCI may have substantial reductions in such pervasive and basic human cognitive activity as thinking about something else while carrying out daily tasks that do not require large amount of concentration and attention. This finding is important clinically because it suggests that brief cognitive tests

measuring participants' propensity to experience spontaneous task-unrelated thoughts can be used as early cognitive markers of AD, which have a potential to substantially increase the diagnostic accuracy of aMCI. Recently, Logie, Parra and Della Sala (2015) have proposed a number of criteria that an effective early cognitive marker should satisfy including, among others, the requirement that (i) impairments on the test are specific to AD so that other disorders (e.g., depression) can be discounted, (ii) there are no improvements in performance due to repeated testing, and (iii) the performance on the test is age invariant in healthy population. None of the currently used standard delayed episodic memory tasks or tests of global cognitive functioning (e.g., MMSE) appear to satisfy these requirements as performance on these tests is usually also impaired in depressed patients and healthy older adults and there may also be practice effects (*cf.* Logie et al., 2015).

In contrast, simple vigilance tasks of spontaneous mind-wandering (like the one used in the present study) can potentially meet most of these requirements. Although disruptions in normal functioning of the brain's default network have been associated with many neuropsychiatric and mental disorders (e.g., Whitfield-Gabrieli & Ford, 2012), they seem to be related to increased rather than reduced mind-wandering. For example, studies using the SART in the laboratory and experience sampling in everyday life, have all shown increased levels of mind-wandering and rumination in participants with major depressive disorder and dysphoria in comparison to healthy controls (e.g., Deng, Li, & Tang, 2014; Hoffmann et al., 2016; Ottaviani et al., 2015). Also, the likelihood of practice effects in the reported frequency of spontaneous task-unrelated thoughts should be minimal or absent, given that participants perform at ceiling on the ongoing vigilance task and think that it measures their concentration rather than mind-wandering *per se*.

In relation to age invariance, although negative age effects on the frequency of mind-wandering have been obtained in the majority of studies with healthy young and old

participants (for a review see Maillet & Schacter, 2016a), it is possible that this is at least partly due to the use of relatively demanding ongoing tasks with predominantly non verbal stimuli (e.g. the SART) (*cf.* O’Callaghan et al., 2015), and/or older adults having higher levels of motivation and interest in performing the SART (e.g., Seli et al., 2017). For example, in two recent studies that used experience sampling (Gardner & Ascoli, 2015) or the vigilance task used in the present study (Kvavilashvili, Niedźwieńska & Kliegel, 2016) no reliable age effects were found in the frequency of task-unrelated thoughts (for similar findings see Berntsen et al., 2017; Kvavilashvili & Fisher, 2007).

Consequently, future research is needed with a wider variety of tasks measuring mind-wandering and related cognitive phenomena (e.g., involuntary autobiographical memories and involuntary future thinking) to assess the presence or absence of age related impairments in spontaneous mind-wandering in healthy population as a function of ongoing task difficulty and other characteristics (i.e., presence of verbal cues). As pointed out by Plimpton et al. (2015), research on mind-wandering has used ongoing tasks that are less conducive to eliciting task-unrelated thoughts compared to the simple vigilance task with verbal cues used in the present study.

Theoretical implications

The results of the present study, together with the findings from studies of focal prospective memory in participants with aMCI and mild AD (Chi et al., 2014; Niedźwieńska et al., 2017; McDaniel et al., 2011), may improve the current understanding of cognitive processes that are most susceptible to decline at the prodromal stages of AD and their underlying brain mechanisms. Indeed, disruptions in delayed episodic memory tasks (which are based on strategic deliberate processes at encoding and retrieval) have been traditionally linked with the tau pathology and cell atrophy in hippocampus both in patients with aMCI and mild AD. However, fMRI studies of episodic memory tasks increasingly suggest that the

normal memory functioning is mediated by a set of interconnected networks involving parts of the default network and frontoparietal executive network in addition to hippocampus and medial temporal lobes (Moscovitch et al., 2016; Ranganath & Ritchey, 2012).

