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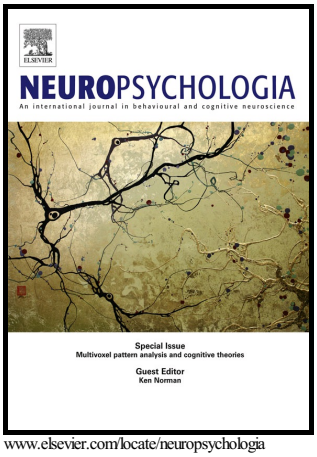

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From mind wandering to involuntary retrieval: Age-related differences in spontaneous cognitive processes

Running title: Spontaneous cognition in older adults

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Abstract

The majority of studies that have investigated the effects of healthy aging on cognition have focused on age-related differences in voluntary and deliberately engaged cognitive processes. Yet many forms of cognition occur spontaneously, without any deliberate attempt at engaging them. In this article we review studies that have assessed age-related differences in four such types of spontaneous thought processes: mind-wandering, involuntary autobiographical memory, intrusive thoughts, and spontaneous prospective memory retrieval. These studies suggest that older adults exhibit a reduction in frequency of both mind-wandering and involuntary autobiographical memory, whereas findings regarding intrusive thoughts have been more mixed. Additionally, there is some preliminary evidence that spontaneous prospective memory retrieval may be relatively preserved in aging. We consider the roles of age-related differences in cognitive resources, motivation, current concerns and emotional regulation in accounting for these findings. We also consider age-related differences in the neural correlates of spontaneous cognitive processes.

Keywords: Aging, spontaneous cognition, mind-wandering, involuntary autobiographical retrieval, intrusive thoughts, prospective memory

1. Introduction

The effects of healthy aging on cognition have been studied over many years, and it is now well established that increasing age is associated with changes in several cognitive domains including episodic memory, autobiographical memory, working memory and attention (Craik & Salthouse, 2000). However, the majority of studies of aging cognition to date have focused on age-related differences in voluntary and deliberately engaged cognitive processes. For example, in a typical episodic memory experiment, participants are asked to voluntarily recall a list of items seen earlier and in studies of autobiographical memory, participants are typically instructed to recall experiences from their everyday lives. Yet many forms of cognition occur spontaneously, without any deliberate attempt at engaging them. For instance, numerous studies during the past decade have shown that when people are asked to perform a cognitive task in the laboratory, they often spontaneously focus on task-irrelevant thoughts, an activity known as mind-wandering (MW; Smallwood & Schooler, 2015). Indeed, recent evidence suggests close to 50% of our daily lives may be spent engaging in MW (Killingsworth & Gilbert, 2010). Despite its prevalence, however, relatively little is known about age-related changes in MW. Similarly, researchers have also delineated other spontaneous thought types such as involuntary autobiographical memory (IAM; Berntsen, 2009), intrusive thoughts (Rachman, 1981), intrusive memories (Holmes et al., 2004), involuntary semantic memories (Kvavilashvili & Mandler, 2004), spontaneously recurring tunes or "earworms" (Beaman & Williams, 2010), déjà vu (Brown, 2003) and some forms of prospective memory (PM) (McDaniel & Einstein,

2000). But we still know relatively little about the effects of aging on these forms of spontaneous cognition.

Despite the relatively modest amount of evidence available concerning the effects of aging on spontaneous cognition, we believe that the time is right to review what is known on this topic, for at least three reasons. First, interest in the general topic of spontaneous cognition has increased rapidly during recent years in both psychology and neuroscience (e.g., Andrews-Hanna et al., 2010; Christoff et al., 2011; O'Callaghan et al., 2015; Smallwood & Schooler, 2015), and the trend seems likely to continue. Second, the emergence of studies on MW in older adults during the past few years (e.g., Jackson & Balota, 2012; Krawietz et al., 2012; Maillet & Rajah, 2013; Nagamatsu et al., 2013; Staub et al., 2014) suggests an increasing focus on spontaneous cognition among cognitive aging researchers. Third, although studies of different spontaneous thought types are typically pursued independently of one another, we think that it is useful to consider them together in order to encourage questions and future investigations about similarities and differences among these processes as a function of aging. In the current review, we focus on four types of spontaneous cognitive processes for which some systematic evidence exists regarding cognitive aging: MW, IAM, intrusive thoughts and spontaneous PM retrieval. We will focus primarily on age-related differences in MW because this type of spontaneous cognition has been studied most extensively. By contrast, there has been virtually no research on age-related differences in earworms or involuntary semantic memory, so we do not consider these phenomena further. Similarly, there is little research on intrusive memories in older adults other than in the context of

post-traumatic stress disorder (Clapp & Beck, 2012). Because the present review is concerned with healthy aging, consideration of psychological disorders is beyond our scope. Finally, we do not consider déjà vu, but refer interested readers to a recent overview of age-related differences in this phenomenon (Moulin et al., 2014).

When surveying the literatures on MW, IAM, spontaneous PM and intrusive thoughts, one may notice differences in which aspects of spontaneous cognition have been most extensively investigated in each. For example, meta-awareness has been a topic of much interest in the MW literature ever since early studies demonstrated that MW often occurs without it (Schooler et al., 2004). In the IAM literature, there has been much interest on elucidating what cues trigger these spontaneous thoughts. Both laboratory and naturalistic studies have found that most IAM have identifiable triggers that tend to predominantly be external (i.e. triggered by an environmental stimulus or event) rather than internal (i.e. triggered by one's train of thought) (Berntsen, 1996; Schlagman & Kvavilashvili, 2008). In the PM literature, it was emphasized early on that PM can occur both spontaneously or deliberately, and researchers expended much effort in developing methodologies to assess spontaneity of thoughts (Einstein et al., 2005; McDaniel & Einstein, 2000). These differences in which aspects of thoughts have been most extensively studied in each literature likely reflect differences in research trends, as well as differences in methodologies used, rather than actual differences between the phenomena of interest. For example, a recent study suggests that similar to MW, intrusive thoughts can also occur without meta-awareness (Takarangi et al., 2014). In the MW literature, that has recently been a surge of interest in identifying triggers for MW

(e.g., Smallwood, 2013), with studies showing that, similar to findings from the IAM literature (e.g., Schlagman & Kvavilashvili, 2008), the content of off-task thoughts can be modulated by task stimuli (McVay & Kane, 2013; Plimpton et al., 2015). There has also been a resurgence of interest in distinguishing between spontaneous and deliberate MW (e.g., Seli et al., 2014; Seli et al., 2015), a topic that has been of interest for some time in the PM literature. These findings highlight that MW, IAM, spontaneous PM, and intrusive thoughts may share much in common, and that greater insight regarding age-related differences in spontaneous thoughts may emerge from considering these phenomena together rather than separately.

Two broad theories of cognitive changes with aging are particularly relevant for making predictions regarding age-related differences in spontaneous cognitive processes: the inhibition deficit theory (Hasher & Zacks, 1988) and the reduced cognitive resources theory (Craik, 1983, 1986; Craik & Byrd, 1982). The inhibition deficit theory of aging suggests that reduced inhibitory abilities in older adults facilitate the initial entrance into working memory of information that is off the goal path, and the prolonged maintenance of such information in working memory (Hasher & Zacks, 1988). Off-goal path thoughts include environmental distractions, evaluations of ongoing events (e.g., "this is not the best talk he's given) and thoughts/plans unrelated to ongoing events (e.g., "I need to remember to make dinner reservations after the talk"). Thus, the inhibitory deficit theory leads to the prediction that older adults may be more likely than young adults to exhibit off-task spontaneous thoughts. There is some evidence that supports this idea, at least indirectly. For example, studies in which young and older adults produce narrative

discourse indicate that older adults are more likely than young to spontaneously produce "off-topic" details that are not relevant to the main topic at hand (e.g., Arbuckle & Gold, 1993; Trunk & Abrams, 2009), and related findings have been reported in studies that require young and old adults to produce extended narratives that involve remembering past experiences, imagining future experiences, or describing a scene (Madore et al., 2014; for review, see Schacter, et al., 2013). By contrast, some of the earliest direct evidence concerning MW suggested that older adults exhibit a reduction in MW compared to young adults (e.g., Giambra, 1989; J. Singer, 1961), a result seemingly inconsistent with predictions made based on the basis of the inhibitory deficit theory.

These findings may instead be more consistent with a second theory of aging that emphasizes a reduction in cognitive resources in older adults (Craik, 1983, 1986; Craik & Byrd, 1982; Lindenberger & Mayr, 2014). Craik (1986) argued that cognitive resources are particularly needed in tasks that provide minimal environmental support and instead rely on self-initiated processing. Thus Craik proposed that, because older adults have fewer cognitive resources compared to young adults, they should be particularly impaired in tasks requiring a high level of self-initiated processing, but minimally impaired in tasks with high environmental support. In the MW literature, it has been suggested that if older adults spend a greater proportion of their cognitive resources on an ongoing task or external activity compared to young adults, then they may have fewer resources left over to exhibit MW compared to young (e.g., Giambra, 1989; Krawietz et al., 2012; Maillet & Rajah, 2013). In the PM literature, the same theory has been used to suggest that

older adults should exhibit preserved PM in tasks that rely on spontaneous processing of a PM cue (e.g. when the PM intention of pressing a special key is spontaneously triggered by a target word), but that older adults may exhibit reduced behavioural performance in tasks relying on deliberate PM (McDaniel & Einstein, 2000). In considering why the reduced cognitive resources theory of aging has been used to predict both an age-related reduction in one spontaneous thought type (MW) and the preservation of another (PM), it is important to note that while MW is task-irrelevant, cue-driven PM is thought to occur spontaneously as part of the ongoing task. Thus, from a reduced cognitive resource perspective, it may be argued that older adults should exhibit intact spontaneous processing of PM cues since this does not require the use of cognitive resources beyond those already used to perform the ongoing task, whereas older adults should exhibit reduced MW since MW does require additional processing resources. A related and more general prediction would be that spontaneous thinking that is cued by environmental stimuli in the focus of attention is preserved in aging, while spontaneous thinking that is environment-independent is reduced.

As we discuss in this article, there is now increasing evidence that factors other than cognitive resources, such as age-related differences in task interest, current concerns, and emotional regulation, may also play an important role in explaining age-related differences in frequency of spontaneous thoughts. In the following sections, we review, in turn, studies that have examined psychological and behavioral characteristics of MW, IAM, intrusive thoughts and spontaneous PM retrieval in young and old adults. Next, we review studies that have used

neuroimaging to assess effects of aging on the neural correlates of these thought types. We conclude by integrating findings across these different literatures and linking them to observations from related studies of cognitive aging.

2. Age-related differences in mind-wandering

2. 1. Definition and methodological aspects

MW refers to a shift of attention away from an ongoing task and/or from events in the external environment, towards the processing of self-generated thoughts about a different time and place, which often occurs without meta-awareness (Smallwood & Schooler, 2006, 2015). A common example is reading to the end of a paragraph, only to realize that one's attention was not focused on the text, and thus having to start over. Although MW is usually thought of as being a spontaneous phenomenon, this does not necessarily need to be the case, as subjects may voluntarily choose to shift their attention away from an ongoing task (Christoff, 2012; Seli et al., 2014; Seli et al., 2015; Shaw & Giambra, 1993). A recent study found that the ratio of deliberate to spontaneous MW was positively correlated to motivation to perform the task, indicating that subjects may be especially prone to intentionally MW when they are not engaged by the task (Seli et al., 2015). We are not aware of any study that has distinguished between spontaneous and deliberate MW in a study involving older adults. Thus, it is important to keep in mind that in the studies described in this review, it is unclear whether there were age-related differences in the intentionality of reported MW, a point which we return to at the end of section 2.2.