Of particular interest is the finding that while the PCC is showing deactivations during successful encoding of items in these episodic memory tasks in non-clinical samples, the successful retrieval involves co-ordinated activations in both medial temporal lobes (including hippocampus) and the PCC (Rugg & Vilberg, 2013; Wagner et al., 2005). The involvement of the PCC has been recently also documented in cognitive tasks that are different from standard episodic memory tests in that they rely on spontaneous conscious occurrence of thoughts and memories in one's mind (*cf.* Cona et al., 2016; Ellamil et al., 2016). Together, these findings suggest that the PCC may be an essential node in the system that facilitates the spontaneous delivery of information to the mind in response to strong environmental or internal cues. If the PCC is crucial in mediating spontaneous retrieval processes in general and especially in mind-wandering about the past and future, then the amyloid pathology in this area of the default network at pre-clinical and prodromal stages of the AD should lead to disproportionate impairments in tasks that rely on such spontaneous processes.

Limitations and future directions

Despite encouraging findings, the present study has some limitations that will need to be addressed in future research such as small samples and the absence of default network imaging data to directly test the role of PCC in reduced mind-wandering in aMCI. Of particular interest would be to assess mind-wandering in older adults with amyloid burden in the PCC, but who do not yet display any cognitive decline as measured by standard neuropsychological tests (see Amariglio et al. 2012; Sperling et al., 2014). Results from such studies could improve our understanding of the disease and its underlying brain pathology, and may increase the diagnostic accuracy of neuropsychological testing.

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Footnotes

¹ Although fMRI studies have also reported the involvement of the brain's frontoparietal control network in addition to the default network (for review, see Fox et al., 2015), this could be primarily due to the fact that most previous studies have not distinguished intentional and unintentional mind-wandering on the one hand, and the occurrence of spontaneous thought from its subsequent maintenance in the mind, on the other (but see Ellamil et al., 2016).

² In focal prospective memory tasks, the spontaneous retrieval is facilitated by an overlap between the features of prospective memory cue event and ongoing activity (e.g., responding to a target word 'tortoise' while processing words semantically in the ongoing task). In nonfocal tasks, the processing of the ongoing task does not encourage spontaneous noticing of prospective memory cue and successful performance requires strategic monitoring (e.g., responding to a syllable 'tor' while processing words for their meaning).

³ This modification was implemented because Vannucci et al. (2015) found that young participants reported significantly more involuntary memories when cue words were presented on only 1/3 of the slides than on 2/3 of the slides. According to Vannucci et al. (2015), inadvertently reading cue words on almost every slide increased the cognitive load of the vigilance task, which interfered with retrieval processes involved in the occurrence of spontaneous task unrelated thoughts and memories.

⁴ One HC and 2 aMCI participants did not report any task-unrelated spontaneous thoughts and therefore this analysis was based on the data of 24 HC and 21 aMCI participants.

⁵ It is also important to stress that stimulus dependent thoughts are different from thoughts about environmental distractions. The latter involve thoughts about stimuli in the environment (e.g., thoughts about the noise coming from outside) while stimulus dependent mind-wandering involves thoughts that are not about the external cue per se (e.g., thinking about winning a swimming competition and receiving a medal in high school after seeing the words

‘winning a prize’ in the vigilance task). In addition, as pointed out by Maillet et al. (2017), the cues may or may not be present at the time when the thought comes to mind.

Table 1.

Demographic Characteristics as a Function of Group (aMCI participants vs. Healthy Controls)

	aMCI (n = 23)	Healthy Controls (n = 25)
Sex	64 % women	76 % women
Age	79.17 (6.67)	77.64 (6.20)
Education (years)	12.26 (3.03)	12.48 (2.68)
NART	36.61 (7.79)	38.64 (5.79)
Mood	6.39 (5.40)	5.04 (3.81)
Health at present	3.61 (1.03)	3.96 (0.46)
Health vs. peers	3.83 (0.72)	4.00 (0.71)
MMSE	27.74 (1.84)	29.44 (0.82)

Note. aMCI = amnesic Mild Cognitive Impairment; NART = National Adult Reading Test; Mood = Geriatric Depression Scale 30; MMSE = Mini-Mental State Examination; Health at present (*1 = poor, 5 = excellent*); Health compared to peers (*1 = significantly worse, 3 = same, 5 = significantly better*).