Three main methods have been used to study age-related differences in MW in a laboratory context. Two of these methods, the "self-caught" and "probe-caught" methods, assess in-the-moment conscious experience during completion of an experimental task (Smallwood & Schooler, 2006). In the "self-caught" method, subjects are asked to monitor their thoughts during the task and to press a button when they notice their minds have wandered away from it. In the "probe-caught" method, thought probes periodically interrupt an ongoing task, and subjects are asked about the thoughts that had just been going through their minds. The main drawback of the probe-caught method that is addressed in part by the self-caught method is that it may miss some instances of MW that occur in between thought probes. On the other hand, compared with the probe-caught method, the self-caught method places extra demands on participants to monitor and be aware of their thoughts. Because young and older adults may differ in this ability, self-caught designs have rarely been used in the aging and MW literature, and when they have, self-caught methods have been combined with probe-caught methods (Giambra, 1989; Jackson & Balota, 2012; Jackson et al., 2013). Finally, a third method that has been used in the MW and aging literature involves retrospective questionnaires that ask subjects to report the frequency with which they experienced certain thoughts following the completion of an experimental task (Lachman & Agrigoroaei, 2012; Maillet & Rajah, 2013; Staub et al., 2014). The main advantage of using retrospective questionnaires is that doing so leaves performance of the task undisturbed. However, the main drawback is that questionnaires rely on the ability of subjects to

remember the thoughts they had during a previous task, an ability that may decline with age.

2.2. Effects of task engagement, current concerns and task difficulty

An early idea regarding MW is that it occurs because individuals have goals and concerns that extend beyond the present moment (Klinger, 2013; Klinger et al., 1973). Mental experiences at any given moment are directed to the most salient features, whether they are external (i.e., ongoing events) or internal (i.e., personal thoughts). When ongoing external events are engaging, attention will be drawn to them. However, attention may shift inwards if the relative saliency of self-generated thoughts about current goals and concerns overtakes the saliency of ongoing external events. Thus, according to this view, age-related differences in either the level of engagement in an ongoing task or in the relative saliency of current concerns in relation to this task could produce age-related differences in frequency of MW.

Several studies have provided evidence consistent with this proposal. In one study (Krawietz et al., 2012), across two experiments, young and older adults read a text on a computer screen one sentence at a time. Every 2-4 minutes, a thought probe interrupted the task and asked participants whether they had just been concentrating on the task or exhibiting MW. Older adults reported significantly less MW than young adults in both experiments. This was the case even when individual differences in reading speed were controlled for, minimizing the concern that age-differences in MW were due to age-related differences in levels of effort on the task. Furthermore, working memory span was not significantly correlated with MW

frequency in either age group. However, older adults reported finding the text significantly more interesting than young adults, and after accounting for text interest, age-related differences in MW were no longer significant.

Similar results were reported in a study by Shake et al. (2015) in which age-related differences in MW were measured during reading of a narrative text (an autobiographical narrative) and an expository text (containing historical and factual descriptions). Both groups reported less MW in the narrative relative to the expository text, and this former text was also rated as less difficult to read and more interesting. Older adults found the texts more interesting than young overall and also reported less MW compared to young for both texts. Age and text interest each accounted for a significant amount of variance in MW. In contrast, cognitive abilities (working memory, vocabulary, processing speed and inductive reasoning) did not account for variance in MW once age and text interest were taken into account.

Several other studies reporting age-related reductions in MW have also found that older adults reported more task interest than young adults (Jackson & Balota, 2012; Jackson et al., 2013; Maillet & Rajah, 2013; Staub et al., 2014). Jackson and Balota (2012) assessed age-related differences in MW in four separate experiments. Three experiments involved the sustained attention to response task (SART; a simple task in which subjects must respond to numbers 1-9 with a button press, except for the number 3, for which the response must be withheld), and the fourth involved a reading task. Older adults exhibited a reduction in MW across all four experiments. Age-related increases in task interest (Experiments 2-3) and subjective ratings of task difficulty (Experiment 2) were observed in the SART, and

both of these factors were negatively predictive of MW. Manipulating task difficulty by slowing down stimulus presentation rate of the SART resulted in more overall MW in the easy task with no age interaction. Conscientiousness scores, measured with the NEO-FFI personality inventory (Costa & McCrae, 1992) were higher in older than in young adults. Furthermore, there was a negative correlation between conscientiousness score and MW. The authors suggested that high-conscientious individuals might complete the task in a more disciplined or persistent fashion than low-conscientious individuals, which may reduce MW.

While these previous studies suggest that age differences in MW may reflect, at least in part, that older adults find cognitive tasks more engaging than young adults, one study reported that older adults exhibit fewer non-trivial current concerns than young, which could also contribute to age differences in MW (Parks et al., 1988). In this study, young adults also reported higher scores on a daydreaming scale relative to older adults (in the current review, we use the term "daydreaming" to refer to mind-wandering measured outside the laboratory, in participants' daily lives). Taken together, the findings of increased interest in ongoing laboratory tasks and fewer current concerns in older adults may indicate that attention is less likely to drift away from an ongoing cognitive task with increasing age. In other words, there may be less competition in older adults between the ongoing task and unrelated concerns.

If current concerns are an important driver of MW, then it is possible that the activities that individuals engage in prior to performing cognitive tasks influence their MW rates. For example, in young adults it has been demonstrated that pre-task

conditions that bias subjects' attention to themselves and/or their personal concerns and goals increase MW during a subsequent task (Antrobus et al., 1966; Kopp et al., 2015; Seibert & Ellis, 1991). Giambra (1989) reasoned that young and older adults may engage in different kinds of activities before participating in experimental studies, which may affect age-related differences in MW rates. Before engaging in thought sampling during a simple attention task, participants' pre-task experiences were controlled for two hours by having them perform memory and reaction-time tasks. Controlling pre-task conditions reduced between-subject variability in MW, but aging was still associated with a reduction in MW during the attention task. Additionally, a manipulation of task difficulty produced increased MW in both age groups during the easier task, with no age interaction. Furthermore, performance on the easier task was at ceiling in both age groups, leading Giambra to suggest that age-related reductions in MW in this task were unlikely to be due to excess attentional capacity in young. Instead, Giambra suggested that increased MW rates in young adults may be attributable to their having more "unfinished business" that consumes their attention, a proposal consistent with the finding of reduced current concerns in older adults (Parks et al., 1988).

Rather than manipulating pre-task conditions, Maillet and Rajah (2013) examined whether the nature of the task itself may influence MW rates differently in young and older adults. Participants were asked to encode word stimuli while performing either pleasantness judgements or man-made/natural judgements. The authors hypothesized that because pleasantness judgments involve making a personal decision about one's likes and dislikes, making these judgements may

trigger more instances of MW than making man-made/nature judgments. The results showed that young but not older adults exhibited more MW in the pleasantness than in the man-made/natural task.

In summary, the studies reviewed in this section suggest that factors such as task difficulty, conscientiousness, task interest, and amount of current concerns may be important factors contributing to age-related differences in MW frequency. Increasing ongoing task difficulty has been associated with decreased MW in both age groups (Giambra, 1989; Jackson & Balota, 2012), suggesting that harder tasks may leave fewer left over resources for MW. However, age-related reductions in MW are observed even when performance is at ceiling in both age groups (Giambra, 1989), or controlled for in each subject (Krawietz et al., 2012), indicating that reduced cognitive resources are likely not the sole contributing factor. Specifically, several studies reveal that older adults are more interested in ongoing experimental tasks than young adults (Jackson & Balota, 2012; Jackson et al., 2013; Krawietz et al., 2012; Maillet & Rajah, 2013; Staub et al., 2014), and one has indicated that they may have fewer current concerns outside the laboratory (Parks et al., 1988), suggesting that their attention may be less prone to drift away compared with young adults. However, as pointed out by Frank et al. (2015), since ratings of task interest/motivation are typically collected following the task, these ratings may be reactive to reports of off-task thoughts during the task and task performance (i.e. it is possible that frequent reports of MW decreases retrospective assessments of interest). Furthermore, given that ratings of task motivation have been particularly associated with deliberate rather than spontaneous MW in young adults (Seli et al.,

2015), it is possible that age-related differences in MW may primarily reflect differences in the former type. These issues should be addressed in future studies.

2.3. Is mind-wandering replaced by performance-related thoughts in older adults?

Older adults worry about their declining cognitive abilities, and negative attitudes and stereotypes can have a negative impact on their task performance (Hess et al., 2009; Levy, 1996; McDaniel et al., 2008). Taken together with the findings of greater task interest by older adults reported in the previous section, these findings suggest the possibility that older adults may exhibit more evaluative thoughts about their ongoing performance in cognitive tasks (commonly referred to as task-related interferences). That is, whereas young adults' current concerns may fall primarily in the category of mind-wandering (thoughts unrelated to the current task about one's past, future, or current worries), older adults may exhibit more thoughts or worries about their performance on the task itself.

In an early study, Parks et al. (1988) measured verbal utterances during two relaxation and two puzzle solving periods. The verbal reports were examined for the presence of attentional-control utterances (thoughts relevant for performing the task) and evaluative thoughts focusing on the appraisal of the participant's previous actions. Both types of thoughts were higher during puzzle solving than during rest and in older than in young adults. The authors suggested that increased anxiety in older adults may have resulted in more problem-solving and evaluative thoughts.

Lachman and Agrigoroaei (2012) assessed the relationship between low control belief (holding the view that little can be done to influence outcome or performance), state anxiety, MW and task-related interferences, and performance

on an episodic memory task in 149 individuals aged 22 to 84. MW and task-related interferences were measured retrospectively with a questionnaire following the episodic memory task, and collapsed into a single off-task score. Individuals with lower control beliefs reported higher state anxiety, which itself increased the likelihood of off-task thoughts during the episodic memory task. Moreover, higher levels of off-task thoughts were associated with lower performance on the task. These relationships held independent of age. Descriptive statistics indicated that frequency of off-task thoughts was negatively correlated with age; however, because MW and task-related interferences were combined into a single measure, it is not possible to know whether age was differentially associated with one or the other.

Two other studies have measured age-related differences in frequency of MW and task-related interferences in tasks of varying difficulty. McVay et al. (2013) found that MW and task-related interferences exhibited opposing changes in frequency during a 1-back relative to a 2-back working memory task. MW frequency was higher across tasks in young than older adults, and in young adults only, MW decreased in the 2-back relative to the 1-back task. In contrast, task-related interference frequency increased in the 2-back relative to the 1-back task across age groups, and older adults exhibited more task-related interferences than young in the 2-back task but not in the 1-back task. In the other study, Zavagnin et al. (2014) measured rates of MW, task-related interferences and environmental distractions in an easier and harder version of the SART. Young adults exhibited more off-task thoughts (collapsed across all categories) compared with older adults. A higher proportion of off-task thoughts reflected MW in young adults, whereas a greater

proportion of thoughts in the oldest older adults (aged 75-85) reflected task-related interferences. Moreover, only the oldest-old exhibited more task-related interferences in the harder compared to the easier task. Taken together, these two studies provide evidence that increased task difficulty is associated with increased frequency of task-related interferences in older adults, and particularly in the oldest old.

In a recent study, Frank et al. (2015) measured age-related differences in frequency of MW and task-related interferences during a reading task, and also measured eye movements using eye tracking. Older adults exhibited reduced MW, but increased task-related interferences compared with young adults. Replicating previous studies, the total frequency of off-task thoughts was lower in older compared to young adults. In both age groups, performance on a reading comprehension test was negatively correlated with MW, and in young adults only, with task-related interferences. In addition, several eye-tracking indicators (off-text fixations, total time off-text, number of words fixated) suggested greater reading disruption for older adults when reporting MW, and for young adults when reporting task-related interferences. The authors suggested that the association between MW and reading comprehension in older adults, as well as differences in eye tracking measures prior to reports of being on-task versus MW, validates older adults' reports of MW. Older adults scored higher than young adults on a mindfulness scale (Baer et al., 2006) and on a positive affect scale (Watson et al., 1988), and there was also a trend for less negative affect. Age-related reductions in MW were partially mediated by positive affect, while age-related increases in task-

related interferences were partially mediated by a subscale of the mindfulness inventory (the tendency to observe and notice one's surroundings). The authors concluded that age-related differences in off-task thought may be due to dispositional factors such as mood, mindfulness and task engagement.

Lastly, in a study mentioned earlier involving a reading comprehension task, Krawietz et al. (2012) reported that while young adults exhibited a greater proportion of MW about themselves than did older adults, older adults exhibited a greater proportion of "text-related" MW than did younger adults. Taken together with the other studies discussed in this section, these results suggest that older adults may exhibit a greater proportion of off-task thoughts related to the task itself compared with young adults, who may exhibit a greater proportion of MW. However, even in studies that have examined both MW and task-related interferences, aging was still associated with an overall reduction in total frequency of off-task thought.

2.4. Age-related changes in the content of mind-wandering episodes

A few studies have examined whether the content of MW episodes themselves changes with age (Giambra, 2000; Jackson et al., 2013). Jackson et al. (2013) examined whether the temporal focus of MW changes with age during different versions of the SART administered in two online experiments. They reported age-related differences in the relative proportions of past, future, and atemporal MW events. Older adults exhibited a higher proportion of atemporal than future-oriented MW episodes, whereas there was no difference in young adults. In addition, they reported a negative correlation between age and past-oriented MW.

We note that the atemporal MW category in this study may have included task-related interferences and distractions, as these categories were not measured separately. Note also that the mean age of the older adult sample used by Jackson et al. was between 56 and 57 years, which is younger than those used in most other studies.

Giambra (2000) conducted an extensive examination of age-related changes in daydreaming content and characteristics in daily life using a retrospective questionnaire: the Imaginal process inventory (IPI; J. Singer, L. & Antrobus, 1970). Data were collected between 1971 and 1996, and individuals (1782 women and 1545 men aged 17-95) were tested up to 6 times during this period. Giambra reported an extensive set of findings, including both cross sectional and three 2-point longitudinal period analyses (5.45-9.54 years, 11.45-16.67 years and 17.40-23.44 years). We review only a subset of these findings here.

Increasing age was associated with decreased frequency of overall daydreaming, and decreased absorption in daydreaming. In addition, increasing age was associated with reduced frequency of daydreams on particular topics, including problem-solving, sexual, heroic, hostile, achievement-oriented and guilt daydreams. A few types of daydreams showed other patterns. For example, bizarre-improbable daydreams showed a U-shaped age function, initially decreasing with increasing age until age 55-64, but then increasing again in the oldest subjects. “Fear of failure” daydreams decreased with age, although there was some evidence on an increase in the oldest subjects.

Other questions in the IPI assessed the extent of visual and auditory imagery contained in daydreams. Increasing age was associated with decreased visual imagery, although the effect was small. Results for auditory imagery were less clear; cross-sectionally there was a decrease with age, although this effect was not found in the longitudinal analyses. Giambra also assessed the participants' emotional reaction towards daydreams. In all age groups, individuals generally experienced positive reactions to daydreams. However, increasing age was associated with a reduction in the extent of positive relative to negative reactions. The author suggested that increasing age is associated with less emotional experience towards daydreams.

Giambra also analyzed the temporal orientation of daydreams. The tendency to have future-oriented daydreams decreased steadily with increasing age, whereas present- and past-oriented daydreams showed a different pattern. Specifically, the tendency to have past-oriented daydreams decreased from young to middle-aged adults, and then increased from middle-aged to older adults. By contrast, the tendency to have present-oriented daydreams increased from young to middle-aged adults and then decreased from middle-aged to older adults. Thus, middle-aged adults exhibit increased present-oriented daydreams but decreased past-oriented daydreams compared with the other groups, similar to Jackson et al. (2013). Assessments of the relative tendency to daydream about the past, present or future within each age group revealed marked differences between the young and oldest age groups. Future-daydreaming was more prominent than both past- and present-daydreaming in the younger age groups, whereas this relationship was reversed in

individuals aged 75-84, in whom past- and present-daydreams were more prominent than future ones. Also, present-daydreams was more prominent than past-daydreams in young adults, but less prominent in individuals aged 75-84. In summary, Giambra's findings reveal that aging may be associated with changes in frequency, content, temporal orientation and emotional reaction towards daydreams.

In another, more recent study (Gardner & Ascoli, 2015), participants received automated phone calls during their daily lives, upon which they were asked to specify whether, in the moment directly preceding the call, they had been exhibiting a past- or future-oriented thought. Young and older adults reported a similar frequency of past-oriented thoughts. However, in contrast to Giambra's (2000) results, older adults exhibited an increase in frequency of future-oriented thoughts compared to young. Several methodological factors could account for the differences in results between the two studies. First, Giambra used a retrospective questionnaire, whereas Gardner and Ascoli used in-the-moment experience sampling; thus the discrepancy in results between the two studies may result from older adults having a reduced ability to remember the occurrence of thoughts in the study by Giambra. Second, Giambra asked specifically about daydreaming experiences, while in Gardner and Ascoli, participants were not asked if they had been engaged in another activity at the time, or whether the thought was spontaneous/deliberate. Thus, it is possible that the discrepancy can be explained because older adults are prone to intentionally think of their future, rather than experiencing future-oriented daydreaming.

2.5. Summary of age-related differences in MW

In summary, laboratory studies of age-related changes in MW have found that increasing age is associated with a reduction in frequency of MW. There is evidence indicating that older adults often exhibit increased task engagement compared with young adults, and that this may an important factor accounting for age-related decreases in MW. Furthermore, several studies indicate that while a greater proportion of off-task thoughts in young adults are comprised of MW rather than task-related interferences, the reverse is often the case in older adults. This pattern may indicate that while older adults are primarily concerned about their performance on ongoing tasks, young adults exhibit more concerns about their daily lives. The finding that older adults seem to be particularly concerned about their task performance in laboratory settings raises the question of whether the findings of age-related reductions in MW would generalize to more naturalistic settings. Results so far have been mixed, with one study reporting age-related decreases in daydreaming frequency using retrospective questionnaires (Giambra, 2000), but Gardner and Ascoli (2015) reporting a paradoxical increase in future-oriented thoughts in older adults in a study using experience sampling. More studies assessing age-related differences in MW in naturalistic settings are needed to assess the reproducibility of Gardner and Ascoli (2015)'s finding, and whether it stems primarily from spontaneous or intentional thoughts. However, if reliable, the discrepancy between findings of age-related decreases in MW in laboratory settings, but increases in naturalistic settings would parallel results in the prospective memory literature. Indeed, while older adults often exhibit reduced performance in

laboratory prospective memory tasks compared to young, they tend to outperform young in naturalistic settings (termed the age prospective memory paradox; Rendell & Craik, 2000). Thus, although speculative at this point, it is possible that age-related reductions in MW frequency have been overestimated by laboratory paradigms, a possibility that should be investigated in future research.

3. Involuntary autobiographical memory

3.1. Definition and methodological aspects

We now shift our focus to studies that have examined age-related differences in involuntary autobiographical memory (IAM). IAMs have been defined as personal memories that come to mind spontaneously, without any deliberate attempt to retrieve them; they simply "pop up" in response to an environmental trigger or to an ongoing train of thought (Berntsen, 2009). An interesting question is whether IAM should be regarded as equivalent to past-oriented spontaneous MW (see Plimpton et al., 2015 for a discussion of this issue). There is some ambiguity in the literature on this question (e.g., Berntsen & Jacobsen, 2008; Plimpton et al., 2015). On the one hand, IAMs and past-oriented MW share many features – namely, both can be spontaneous and related to personal experiences. In addition, studies have found that both MW and IAM decrease in frequency as the ongoing task gets harder/less habitual (e.g., Mason et al., 2007; Schlagman & Kvavilashvili, 2008). However, with respect to the aging literature, there are clear differences in the methodologies that have been used in the MW and IAM literatures that preclude a more direct comparison of the two phenomena. Most notably, while age-related differences have almost exclusively been assessed in laboratory studies, age-related differences have

so far exclusively been conducted in naturalistic settings, either through retrospective questionnaires or diary studies. These studies are reviewed next.

3.2. Age-related differences in IAM measured using retrospective estimates

Three studies have examined age-related differences in frequency of involuntary memories using retrospective estimates (Berntsen & Rubin, 2002; Moulin et al., 2014; Rubin & Berntsen, 2009). Moulin, Souchay et al. (2014) asked young and older adults how often they exhibited involuntary memories in their daily lives (daily / once a week / once a month / once every six months / never). Both young and older adults reported exhibiting IAMs on average between once a week and once a month, with no age-related difference. We note that this estimate of frequency of IAMs is much lower than the one typically found in diary studies (e.g., average of 22 per day; Rasmussen & Berntsen, 2011) or laboratory studies (e.g. average of 6-7 in a one hour session; Schlagman & Kvavilashvili, 2008). This observation raises questions about whether subjects can adequately estimate frequency of IAMs (and other spontaneous thought types) in their daily lives using retrospective questionnaires.

Berntsen and Rubin (2002) asked 1241 participants aged 20-93 about several details of IAMs during their daily lives: their frequency, the participants' age the last time they had an involuntary memory, and whether the memory was about a happy or sad event. Most involuntary memories came from the previous year and were happy rather than sad. In addition, a decrease in frequency of involuntary memories with increasing age was observed. Rather than asking participants about IAM generally, Rubin and Berntsen (2009) asked 2020 individuals aged 15-96 how

often they experienced voluntary and involuntary memories of specific events. Half were asked about their confirmation day (which occurs at around age 14), and the other half were asked about an important event from last week. Voluntary memories were statistically more likely than involuntary memories, but both were similar in frequency (2.72 and 2.86 on a 5 point scale, respectively). Emotional intensity, and the extent to which the event could be part of the participant's life story predicted frequency of both voluntary and involuntary memories. No age-related differences were observed in frequency of either voluntary or involuntary memories. The authors speculated that this discrepancy with the findings of Berntsen and Rubin (2002), who had observed an age-related decrease in IAMs, may be attributable to methodological differences (it may be harder for older adults to estimate general frequency of IAM, compared to being asked about the frequency of a specific memory). Several ratings such as reliving, visual and auditory imagery and intensity of IAM were positively correlated with age. The authors suggested that these results are consistent with findings of generally higher ratings with increasing age on various dimensions in studies of autobiographical memory (Rubin & Schulkind, 1997).