Table 2.
Mean Scores on Neuropsychological Test Battery in Participants with aMCI and Healthy Controls

	aMCI (n = 23)	HC (n = 25)	<i>d</i>
Episodic memory			
WMS Logical memory: immediate recall	22.44 (9.79)***	42.76 (11.75)	1.88
WMS Logical memory: delayed recall	7.78 (7.18)***	26.48 (8.22)	2.42
WMS Verbal Paired Associates: immediate recall	6.00 (5.97)***	16.84 (7.16)	1.64
WMS Verbal Paired Associates: delayed recall	1.61 (1.73)***	5.28 (2.28)	1.81
HVLT: immediate recall 1	4.13 (1.58)***	6.80 (1.73)	1.61
HVLT: immediate recall 2	5.17 (1.92)***	8.76 (1.79)	1.93
HVLT: immediate recall 3	6.35 (1.50)***	9.80 (1.61)	2.22
HVLT: delayed recall	2.35 (2.72)***	8.84 (2.78)	2.36
Short-term memory			
WMS Digit Span: Forward	10.84 (2.32)	10.30 (2.82)	.21
WMS Digit Span: Backward	6.35 (2.17)*	7.76 (2.26)	.64
Attention and executive functions			
Verbal Fluency: Letters	33.74 (11.32)**	44.04 (12.77)	.85
Verbal Fluency: Category	12.57 (4.98)***	19.24 (5.77)	1.24
Trail Making Test – Part A	45.91 (12.95)**	36.05 (9.79)	.86
Trial Making Test – Part B	134.44 (61.02)***	74.06 (23.68)	1.31

Note. aMCI = amnesic Mild Cognitive Impairment; HC = healthy controls; HVLT = Hopkins Verbal Learning Test; WMS = Wechsler Memory Test
 For each test, a high score indicates a better performance with the exception of scores referring to time used to complete the Trail Making Test (A and B).
 Differences between aMCI and HC are indicated by * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 3

Mean (Standard Deviation) Target Detection, Response Time and Concentration Rating in Participants with aMCI and Healthy Controls, and Results of Independent Samples T-test.

	aMCI	Healthy Controls	<i>t</i>	<i>df</i>	<i>p</i>	<i>d</i>
Target Detection ^a	10.87 (0.34)	10.96 (0.20)	1.12	46	0.27	.32
Response Time (ms)	2045.26 (569.17)	1672.68 (218.63)	-3.04	46	0.004	.86
Concentration ^b	3.97 (0.81)	4.29 (0.69)	1.47	46	0.15	.43

Note. aMCI = amnesic Mild Cognitive Impairment; ^a Out of a Total of 11 Targets Presented;

^b Concentration Ratings were Made on a 5-Point Scale (*1 = not at all; 5 = fully concentrating*).

Figure Caption

Figure 1. Mean Number of Thought Probes as a Function of Thought Type (Task-Related Thoughts vs. Spontaneous Task-Unrelated Thoughts vs. No Thoughts) and Group (aMCI participants vs. Healthy Controls). Error Bars Represent 1SE of the Mean.