3.3. Age-related differences in IAM measured in the moment

Rather than using retrospective estimates as in the preceding studies, Schlagman et al. (2007; 2006) examined IAM in young and older adults using a 7-day diary paradigm. Participants were asked to write down any IAMs that occurred during this time, and answer some questions about them. If participants were unable to fill out the questionnaire or felt the content of the IAM was too personal,

they could note this in the form of a "tick". Young adults reported more overall IAMs compared to older adults. This difference appeared to be primarily due to difference in number of ticks rather than fully recorded memories. Most IAMs in young adults were about recent events (i.e. <5 years), whereas older adults had a similar proportion of IAM about events from the last decade compared with those that occurred 50-59 years ago, when participants would have been in their twenties (the "reminiscence bump", e.g., Rubin, 1999). In both age groups, IAMs occurred most often in response to an external relative to an internal trigger, and were more frequent during habitual/automatic activities compared with tasks requiring more attention. However, older adults reported being more concentrated on the ongoing activity than young adults when the IAM occurred. The authors suggested that since older adults may need to pay more attention to perform habitual activities, they may have fewer resources left to exhibit IAM, an argument similar to the one sometimes made in the MW literature. Interestingly, in contrast to findings from voluntary autobiographical memory, which have typically found an age-related reduction in specific memories (single event or episode) compared with general memories (extended events lasting for a long period or repeated events(e.g., Levine et al., 2002) there were no age-related differences in the proportion of specific IAMs recalled. Compared to young, the content of IAMs in older adults was more positive in nature, and older adults rated IAMs about events that are objectively negative in nature as less negative than young adults. The authors suggested that these age-related differences may help older adults maintain a positive self-concept.

To compare age-related differences in voluntary and involuntary AM, Schlagman et al. (2009) performed a similar 7 day diary study as the one described above, but in addition, had participants come into the lab and voluntarily recall 30 memories in response to word cues (10 negative, 10 positive and 10 neutral). There was an age-related reduction both in frequency of IAMs, and in the frequency with which older adults succeeded in voluntarily retrieving AMs in response to word cues. Most IAMs were triggered by environmental cues as opposed to internal cues, and this effect was larger in older adults. Furthermore, older adults, more so than young adults, reported exhibiting IAMs in habitual tasks compared with attentionally demanding tasks even though older adults reported marginally higher levels of concentration on these tasks. Young adults exhibited more specific voluntary memories relative to older adults. On the other hand, there were no age-related differences in the number of specific involuntary memories recorded. Additionally, older adults reported that their IAMs were more pleasant than those of young adults, while there were no age-differences in pleasantness ratings for voluntary memories. Older adults rated both their involuntary and voluntary memories as more vivid and unusual compared with young adults. Finally, similar to Schlagman et al. (2007; 2006), in young adults both voluntary and involuntary memories were about events that occurred in the previous five years, while in older adults there was both a recency effect and reminiscence bump (previous 10 to 30 years).

In summary, findings from studies of age-related differences in IAM display several signs of convergence with those of the MW literature. First, three of the five

studies of IAM reviewed here, including the two that assessed in-the-moment IAM, reported that their frequency decreases with age (and the others found no age differences), which converges with studies reporting age-related decreases in MW. Because older adults report being more concentrated on ongoing activities compared with young adults when IAMs occur, Schlagman et al. (2009; 2007) suggested that the age-related decrease in frequency of IAMs may be attributable in part to reduced attentional capacity in older adults, a proposal similar to that sometimes made in the MW literature. Second, the finding of more unusual IAMs (Schlagman et al., 2009) in older adults may be related to the finding of age-related increases in MW about bizarre-improbable events (Giambra, 2000). One difference between studies of IAM and MW is that whereas older adults report increased ratings of vividness (Schlagman et al., 2009), reliving, intensity and visual and auditory detail (Rubin & Berntsen, 2009) in their IAMs, they report decreased ratings of visual imagery (Giambra, 2000; Parks et al., 1988), and decreased absorption for MW (Giambra, 2000). These differences may be attributable in part to different methodologies used in these studies. The ratings in the IAM studies were made immediately after the IAM occurred in one study (Schlagman et al., 2009), or in response to very specific events in the other (Rubin & Berntsen, 2009). In contrast, ratings in the MW literature were made about MW in general (Giambra, 2000; Parks et al., 1988). Thus, it may have been easier for older adults to rate specific events in the IAM studies compared with more nonspecific events in the MW studies. This underscores the need for experience sampling studies of age-related differences in MW in naturalistic settings.

4. Intrusive thoughts

Intrusive thoughts refer to repeatedly occurring, unwanted, and difficult to control thoughts that are generally accompanied by subjective discomfort (Rachman, 1981). Intrusive thoughts share with MW and IAM their spontaneous and autobiographical nature. However, intrusive thoughts are associated with negative appraisal and stress (e.g., Brose et al., 2011), whereas these features are not generally associated with MW and IAM. Three main methods have been used to study age-related differences in intrusive thoughts: assessing the frequency of an experimenter-induced intrusive thoughts in the lab, assessing the occurrence of intrusive thoughts on a day to day basis, and assessing general frequency of intrusive thoughts using retrospective questionnaires. We review studies using each of these methodologies, in turn, in the following sub-sections.

4.1. Age-related differences in experimenter-induced intrusive thoughts

Several studies have examined age-related differences in intrusive thoughts in a laboratory context by first having subjects think of a specific thought (e.g. "I hope my friend is in a car accident") (Beadel et al., 2013; Lambert et al., 2013; Magee et al., 2014; Magee & Teachman, 2012). Participants then complete thought suppression and/or thought monitoring tasks in which they are asked to record when the experimental thought occurred by holding down a button. In the thought suppression task, participants are asked to try and suppress the thought, while in the monitoring task, they are asked to think about anything they want, but to notice the occurrence of the experimental thought. We note that this self-caught reporting of intrusive thoughts differs from the probe-caught methods typically used in the

MW literature. A concern with the self-caught method in the MW literature is that young and older adults may differ in their ability to monitor and become aware of their thoughts while performing a concurrent task. Such concerns may be attenuated in the intrusive thought literature, because in contrast to MW studies, there is no concurrent task to perform.

Four studies using self-caught reporting of experimenter-induced intrusive thoughts have found either no age-related difference in the amount or duration with which the intrusive thought occurred, or reductions in older adults (Beadel et al., 2013; Lambert et al., 2013; Magee et al., 2014; Magee & Teachman, 2012). Importantly, age-related increases in occurrence of intrusive thoughts were not observed even when using a thought that older adults reported having more prior experience with than did young adults ("I will lose my memory and forget my friends and family") (Beadel et al., 2013). Despite no actual age-related increase in intrusive thought frequency, some studies have found that older adults report more subjective effort in suppressing the intrusive thought (Magee et al., 2014; Magee & Teachman, 2012), perhaps due to the use of compensatory control mechanisms in older adults. Age-related differences in affective reactivity to intrusive thoughts have also been observed. Specifically, older adults report less of a decrease in positive affect after being exposed to the intrusive thought compared with young adults, whereas findings regarding negative affect have been more mixed (Magee et al., 2014; Magee & Teachman, 2012).

4.2. Age-related differences in daily life intrusive thoughts

While the preceding studies investigated the effects of age on specific experimenter-induced intrusive thoughts, other studies have examined intrusive thoughts that occur in daily life. Brose et al. (2011) investigated the relationship between daily stressors (e.g. arguments, disagreements, health concerns, financial concerns), intrusive thoughts (ratings on questions such as "Today, I cannot get certain thoughts out of my mind"), and negative affect in young and older participants across 100 sessions. Older adults exhibited a reduction in intrusive thoughts across the 100 sessions compared with young adults. Days with stressors were associated with increased intrusive thoughts and increased negative affect; however, the association between intrusive thoughts and negative affect was reduced in older compared with young adults.

Stawski et al. (2011) similarly investigated the association between daily stressors, negative affect and "cognitive interference", defined as the experience of intrusive off-task thoughts, and the intentional suppression of and failure to suppress such thoughts". The study included six sessions over a 14-day period. Older adults aged 70-87 participated in the study; no younger adult group was included. Individuals reporting higher occurrence of daily stress also reported higher levels of cognitive interference. At the between-subject level, the effect of daily stress on cognitive interference was accounted for by negative affect, indicating that cognitive interference may reflect rumination or thoughts about one's mood. At the within-subject level, daily stress and negative affect each predicted cognitive interference. Increasing age was associated with a higher amount of cognitive interference; however, the association between daily stress and

cognitive interference decreased with age. Thus, the studies by Stawski et al. (2011) and Brose et al. (2011) both suggest that increasing age may be associated with decreased reactivity to stress and intrusive thoughts.

Two other studies (Borella et al., 2007; Erskine et al., 2007) have assessed age-related differences in intrusive thoughts in daily life using the White Bear Suppression Inventory (WBSI; Wegner & Zanakos, 1994), which measures frequency of intrusive thoughts in daily life as well as the tendency to suppress these thoughts. These studies indicate that while the score on this inventory seems to initially decrease from young to young-old adults, it then increases to a level above that of young adults in the oldest-old adults (aged 75 and above) (Borella et al., 2007). Ersktein et al. (2007) reported that scores on this inventory were predicted by rumination and trait anxiety in both age groups. Furthermore, after controlling for these factors (both rumination and trait anxiety were elevated in young adults), age-related differences in the WBSI were eliminated. Borella et al. (2007) subdivided the overall score on the WBSI intro three categories: unwanted intrusive thoughts, thought suppression and self-distraction. Old-old adults (aged 75 and above) scored higher than young-old (65-74) and young adults on both unwanted intrusive thought and thought suppression categories, whereas the latter two groups did not significantly differ from each other. Furthermore, working memory capacity was positively correlated with tendency to suppress thoughts in the old-old group. Working memory capacity was also negatively correlated with intrusions in the memory recall laboratory task in all age groups.

In summary, studies using experimenter-induced intrusive thoughts have found either no age differences, or an age-related reduction in frequency of intrusive thoughts (Beadel et al., 2013; Lambert et al., 2013; Magee et al., 2014; Magee & Teachman, 2012). Studies assessing real life intrusive thoughts have yielded mixed results, with some reporting an age-related reduction (Brose et al., 2011; Erskine et al., 2007), and others reporting an increase with age, but only in the oldest older adults (Borella et al., 2007; Stawski et al., 2011). In addition, the majority of studies of aging and intrusive thoughts have reported decreased affective reactivity to intrusive thoughts with age, which is consistent with similar reports from the MW and IAM literatures.

5. Prospective memory

5.1. Definition and methodological aspects

Prospective memory refers to memory for actions to be performed in the future, for example, remembering to make a phone call once one gets home. In a typical PM laboratory task (e.g., Einstein & McDaniel, 1990; Einstein et al., 1995), subjects perform an ongoing task (e.g. pleasantness judgements on a word list), while remembering to press a special key when a target word (PM cue) appears. A critical component of PM tasks is that there is no explicit prompt to initiate memory retrieval: subjects could keep on doing the pleasantness judgement when the target word appears. Rather, they must remember to carry out the PM task at the right time. In contrast with other thought types measures so far, PM measured in this way may not involve mental time travel (Berntsen & Jacobsen, 2008) or a detailed mental simulation. Furthermore, unlike MW and intrusive thoughts, PM is a

necessary component for successful task performance: participants are evaluated according to whether they successfully carried out the PM task. This feature potentially has implications regarding how some variables such as motivation relate to MW and intrusive thoughts relative to PM. That is, a motivated individual may try to exhibit less MW or block out experimenter-induced intrusive thoughts on the one hand, but want to remember the PM intention on the other.