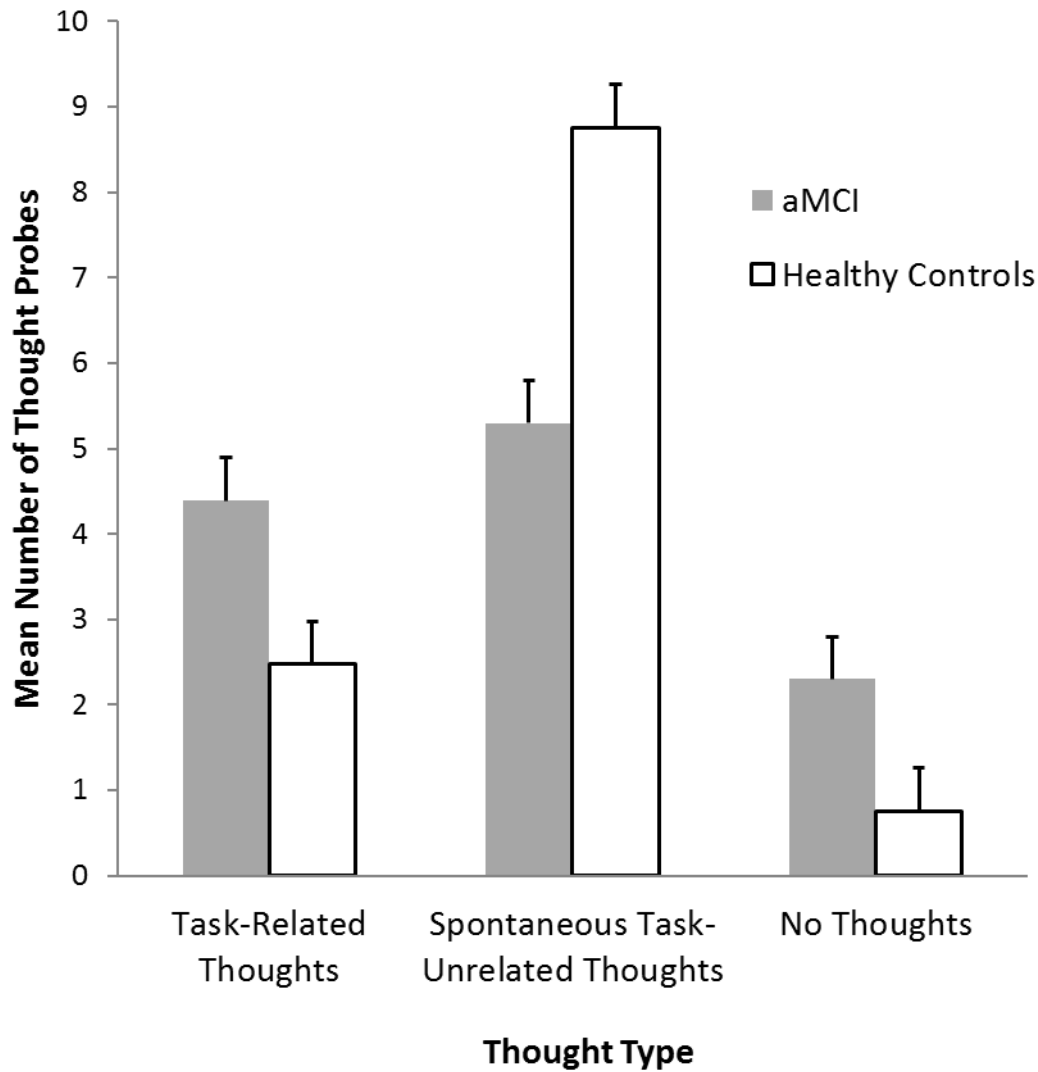
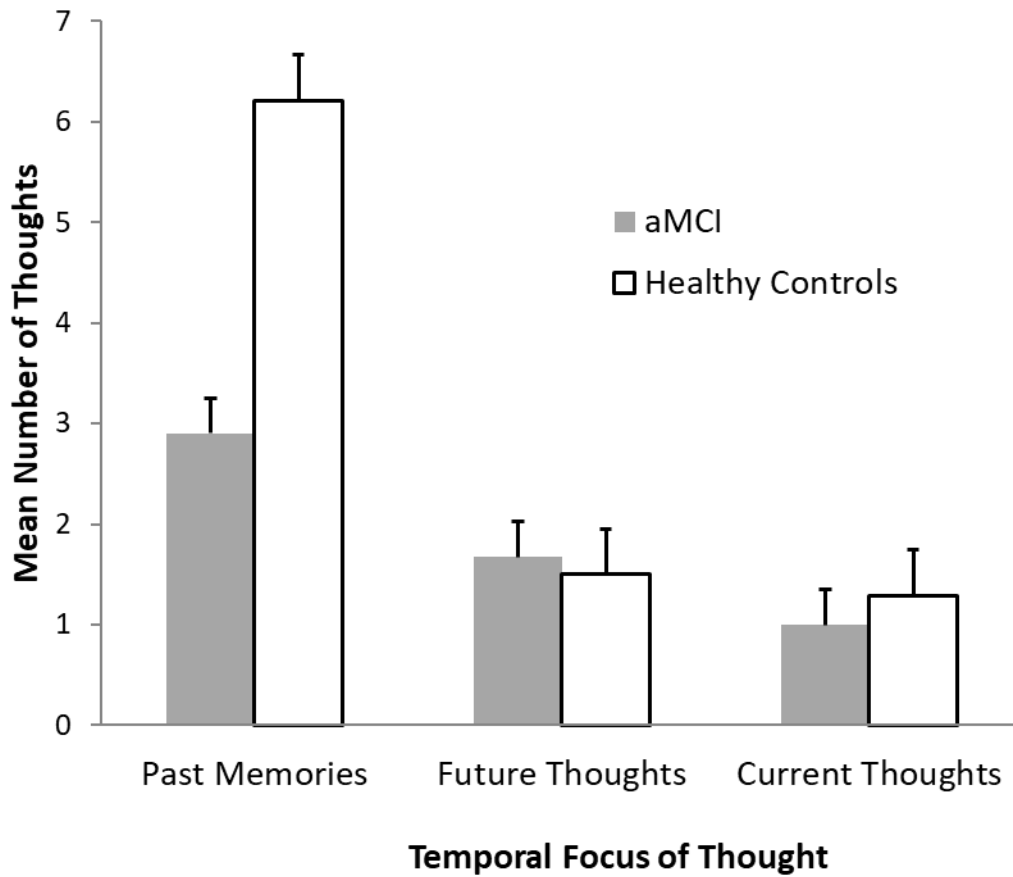