Furthermore, unlike IAM and intrusive thoughts, PM does not always come to mind spontaneously. Indeed, it has been suggested that individuals may accomplish PM tasks using a mixture of deliberate and automatic (spontaneous) retrieval processes (McDaniel & Einstein, 2000). Deliberate processes include rehearsal of the intention and monitoring of the environment for the appropriate event/time. On the other hand, spontaneous PM refers to instances in which the PM event automatically triggers the intention, or in which the intention effortlessly comes into awareness. PM has received a great deal of attention in recent years and the question of how it is affected with aging has already been summarized in many reviews and meta-analyses (Henry et al., 2004; Kliegel et al., 2008; McDaniel & Einstein, 2011; Uttl, 2011). Our focus here is on aging studies that have explicitly attempted to isolate spontaneous PM retrieval.

5.2. Age-related differences in focal relative to non-focal PM tasks

Many factors have been proposed to affect the extent to which deliberate relative to spontaneous processes are used in PM tasks, including the nature of the ongoing task, and the type/saliency of the PM cue (McDaniel & Einstein, 2000). One factor that has been particularly emphasized in the aging literature is whether the

ongoing task is focal or non-focal (Einstein et al., 2005; McDaniel & Einstein, 2000). A focal PM task is one in which the ongoing task encourages processing of the features of the PM target. For example, making semantic judgements on words while remembering to press a special key for a target word would be a focal task in that the semantic task encourages processing of the meaning of the target word. In this case, processing of the PM target as part of the ongoing task may spontaneously trigger retrieval of intended action. On the other hand, a non-focal PM task would be one in which the key features of the PM target are not processed as part of the ongoing task. For example, performing a semantic judgement task on words while remembering to press a special key for words that contain the letters "fr" would be non-focal since it does not focus attention of the letters.

McDaniel and Einstein (2000) noted that age-related differences in PM tasks were large in studies using non-focal tasks but small or absent in focal tasks, arguing that age-related differences may disappear in PM tasks that rely on spontaneous processing. However, more recently two meta-analyses have failed to find support for this suggestion. Kliegel et al. (2008) found that older adults exhibited reductions in performance in both focal and non-focal tasks compared to young; however, age-related differences in performance were greater for non-focal tasks. Uttl (2011) found large age-related reductions in performance in studies using both focal and non-focal tasks. Uttl suggested that these results contradict claims that PM with focal cues is spared with aging. The author further suggested that methodological issues such as ceiling effects, age confounds and low statistical power could explain why some prior studies had failed to find age-related differences in PM tasks.

5.3. Task costs as a way of measuring spontaneous PM retrieval

While the assumption that focal PM tasks rely to a greater extent on spontaneous processes relative to non-focal tasks is likely valid, it is still possible that subjects engage in some monitoring during these tasks. Thus, one possibility is that young adults engage in more monitoring compared to older adults in some focal tasks (perhaps due to having more cognitive resources), which could explain why they perform better. To exclude the possibility that subjects engage in monitoring, it has been proposed that one needs to measure ongoing task costs when participants have a PM demand relative to when they do not (Mullet et al., 2013; Smith, 2003). The idea is to compare reaction times during an ongoing task in a condition in which there is and is not a PM demand. If subjects are engaging in monitoring during the task with a PM demand, then this engagement should result in higher RT in ongoing task trials compared to when this same ongoing task is performed without a PM demand. On the other hand, the finding of no significant difference in RT in the ongoing task when there is versus is not a PM demand is taken to indicate that participants are relying solely on spontaneous retrieval to perform the PM task.

Two studies have studied age-related differences in PM while measuring task costs. In one study (Mullet et al., 2013, experiment 1), across groups, task costs were present in a non-focal, but not a focal PM task. Thus, monitoring was likely present only in the non-focal task. Moreover, older adults performed as well as young only in the focal, but not the non-focal task. Since older adults performed as well as young only in the focal task, in which there was no evidence for monitoring, the authors suggested that spontaneous PM retrieval may be spared in aging. In another

study, May et al. (2015) investigated the impact of emotional PM cues on performance in young and older adults. In both age groups, performance on the PM task was better when the PM target was emotional (positive and negative) compared to neutral. Task costs, indicative of monitoring, were found across all tasks. However, there was no additional task costs in tasks with emotional versus neutral PM tasks. Thus, the authors suggested that the benefit of an emotional relative to a neural PM target does not result from an increase in monitoring, and instead likely relies on spontaneous processes in both age groups.

5.4. Age-related differences in the intention-interference paradigm

Other studies (Cohen et al., 2015; Mullet et al. 2013, experiments 2 and 3; Scullin et al., 2011) have used the intention-interference paradigm (Cohen et al., 2005; Einstein et al., 2005) to assess age-related differences in spontaneous PM retrieval. In this paradigm, participants first either perform an ongoing task with a PM demand (Mullet et al., 2013; Scullin et al., 2011), or they are told about a PM task they will later need to perform (Cohen et al., 2005), depending on the study. Participants then perform an unrelated task during which they are told there is no PM demand. The key aspect of this procedure is that PM cues are presented during the unrelated task, during which subjects are presumably not monitoring for it since it is task-irrelevant. Thus, if participants exhibit increased RT for the PM target compared to control items in the unrelated task, this is taken to indicate the presence of spontaneous processing of the PM cue.

In two such experiments, young and older adults first performed an ongoing task (an imageability judgement on word stimuli) with a PM demand (pressing a

special key for target words) (Mullet et al., 2013; Scullin et al., 2011). In one study, participants were then told that the PM task was finished, while in the other, they were told that the PM task was suspended, and would be resumed later in the experiment. In both experiments, participants then performed a second, unrelated task (word/non-word judgement) with no PM demand. When participants were told the PM intention was finished (Scullin et al., 2011), only older, but not young adults, exhibited increased RT for the PM targets compared to control items in the word/non-word task. Furthermore, this effect in older adults was negatively associated with a composite measure of inhibitory abilities. The authors suggested that this age-related difference was unlikely to be advantageous and likely reflect a reduced ability to inhibit completed intentions. On the other hand, when participants were told the PM intention was suspended (Mullet et al., 2013), both young and older adults exhibited greater RT for target relative to control items. Thus, these two studies suggest that both young and older adults exhibit spontaneous processing of the PM cue when the PM task is suspended, but that only older adults continue to do so when the PM task is finished, which may reflect age-related decreases in the ability to inhibit finished intentions.

Mullet et al. (2013, Experiment 3) used a similar design to Scullin et al. (2011)(suspended PM instructions). However, during this suspended phase, one group of participants were presented with the exact target PM cue ("money") while the other group was presented with associated lures to the target word ("profit, wallet, fund"). Young adults exhibited increased RT for both the exact PM target and the associated lures compared to control items. On the other hand, older adults only

exhibited increased RT for the exact PM target, but not for associated lures, compared to control items. The authors suggested that spontaneous retrieval processes may be less sensitive in older relative to young adults, being triggered by a more narrow range of stimuli. The authors suggest that this mechanism may potentially also account for the findings of reduced IAM in older relative to young adults reviewed earlier.

Cohen et al. (2005) conducted two experiments designed to assess intention-interference in young and older adults. Participants read actions (e.g. "Put the marble in the plastic bag''), and were then told they would either need to perform those actions (task condition) or that they would not have to perform them (ignore condition). Participants then performed an intervening Stroop color-naming task in which words related to the intention periodically appeared (e.g. marble, plastic, bag). In both age groups, RT was higher for intention-related words in the task condition relative to the ignore condition. Similar results were obtained in a second experiment in which participants either read about the action and performed it right away, or performed it after the Stroop task. In both age groups, RT was higher for intention-related words when the action had to be performed following the Stroop task versus when it had already been completed. Thus, in contrast to the results obtained in Scullin et al. (2011), older adults did not exhibit an exaggerated response to PM cues compared to young adults after the PM task had been finished. The authors concluded that these results were inconsistent with an inhibitory deficit account of aging.

5.5. Age-related differences in PM retrieval in a naturalistic setting

Kvavilashvili and Fisher (2007) assessed age-related differences in spontaneous versus deliberate PM retrieval in a naturalistic diary study. Specifically, participants came in the lab on Monday and were asked to call the experimenter at a time of their choosing on the following Sunday. Throughout the week, they were also asked to keep a diary detailing all instances in which they remembered the PM intention, and how the intention came to mind. 81% of older adults and 68% of young adults remembered to call the experimenter within 10 minutes of the initially chosen time (this difference was not statistically significant). There were no age differences in instances of remembering the PM intention (termed "rehearsals") throughout the week. In young adults only, the number of rehearsals was positively associated with success on the PM task; older adults appeared to be successful regardless of the amount of rehearsals. Older adults also reported being significantly more motivated to complete the PM task compared to young adults. The authors suggested that this increased motivation may account for older adults' high performance on the PM task. Most relevant to the aims of the current review, participants also reported what triggered their rehearsal of the PM intention. The experimenters classified these into external triggers (stimuli in the environment), internal triggers (thoughts) or no triggers. Furthermore, internal triggers were divided into self-initiated (if the participant had deliberately been thinking about future intentions) and incidental (if the participant had been thinking about seemingly unrelated things). There were no age differences in trigger type: in both age groups, the no-trigger category was reported most often, followed by external triggers, incidental internal triggers and self-initiated thoughts. Thus, in both age

groups, only a minority of rehearsals were self-initiated (15% in young, 8% in old), with the majority occurring incidentally.

In summary, PM can be performed using both deliberate and spontaneous processes. Investigators have recently been interested in developing paradigms to tease apart spontaneous and deliberate processes, to assess the hypothesis that aging may spare PM when it relies only on spontaneous processes. First, meta-analysis of studies that have attempted to vary the extent of spontaneous processing using the focal/non-focal distinction have reported reduced performance in older adults, even in focal tasks (Kliegel et al., 2008; Uttl, 2011). However, it has been noted that monitoring may still occur, even in focal tasks. Second, one study that measured task costs to ensure that no deliberate processing was occurring also did not find any age-related difference in performance on the PM task (Mullet et al., 2013), suggesting sparing of spontaneous PM retrieval with aging. Third, studies using intention-interferences paradigms, in which presumably, no monitoring should occur have also suggested preserved spontaneous PM retrieval in older adults (Cohen et al., 2005; Mullet et al., 2013; Scullin et al., 2011). However, the range of stimuli that spontaneously trigger the PM intention may be more narrow in older versus young adults (Mullet et al., 2013), a finding which the authors suggested may also contribute to age-related reductions in IAM. Finally, one naturalistic study has found that for a time-based PM task, both young and older adults thought of the PM intention to a similar extent in a one-week period, and that retrievals were primarily spontaneous in nature, rather than deliberate (Kvavilashvili & Fisher, 2007). A numerically higher percentage of older relative to

young adults successfully carried out the PM intention, which the authors suggested may partially be due to higher levels of motivation in the former group.