Figure 2. Mean Number of Spontaneous Task-Unrelated Thoughts as a Function of Temporal Focus of Thought (Past Memories vs. Future Thoughts vs. Current Thoughts) and Group (aMCI participants vs. Healthy Controls). Error Bars Represent 1SE of the Mean.



SUPPLEMENTARY MATERIAL

Effects of Cue Valence on Thought Temporality

As the majority of spontaneous task-unrelated thoughts were reported as being triggered by word cues encountered in the vigilance in both aMCI and in HC participants, we were able to examine cue valence as a function of thought temporality and aMCI status.

Not all participants reported thoughts from all three temporal categories. Therefore, three mixed ANOVAs were conducted separately for spontaneous task-unrelated thoughts about the past (i.e., memories), present and future with group (aMCI, HC) as a between subjects factor and cue valence (positive, negative, neutral) as a within subjects factor. The analysis on past memories resulted in the main effect of group with higher number of memories reported by HC than aMCI participants, $F(1, 42) = 14.34, p < .001, \eta_p^2 = 0.26$, and the main effect of cue valence, $F(2,84) = 6.76, p = .002, \eta_p^2 = 0.14$, with neutral cues eliciting fewer memories than both positive cues ($p = .003$) and negative cues ($p = .001$), which did not differ from each other ($p = .93$). However, these main effects were qualified by a marginally significant group by cue valence interaction with a medium effect size, $F(2,84) = 2.93, p = .059, \eta_p^2 = .07$ (see Figure S1). A simple main effects analysis revealed a significant main effect of cue valence in HC, $F(2,41) = 7.94, p = .001, \eta_p^2 = 0.28$. Pair wise comparisons indicated that positive and negative cues both elicited more memories than neutral cues ($p < .001$ and $p = .02$, respectively), but they did not differ from each other ($p = .16$). For aMCI participants, the main effect of cue valence was approaching significance with large effect size, $F(2, 41) = 3.00, p = .061, \eta_p^2 = 0.13$. Pair wise comparisons showed that only negative cues, but not positive cues, elicited more memories than neutral cues ($p = .017$ and $p = .44$, respectively), while positive and negative cues did not differ from each other ($p = .16$).

In the case of spontaneous future thoughts, the results revealed a significant main effect of cue valence, $F(2,54)=6.21, p = .004, \eta_p^2 = 0.19$, with positive cues ($M = .86, SD =$

.69) eliciting more future thoughts than negative cues ($M = .31, SD = .47$) and neutral cues ($M = .41, SD = .57$) ($p = .005$ and $p = .015$, respectively), which did not differ from each other ($p = .55$). Neither the main effect of group or the group by cue valence interaction was significant ($F_s < 1.44$). In the case of current thoughts, no significant main effects or an interaction was found ($F_s < 1$).