6. Neuroimaging of age-related differences in spontaneous thoughts

6.1. Age-related differences in the neural correlates of MW

We have focused so far on cognitive and behavioral studies, but one promising avenue for future research concerns the investigation of age-related differences in the neural correlates of MW, IAM intrusive thoughts, and spontaneous PM retrieval. In young adults, studies of individual differences in MW frequency, and of comparisons of periods of MW relative to on-task reports have revealed that MW is associated with activation in regions of the default network, a set of regions involved in internally directed attention and self-referential processing (Buckner et al., 2008; Christoff et al., 2009; Maillet & Rajah, 2014; Mason et al., 2007; Stawarczyk et al., 2011). MW has also been associated with regions outside the default network including the right dorsolateral/rostrolateral prefrontal cortex, left ventrolateral prefrontal cortex the insula and the lingual gyrus (for meta-analysis, see Fox et al., 2015). It has been suggested that distinct portions of the right dorsolateral/rostrolateral prefrontal cortex may be involved in meta-awareness, and/or in executive control processes recruited during MW, for example when planning a future event (Axelrod et al., 2015; Christoff et al., 2009; Smallwood, 2013). The left ventrolateral prefrontal cortex may be involved in verbal aspects of MW (Smallwood, 2013), while the lingual gyrus may be involved in visual imagery (Fox et al., 2015). Thus, identifying which brain regions exhibit age-related

differences during MW may reveal insights into which aspects of MW are altered with age.

Although not measuring MW directly, several studies using a variety of tasks have revealed that older adults often exhibit increased activation/reduced deactivation of regions of default network compared with young adults (e.g., de Chastelaine et al., 2011; Duzel et al., 2011; Grady et al., 2006; Leshikar et al., 2010; Miller et al., 2008; Persson et al., 2007; Spreng & Schacter, 2012). It has often been suggested that these age-related differences in brain activation may reflect reductions in attention or increases in task-unrelated thoughts such as MW or thoughts about the scanning environment (Grady et al., 2006; Leshikar et al., 2010; Rajah et al., 2010; Reuter-Lorenz & Cappell, 2008). These suggestions seem incompatible with the behavioral studies reviewed earlier, which consistently suggest a reduction in overall frequency of off-task thoughts in older adults.

However, it is unclear if the finding of age-related reduction in frequency of off-task thoughts during behavioral tasks necessarily extends to functional magnetic resonance imaging. fMRI tasks take place in a relatively uncomfortable and noisy environment in which older adults may have more difficulty concentrating than younger adults (Gutchess & Park, 2006; Stevens et al., 2008). For example, one study found that during an episodic encoding task, older but not younger adults exhibited increased activation in a region of auditory cortex during presentation of stimuli that were later forgotten versus those later remembered (Stevens et al., 2008). The authors suggested that older adults may have been distracted by the scanner noise, which negatively impacted episodic encoding.

Another possibility, noted in a recent review (Lustig & Jantz, 2015), concerns differences in the tasks used in behavioural versus fMRI studies. The authors noted that the tasks used in behavioural studies measuring MW (e.g. the SART, reading tasks) require constant, sustained attention, while many tasks used in fMRI studies incorporate long inter-trial intervals, and sometimes involve retrieving episodic or semantic details into the focus of attention. It is possible that in behavioural tasks, older adults spend a greater proportion of their resources on the task, leaving less opportunity for MW, whereas fMRI tasks provide more opportunities for off-task thoughts. Another possibility suggested by Lustig and Jantz (2015) is based on findings of reduced connectivity within the default-mode network (Andrews-Hanna et al., 2007; Damoiseaux et al., 2008): these alterations in connectivity may result in reduced, noisier, or less coherent outputs that are harder to track and report in older adults.

Although no study has assessed age-related differences in the neural correlates of in-the-moment MW, two studies have examined how brain activation during resting-state conditions relates to MW in older adults. In Mevel et al. (2013), young and older adults underwent resting-state fMRI, and subsequently filled out an inner experience questionnaire that asked participants to report the amount of time they had been thinking in general, and thinking in particular about specific things such as future intentions, emotional thoughts, and self-based thoughts. Participants also completed autobiographical memory and semantic memory tasks. Resting state scans revealed age-related reductions in connectivity within the default-mode network that were correlated with performance in the autobiographical memory

tasks. No age-related differences were found in the inner experience questionnaire. Since age-related differences in connectivity were observed in the absence of differences in the content of thoughts, the authors suggested that connectivity differences may instead be attributable to differences in brain functional integrity.

In a study by O'Callaghan et al. (2015), a group of older adults viewed visual shapes and reported on the content of ongoing thoughts in response to periodically appearing thought probes. The frequency of MW during this task was then related to functional connectivity during a separate resting-state scan. Total MW frequency was positively related to increased connectivity between regions of lateral and medial temporal lobes, and decreased connectivity between regions of temporal lobe on the one hand and both posterior cingulate and medial prefrontal cortex on the other. Moreover, specific sub-types of MW were associated with distinct connectivity profiles. Frequency of introspective/metacognitive MW (defined as "introspection about the mental states of self or others") was positively associated with connectivity between right hippocampal formation and bilateral posterior cingulate cortex, while frequency of memory-based construction MW (which includes memory-related processing, scene construction and mental imagery) was positively associated with connectivity between bilateral temporal pole and bilateral hippocampal formation. These findings provide preliminary evidence that the propensity to MW during behavioral tasks is related to functional connectivity in default-mode network in older adults, and that specific types of thoughts may have specific connectivity profiles.

An interesting avenue for future research is to assess age-related differences

in frequency and neural correlates of off-task thoughts measured on-line during an fMRI task. First, it would be interesting to determine if the finding of age-related increases in proportion of off-task thoughts about task-related interferences extends to neuroimaging studies. If so, it may be particularly interesting to examine the neural correlates of task-related interferences in older adults. In young adults, task-related interferences have been associated with activation in the medial prefrontal cortex (Stawarczyk et al., 2011; see also Bengtsson et al., 2009). Thus, if older adults are indeed more concerned with their task performance compared to young, then one may predict an age-related increase in activation in medial prefrontal cortex during task-related interferences. Second, it would be interesting to directly test the hypothesis that older adults are more distracted by scanner noise compared to young as indirectly suggested by Stevens et al. (2008).

6.2. Age-related differences in the neural correlates of other spontaneous thoughts

There has been almost no neuroimaging research concerning aging and either IAM, intrusive thoughts or spontaneous PM retrieval. We are not aware of any studies that have assessed age-related differences in the neural correlates of IAM or spontaneous PM retrieval, but one study has assessed how frequency of intrusive thoughts in daily life relates to brain activation in young and older adults. Kuhn et al. (2013) measured frequency of intrusive thoughts using a 3-item questionnaire on 100 days spread out across 6 months. Participants also underwent fMRI scanning while performing a verbal and a numerical task, interspersed with periods of fixation. The researchers computed a contrast of brain activation for fixation greater than the two behavioral tasks, and correlated this measure with the average

frequency of intrusive thoughts over the 100 sessions. They found a positive association between frequency of intrusive thoughts and activation in the inferior frontal gyrus and cingulate cortex in both young and older adults. The authors noted the brain regions that they found to be associated with intrusive thoughts differed from those usually associated with MW (i.e. default-mode network). Instead, based on previous findings suggesting that these regions are involved in inner speech and verbalization, the authors suggested that intrusive thoughts may be more verbal in nature than the thoughts typically generated during MW.

7. Conclusions and additional considerations

In summary, the studies reviewed here suggest that healthy older adults generally exhibit a decrease in frequency of MW and IAM. Similar findings emerge from some studies of intrusive thoughts, but the results are not as consistent as in studies of MW and IAM. In contrast, findings from the PM literature suggest that spontaneous processing in older adults may be preserved in very specific conditions in which a cue processed as part of an ongoing task automatically triggers an associated intention. However, even this process may be somewhat limited in aging as older adults exhibited similar spontaneous PM retrieval to young only when the exact PM cue was used, rather than semantically related ones (Mullet et al., 2013).

The findings of generally decreased MW, IAM and intrusive thoughts in older versus young adults is inconsistent with predictions based on the inhibitory deficit theory of aging (Hasher & Zacks, 1988). However, these findings do not necessarily argue against the presence of an inhibitory deficit in aging per se. For example, if older adults have fewer resources available for MW during the performance of an

ongoing task, or if they have fewer non-trivial concerns giving rise to MW compared to young, then there may be no need to inhibit these thoughts in the first place. In other words, there may be less competition in older adults between an ongoing task and unrelated concerns.

The findings reported in this review are more consistent with predictions made by the reduced cognitive resources theory of aging (Craik, 1983, 1986; Craik & Byrd, 1982; Lindenberger & Mayr, 2014). This theory predicts that spontaneous cognition should be preserved in aging if it occurs as part of the ongoing task, such as when spontaneous PM retrieval automatically triggers the PM intention. The cognitive resources view also predicts age-related reductions in spontaneous cognition that requires cognitive resources beyond those required to perform the ongoing task, such as MW. Studies of IAM indicate that older adults report being more concentrated on daily life activities compared to young: thus it is possible that a similar mechanism also contributes to age-related reductions in daily life IAM (Schlagman et al., 2009; Schlagman et al., 2007). However, it is unlikely that age-related differences in spontaneous cognition can entirely be accounted for by age-related reductions in cognitive resources. For example, it is unclear how this perspective could explain age-related increases in task-related interferences observed in some studies. Several other factors, including age-related differences in task interest, motivation, and current concerns may also be important to consider.

One theme that emerges across the MW, IAM and intrusive thought literatures is that older adults appear to be less emotionally involved in or affected by spontaneous thoughts (Brose et al., 2011; Giambra, 2000; Magee et al., 2014;

Magee & Teachman, 2012; Schlagman et al., 2006). These findings may reflect more effective emotional regulation in older than younger adults (Urry & Gross, 2010). MW episodes have been linked to increased unhappiness (Killingsworth & Gilbert, 2010), and intrusive thoughts have been associated with stress and negative affect (Brose et al., 2011). The ability to emotionally distance oneself from ongoing thoughts, especially negative ones, may contribute to good mood, lead to decreased rumination, and may thus be related to the positivity effect commonly reported in the aging literature (Mather, 2012; Mather & Carstensen, 2005). However, the studies reported here also provide evidence that some of these benefits may start to decrease in the oldest old adults. Compared with young-old adults, there is evidence that the oldest old may experience more bizarre-improbable daydreams (Giambra, 2000), more intrusive thoughts (Borella et al., 2007), and more evaluative thoughts about their ongoing performance on hard cognitive tasks (Zavagnin et al., 2014).

Although not emphasized as much in the current review, other factors may also contribute to age-related differences in spontaneous thought processes. For example, research suggests that older adults are less able than young adults to deliberately recall or imagine specific episodic details (Addis et al., 2008; Levine et al., 2002; Schacter et al., 2013). Because MW is often directed at past or future events, reduced capability to bring specific episodic details to mind could also contribute to a reduction in frequency of spontaneous thought processes (Jackson et al., 2013) (but see Schlagman et al., 2009 for evidence that age-related reductions in memory specificity may not extend to spontaneous memories). Another potentially important factor is whether there are age-related differences in meta-awareness

that one is experiencing spontaneous thought processes. For example, if older adults exhibit reductions in meta-awareness, then this may reduce the rate at which spontaneous thoughts are reported. Determining the extent to which these factors contribute to age-related differences in different spontaneous thought processes is an important area of future research.