Thought characteristics

Table S1 shows the mean ratings of pleasantness and rehearsal, calculated for each type of thought (memories, current and future thoughts) per participant across 12 stop trials, and the results of t-tests comparing the aMCI and HC groups. No statistically significant group differences were obtained for these ratings, except for aMCI participants reporting that they had rehearsed their current thoughts more often compared to HC. Table S1 also shows mean proportions of past memories in aMCI and HC participants that were independently coded by the first and second authors as specific, one-off memories of events that happened at a particular place and time ($Kappa = .89, SE = .03$). In the literature on autobiographical memory, specific memories are distinguished from general memories that refer to repetitive events or events that lasted over extended time period (Williams, 1996). No statistically significant group differences were obtained for the mean proportion of specific memories.

Table S2 shows the frequency of past memories and future thoughts in terms of their temporal distance from the present moment in aMCI and HC participants. Chi-square tests did not reveal any group differences either in how much into the future the projections were, $\chi^2(2, N = 62) = 1.68, p = .431$, or how old past memories were, $\chi^2(3, N = 213) = 0.76, p = .859$. However, Chi-square tests revealed that both future thoughts and past memories were unevenly distributed in terms of their temporal distance from the present moment, $\chi^2(2, N = 62) = 44.94, p < .001$ and $\chi^2(3, N = 213) = 64.95, p < .001$, respectively. While the majority of future thoughts (73%) were projections into the immediate future (within one week after

the session) with no instances of thoughts into distant future (i.e., more than one year ahead), the pattern was reversed for past memories with only 27% of memories being less than one week long and 46% referring to distant events that had occurred more than one year ago (*cf.* Plimpton et al., 2015).

Figure S1. Mean Number of Spontaneous Past Memories as a Function of Cue Valence (Positive vs. Negative vs. Neutral) and Group (aMCI participants vs. Healthy Controls).

Error Bars Represent 1SE of the Mean.