The consideration of several different spontaneous thought types within the same review highlights that many avenues for future research may come from applying methodologies used to study one spontaneous thought type to study another. For example, the aging and MW literature may benefit from naturalistic studies (e.g. diary studies) that have been used in the IAM literature (Schlagman et al., 2007; Schlagman et al., 2006) and in the PM literature (Kvavilashvili & Fisher, 2007). This is especially important given evidence in the PM literature that age-related reductions in PM may not extend to more naturalistic settings (Rendell & Craik, 2000, see also Garder and Ascoli, 2015). When studying MW, aging studies may also benefit from an increased focus on triggers, which are often of interest in the IAM literature. On the other hand, the aging and IAM literature may benefit from using laboratory paradigms similar to those used in the MW literature (e.g. thought probes) to study IAM in a more controlled paradigm. Laboratory studies of IAM have been conducted in young adults (Mace, 2006; Plimpton et al., 2015; Schlagman & Kvavilashvili, 2008; Vannucci et al., 2014), but not yet in older adults. Finally, the aging and MW literature may also benefit from separating out spontaneous versus deliberate MW, a distinction that has been of interest in the PM literature for quite some time (McDaniel & Einstein, 2000).

Lastly, we think that interesting insights concerning age-related differences in spontaneous thought processes may come from studies using neuroimaging methods. One intriguing area for future research concerns elucidating why older adults often exhibit increased activation in areas of default-mode network during tasks requiring externally-directed attention, despite current evidence from behavioral studies indicating that they exhibit less MW compared to young. Neuroimaging methods may also be important for assessing the relative importance of factors such as availability of working memory resources for MW in young compared to older adults. For example, in young adults, a recent study found that transcranial direct current stimulation applied to the left dorsolateral prefrontal cortex increased self-reports of MW during a vigilance task, with no change in behavioral performance on the task itself compared to a sham condition (Axelrod et al., 2015). The authors suggested that the brain stimulation may have temporarily increased working memory capacity, allowing for more MW during the vigilance task. Provided this conclusion is valid, assessing whether there are age-related differences in the extent to which frequency of MW is affected in such a paradigm could help understand the extent to which availability of working memory resources is necessary for MW in young compared to older adults.

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References

Addis, DR, Wong, AT, Schacter, DL. (2008). Age-related changes in the episodic simulation of future events. Psychol Sci, 19(1), 33-41.

Andrews-Hanna, JR, Reidler, JS, Huang, C, Buckner, RL. (2010). Evidence for the default network's role in spontaneous cognition. J Neurophysiol, 104(1), 322-335.

Andrews-Hanna, JR, Snyder, AZ, Vincent, JL, Lustig, C, Head, D, Raichle, ME, Buckner, RL. (2007). Disruption of large-scale brain systems in advanced aging. Neuron, 56(5), 924-935.

Antrobus, JS, Singer, JL, Greenberg, S. (1966). Studies in the stream of consciousness: experimental enhancement and suppression of spontaneous cognitive processes. Percept. Mot. Skills, 23, 399–417.

Arbuckle, TY, Gold, DP. (1993). Aging, inhibition, and verbosity. J Gerontol, 48(5), P225-232.

Axelrod, V, Rees, G, Lavidor, M, Bar, M. (2015). Increasing propensity to mind-wander with transcranial direct current stimulation. Proc Natl Acad Sci U S A, 112(11), 3314-3319.

Baer, RA, Smith, GT, Hopkins, J, Krietemeyer, J, Toney, L. (2006). Using self-report assessment methods to explore facets of mindfulness. Assessment, 13(1), 27-45.

Beadel, JR, Green, JS, Hosseinbor, S, Teachman, BA. (2013). Influence of age, thought content, and anxiety on suppression of intrusive thoughts. J Anxiety Disord, 27(6), 598-607.

Beaman, CP, Williams, TI. (2010). Earworms (stuck song syndrome): towards a natural history of intrusive thoughts. Br J Psychol, 101(Pt 4), 637-653.

Bengtsson, SL, Lau, HC, Passingham, RE. (2009). Motivation to do well enhances responses to errors and self-monitoring. Cereb Cortex, 19(4), 797-804.

Berntsen, D. (1996). Involuntary autobiographical memories. Applied Cognitive Psychology, 10, 435–454.

Berntsen, D. (2009). Involuntary Autobiographical Memories. New York: Cambridge University Press.

Berntsen, D, Jacobsen, AS. (2008). Involuntary (spontaneous) mental time travel into the past and future. Conscious Cogn, 17(4), 1093-1104.

Berntsen, D, Rubin, DC. (2002). Emotionally charged autobiographical memories across the life span: the recall of happy, sad, traumatic, and involuntary memories. Psychol Aging, 17(4), 636-652.

Borella, E, Carretti, B, Cornoldi, C, De Beni, R. (2007). Working memory, control of interference and everyday experience of thought interference: when age makes the difference. Aging Clin Exp Res, 19(3), 200-206.

Brose, A, Schmiedek, F, Lovden, M, Lindenberger, U. (2011). Normal aging dampens the link between intrusive thoughts and negative affect in reaction to daily stressors. Psychol Aging, 26(2), 488-502.

Brown, AS. (2003). A review of the deja vu experience. Psychol Bull, 129(3), 394-413.

Buckner, RL, Andrews-Hanna, JR, Schacter, DL. (2008). The brain's default network: anatomy, function, and relevance to disease. Ann N Y Acad Sci, 1124, 1-38.

Christoff, K. (2012). Undirected thought: Neural determinants and correlates. Brain Res, 1428, 51-59.

Christoff, K, Gordon, AM, Smallwood, J, Smith, R, Schooler, JW. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. Proc Natl Acad Sci U S A, 106(21), 8719-8724.

Christoff, K, Gordon, AM, Smith, R. (2011). The role of spontaneous thought in human cognition. In O. Vartanian & D. R. Mandel (Eds.), Neuroscience of Decision Making (pp. 259-284). New York: Psychology Press.

Clapp, JD, Beck, JG. (2012). Treatment of PTSD in older adults: Do cognitive-behavioral interventions remain viable? Cogn Behav Pract, 19(1), 126-135.

Cohen, A-L, Dixon, RA, Lindsay, DS. (2005). The intention interference effect and aging: Similar magnitude of effects for young and old adults. Applied Cognitive Psychology, 19, 1177–1197.

Costa, P, McCrae, RR. (1992). Revised NEO Personality Inventory (NEO-PI-R) and NEO Five-Factor Inventory (NEO-FFI) Professional Manual. Odessa, FL: Psychological Assessment Resources.

Craik, FIM. (1983). On the transfer of information from temporary to permanent memory. Philosophical Transactions of the Royal Society of London, 302(1110), 341-358.

Craik, FIM. (1986). A functional account of age differences in memory. . In K. F. & H. Hagendorf (Eds.), Human Memory and Cognitive Capabilities: Mechanisms and Performances (pp. 409-422). Amsterdam: Elsevier.

Craik, FIM, Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. Craik & S. E. Trehub (Eds.), Aging and Cognitive Processes (pp. 191-211). New York: Plenum Press.

Craik, FIM, Salthouse, TA. (2000). The Handbook of Aging and Cognition. Mahwah, NJ: Lawrence Erlbaum Associates.

Damoiseaux, JS, Beckmann, CF, Arigita, EJ, Barkhof, F, Scheltens, P, Stam, CJ, Smith, SM, Rombouts, SA. (2008). Reduced resting-state brain activity in the "default network" in normal aging. Cereb Cortex, 18(8), 1856-1864.

de Chastelaine, M, Wang, TH, Minton, B, Muftuler, LT, Rugg, MD. (2011). The effects of age, memory performance, and callosal integrity on the neural correlates of successful associative encoding. Cereb Cortex, 21(9), 2166-2176.

Duzel, E, Schutze, H, Yonelinas, AP, Heinze, HJ. (2011). Functional phenotyping of successful aging in long-term memory: Preserved performance in the absence of neural compensation. Hippocampus, 21(8), 803-814.

Einstein, GO, McDaniel, MA. (1990). Normal aging and prospective memory. J Exp Psychol Learn Mem Cogn, 16(4), 717-726.

Einstein, GO, McDaniel, MA, Richardson, SL, Guynn, MJ, Cunfer, AR. (1995). Aging and prospective memory: examining the influences of self-initiated retrieval processes. J Exp Psychol Learn Mem Cogn, 21(4), 996-1007.

Einstein, GO, McDaniel, MA, Thomas, R, Mayfield, S, Shank, H, Morrisette, N, Breneiser, J. (2005). Multiple processes in prospective memory retrieval: factors determining monitoring versus spontaneous retrieval. J Exp Psychol Gen, 134(3), 327-342.

Erskine, JAK, Kvavilashvili, L, Kornbrot, DE. (2007). The predictors of thought suppression in young and old adults: Effects of rumination, anxiety, and other variables. Personality and Individual Differences, 42, 1047-1057.

Fox, KC, Spreng, RN, Ellamil, M, Andrews-Hanna, JR, Christoff, K. (2015). The wandering brain: meta-analysis of functional neuroimaging studies of mind-wandering and related spontaneous thought processes. Neuroimage, 111, 611-621.

Frank, DJ, Nara, B, Zavagnin, M, Touron, DR, Kane, MJ. (2015). Validating older adults' reports of less mind-wandering: An examination of eye movements and dispositional influences. Psychol Aging, 30(2), 266-278.

Gaesser, B, Sacchetti, DC, Addis, DR, Schacter, DL. (2011). Characterizing age-related changes in remembering the past and imagining the future. Psychol Aging, 26(1), 80-84.

Gardner, RS, Ascoli, GA. (2015). The natural frequency of human prospective memory increases with age. Psychol Aging, 30(2), 209-219.

Giambra, LM. (1989). Task-unrelated-thought frequency as a function of age: a laboratory study. Psychol Aging, 4(2), 136-143.

Giambra, LM. (2000). Daydreaming characteristics across the life-span: age differences and seven to twenty year longitudinal changes. In R. Kunzendorf & B. Wallace (Eds.), Individual Differences in Conscious Experience (pp. 147–206). Amsterdam: John Benjamins.

Grady, CL, Springer, MV, Hongwanishkul, D, McIntosh, AR, Winocur, G. (2006). Age-related changes in brain activity across the adult lifespan. J Cogn Neurosci, 18(2), 227-241.

Gutchess, AH, Park, DC. (2006). fMRI environment can impair memory performance in young and elderly adults. Brain Res, 1099(1), 133-140.

Hasher, L, Zacks, RT. (1988). Workng memory, comprehension, and aging: a review and a new view. The psychology of learning, 22, 193-225.

Henry, JD, MacLeod, MS, Phillips, LH, Crawford, JR. (2004). A meta-analytic review of prospective memory and aging. Psychol Aging, 19(1), 27-39.

Hess, TM, Hinson, JT, Hodges, EA. (2009). Moderators of and mechanisms underlying stereotype threat effects on older adults' memory performance. Exp Aging Res, 35(2), 153-177.

Holmes, EA, Brewin, CR, Hennessy, RG. (2004). Trauma films, information processing, and intrusive memory development. J Exp Psychol Gen, 133(1), 3-22.