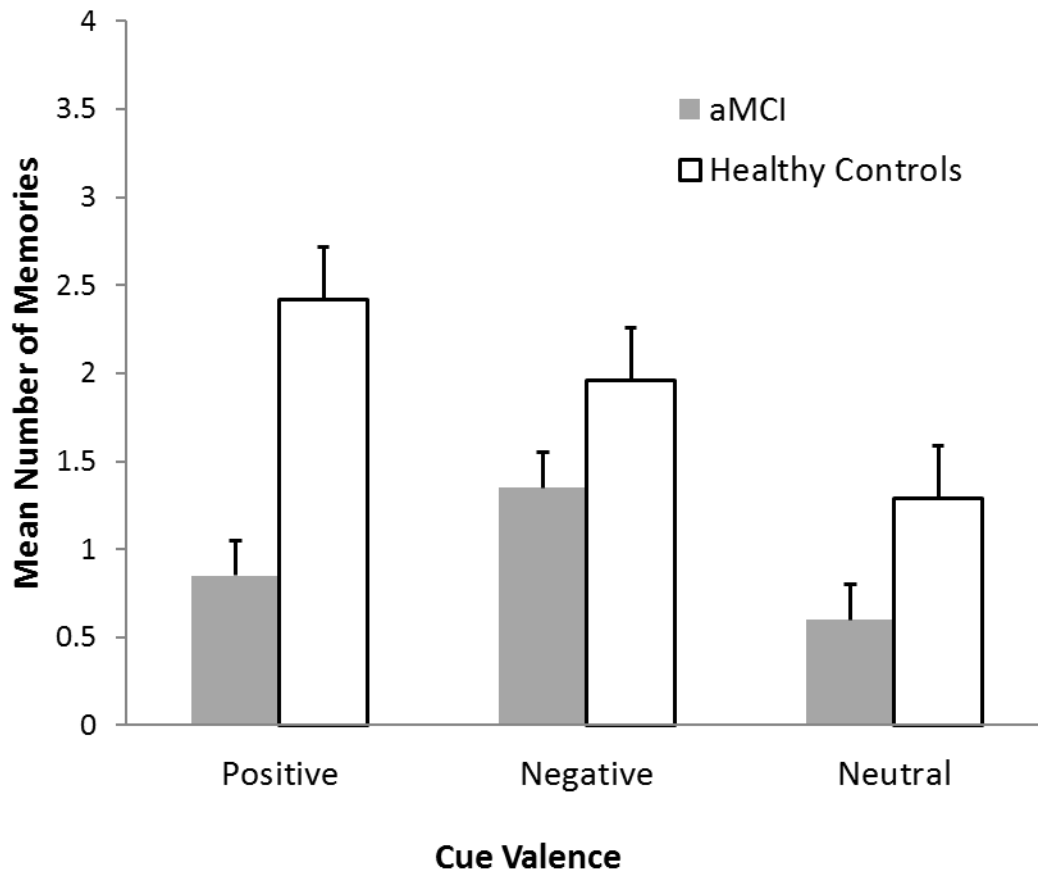


Table S1. Mean Ratings of Pleasantness and Rehearsal (Standard Deviation) as a Function of Temporal Focus of Spontaneous Task-Unrelated Thought (Past Memory vs. Present vs. Future) and Group (aMCI participants vs. Healthy Controls), and Mean Proportions of Specific Past Memories (Standard Deviation) in aMCI and Healthy Control Participants. The Results of Independent Samples T-tests for each Temporality of Thought are Reported in the Right Hand Columns.

	aMCI	Healthy Controls	<i>t</i>	<i>df</i>	<i>P</i>
Pleasantness^a					
Past Memory	3.44 (0.73)	3.44 (0.55)	0.02	43	0.99
Current	3.38 (0.96)	2.97 (0.90)	-1.25	30	0.22
Future Thought	3.71 (0.77)	3.45 (0.88)	-0.90	30	0.37
Rehearsal^b					
Past Memory	2.87 (1.36)	3.08 (0.92)	0.63	43	0.53
Current	3.66 (1.46)	2.68 (1.12)	-2.14	30	0.04
Future Thought	2.70 (1.12)	3.03 (0.99)	0.87	30	0.39
Specificity^c					
Past Memory	43.18 (38.88)	53.67 (28.15)	1.05	43	0.30

Note. aMCI = amnesic Mild Cognitive Impairment; ^a Ratings were Made on a 5-Point Scale (1= Very Unpleasant, 3=Neutral, 5=Very Pleasant); ^b Ratings were Made on a 5-Point Scale (1=Never, 2=Once or Twice, 3=A Few Times, 4=Several Times, and 5=Many Times). ^c Past Memories were Coded as Specific or General. Means Represent Mean Proportions of Specific Memories Averaged across Individual Means of Participants.

Table S2. *Frequency (Percentage) of Past Memories and Future Thoughts as a Function of Group (aMCI vs. Healthy Controls) and Temporal Distance from the Present (less than a week vs. less than a month vs. less than a year vs. longer than a year).*

(a) Spontaneous Past Memories

	Temporal Distance from Present Time				Total
	< 1 Week	< 1 Month	< 1 Year	> 1 Year	
aMCI	20 (31%)	6 (19%)	8 (12%)	31 (48%)	65 (100%)
Healthy Control	41 (28%)	18 (12%)	22 (15%)	67 (45%)	148 (100%)
Total	61 (27%)	24 (11%)	30 (14%)	98 (46%)	213 (100%)

(b) Spontaneous Future Thoughts

	Temporal Distance from Present Time				Total
	< 1 Week	< 1 Month	< 1 Year	> 1 Year	
aMCI	25 (74%)	8 (23%)	1 (3%)	0 (0%)	34 (100%)
Healthy Control	20 (71%)	5 (18%)	3 (11%)	0 (0%)	28 (100%)
Total	45 (73%)	13 (21%)	4 (6%)	0 (0%)	62 (100%)

Note. aMCI = amnesic Mild Cognitive Impairment

Supplementary References

Plimpton, B., Patel, P., Kvavilashvili, L. (2015). Role of triggers and dysphoria in mind-wandering about past, present and future: A laboratory study. *Conscious and Cognition*, 33, 261-76.

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