Jackson, JD, Balota, DA. (2012). Mind-wandering in younger and older adults: Converging evidence from the sustained attention to response task and reading for comprehension. Psychol Aging, 27(1), 106-119.

Jackson, JD, Weinstein, Y, Balota, DA. (2013). Can mind-wandering be timeless? Atemporal focus and aging in mind-wandering paradigms. Front Psychol, 4, 742.

Killingsworth, MA, Gilbert, DT. (2010). A wandering mind is an unhappy mind. Science, 330(6006), 932.

Kliegel, M, Jager, T, Phillips, LH. (2008). Adult age differences in event-based prospective memory: a meta-analysis on the role of focal versus nonfocal cues. Psychol Aging, 23(1), 203-208.

Klinger, E. (2013). Goal Commitments and the content of thoughts and dreams: basic principles. Front Psychol, 4, 415.

Klinger, E, Gregoire, KC, Barta, SG. (1973). Physiological correlates of mental activity: eye movements, alpha, and heart rate during imagining, suppression, concentration, search, and choice. Psychophysiology, 10(5), 471-477.

Kopp, K, D'Mello, S, Mills, C. (2015). Influencing the occurrence of mind wandering while reading. Conscious Cogn, 34, 52-62.

Krawietz, SA, Tamplin, AK, Radvansky, GA. (2012). Aging and mind wandering during text comprehension. Psychol Aging, 27(4), 951-958.

Kuhn, S, Schmiedek, F, Brose, A, Schott, BH, Lindenberger, U, Lovden, M. (2013). The neural representation of intrusive thoughts. Soc Cogn Affect Neurosci, 8(6), 688-693.

Kvavilashvili, L, Fisher, L. (2007). Is time-based prospective remembering mediated by self-initiated rehearsals? Role of incidental cues, ongoing activity, age, and motivation. J Exp Psychol Gen, 136(1), 112-132.

Kvavilashvili, L, Mandler, G. (2004). Out of one's mind: a study of involuntary semantic memories. Cogn Psychol, 48(1), 47-94.

Lachman, ME, Agrigoroaei, S. (2012). Low perceived control as a risk factor for episodic memory: the mediational role of anxiety and task interference. Mem Cognit, 40(2), 287-296.

Lambert, AE, Smyth, FL, Beadel, JR, Teachman, BA. (2013). Aging and repeated thought suppression success. PLoS One, 8(6), e65009.

Leshikar, ED, Gutchess, AH, Hebrank, AC, Sutton, BP, Park, DC. (2010). The impact of increased relational encoding demands on frontal and hippocampal function in older adults. Cortex, 46(4), 507-521.

Levine, B, Svoboda, E, Hay, JF, Winocur, G, Moscovitch, M. (2002). Aging and autobiographical memory: dissociating episodic from semantic retrieval. Psychol Aging, 17(4), 677-689.

Levy, B. (1996). Improving memory in old age through implicit self-stereotyping. J Pers Soc Psychol, 71(6), 1092-1107.

Lindenberger, U, Mayr, U. (2014). Cognitive aging: is there a dark side to environmental support? Trends Cogn Sci, 18(1), 7-15.

Lustig, C, Jantz, T. (2015). Questions of age differences in interference control: When and how, not if? Brain Res, 1612, 59-69.

Mace, JH. (2006). Episodic remembering creates access to involuntary conscious memory: demonstrating involuntary recall on a voluntary recall task. Memory, 14(8), 917-924.

Madore, KP, Gaesser, B, Schacter, DL. (2014). Constructive episodic simulation: dissociable effects of a specificity induction on remembering, imagining, and

describing in young and older adults. J Exp Psychol Learn Mem Cogn, 40(3), 609-622.

Magee, JC, Smyth, FL, Teachman, BA. (2014). A web-based examination of experiences with intrusive thoughts across the adult lifespan. Aging Ment Health, 18(3), 326-339.

Magee, JC, Teachman, BA. (2012). Distress and recurrence of intrusive thoughts in younger and older adults. Psychol Aging, 27(1), 199-210.

Maillet, D, Rajah, MN. (2013). Age-related changes in frequency of mind-wandering and task-related interferences during memory encoding and their impact on retrieval. Memory, 21(7), 818-831.

Maillet, D, Rajah, MN. (2014). Dissociable roles of default-mode regions during episodic encoding. Neuroimage, 89, 244-255.

Mason, MF, Norton, MI, Van Horn, JD, Wegner, DM, Grafton, ST, Macrae, CN. (2007). Wandering minds: the default network and stimulus-independent thought. Science, 315(5810), 393-395.

Mather, M. (2012). The emotion paradox in the aging brain. Ann N Y Acad Sci, 1251, 33-49.

Mather, M, Carstensen, LL. (2005). Aging and motivated cognition: the positivity effect in attention and memory. Trends Cogn Sci, 9(10), 496-502.

May, CP, Manning, M, Einstein, GO, Becker, L, Owens, M. (2015). The best of both worlds: emotional cues improve prospective memory execution and reduce repetition errors. Neuropsychol Dev Cogn B Aging Neuropsychol Cogn, 22(3), 357-375.

McDaniel, MA, Einstein, GO. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. Applied Cognitive Psychology, 14, S127–S144.

McDaniel, MA, Einstein, GO. (2011). The neuropsychology of prospective memory in normal aging: a componential approach. Neuropsychologia, 49(8), 2147-2155.

McDaniel, MA, Einstein, GO, Jacoby, L. (2008). New considerations in aging and memory: the glass may be half full. In F. I. M. Craik & T. A. Salthouse (Eds.), The Handbook of Aging and Cognition (3rd ed.). Great Britain: Psychology Press.

McVay, JC, Kane, MJ. (2013). Dispatching the wandering mind? Toward a laboratory method for cuing "spontaneous" off-task thought. Front Psychol, 4, 570.

McVay, JC, Meier, ME, Touron, DR, Kane, MJ. (2013). Aging ebbs the flow of thought: adult age differences in mind wandering, executive control, and self-evaluation. Acta Psychol (Amst), 142(1), 136-147.

Mevel, K, Landeau, B, Fouquet, M, La Joie, R, Villain, N, Mezenge, F, Perrotin, A, Eustache, F, Desgranges, B, Chetelat, G. (2013). Age effect on the default mode network, inner thoughts, and cognitive abilities. Neurobiol Aging, 34(4), 1292-1301.

Miller, SL, Celone, K, DePeau, K, Diamond, E, Dickerson, BC, Rentz, D, Pihlajamaki, M, Sperling, RA. (2008). Age-related memory impairment associated with loss of parietal deactivation but preserved hippocampal activation. Proc Natl Acad Sci U S A, 105(6), 2181-2186.

Moulin, CJA, Souchay, C, Buchanan, S, Bradley, R, Karadoller, DZ, Akan, M. (2014). Déjà Vu in Older Adults. In B. L. Schwartz & A. S. Brown (Eds.), Tip-of-the-Tongue States and Related Phenomena. New York, NY: Cambridge University Press.

Mullet, HG, Scullin, MK, Hess, TJ, Scullin, RB, Arnold, KM, Einstein, GO. (2013). Prospective memory and aging: evidence for preserved spontaneous retrieval with exact but not related cues. Psychol Aging, 28(4), 910-922.

Nagamatsu, LS, Kam, JW, Liu-Ambrose, T, Chan, A, Handy, TC. (2013). Mind-wandering and falls risk in older adults. Psychol Aging, 28(3), 685-691.

O'Callaghan, C, Shine, JM, Lewis, SJ, Andrews-Hanna, JR, Irish, M. (2015). Shaped by our thoughts--a new task to assess spontaneous cognition and its associated neural correlates in the default network. Brain Cogn, 93, 1-10.

Parks, CW, Klinger, E, Perlmutter, M. (1988). Dimensions of thought as a function of age, gender and task difficulty. Imagination, Cognition and Personality, 8(1), 49-62.

Persson, J, Lustig, C, Nelson, JK, Reuter-Lorenz, PA. (2007). Age differences in deactivation: a link to cognitive control? J Cogn Neurosci, 19(6), 1021-1032.

Plimpton, B, Patel, P, Kvavilashvili, L. (2015). Role of triggers and dysphoria in mind-wandering about past, present and future: A laboratory study. Conscious Cogn, 33C, 261-276.

Rachman, S. (1981). Part I. Unwanted intrusive cognitions. Advances in Behaviour Research and Therapy, 3(3), 89-99.

Rajah, MN, Languay, R, Valiquette, L. (2010). Age-related changes in prefrontal cortex activity are associated with behavioural deficits in both temporal and spatial context memory retrieval in older adults. Cortex, 46(4), 535-549.

Rasmussen, AS, Berntsen, D. (2011). The unpredictable past: spontaneous autobiographical memories outnumber autobiographical memories retrieved strategically. Conscious Cogn, 20(4), 1842-1846.

Rendell, PG, Craik, FIM. (2000). Virtual Week and Actual Week: Age-related Differences in Prospective Memory. Applied Cognitive Psychology, 14, S43-S62.

Reuter-Lorenz, P, Cappell, KA. (2008). Neurocognitive Aging and the Compensation Hypothesis. Current Directions in Psychological Science, 17(3), 177-182.

Rubin, DC. (1999). Autobiographical memory and aging: Distributions of memories across the life-span and their implications for servey research. In D. C. Park & N. Schwarz (Eds.), Cognition, aging and self-reports. Hove, England: Psychology Press.

Rubin, DC, Berntsen, D. (2009). The frequency of voluntary and involuntary autobiographical memories across the life span. Mem Cognit, 37(5), 679-688.

Rubin, DC, Schulkind, MD. (1997). Distribution of important and word-cued autobiographical memories in 20-, 35-, and 70-year-old adults. Psychol Aging, 12(3), 524-535.

Schacter, DL, Gaesser, B, Addis, DR. (2013). Remembering the past and imagining the future in the elderly. Gerontology, 59(2), 143-151.

Schlagman, S, Kliegel, M, Schulz, J, Kvavilashvili, L. (2009). Differential effects of age on involuntary and voluntary autobiographical memory. Psychol Aging, 24(2), 397-411.

Schlagman, S, Kvavilashvili, L. (2008). Involuntary autobiographical memories in and outside the laboratory: how different are they from voluntary autobiographical memories? Mem Cognit, 36(5), 920-932.

Schlagman, S, Kvavilashvili, L, Schulz, J. (2007). Involuntary auto- biographical memory and aging. In J. H. Mace (Ed.), Involuntary memory. Malden, MA: Blackwell.

Schlagman, S, Schulz, J, Kvavilashvili, L. (2006). A content analysis of involuntary autobiographical memories: examining the positivity effect in old age. Memory, 14(2), 161-175.

Schooler, JW, Reichle, ED, Halpern, DV. (2004). Zoning out while reading: evidence for dissociations between experience and metaconsciousness. In D. T. Levin (Ed.), Thinking and seeing: Visual metacognition in adults and children (pp. 203-226). Cambridge, MA: MIT press.

Scullin, MK, Bugg, JM, McDaniel, MA, Einstein, GO. (2011). Prospective memory and aging: preserved spontaneous retrieval, but impaired deactivation, in older adults. Mem Cognit, 39(7), 1232-1240.

Seibert, PS, Ellis, HC. (1991). Irrelevant thoughts, emotional mood states, and cognitive task performance. Mem Cognit, 19(5), 507-513.

Seli, P, Carriere, JS, Smilek, D. (2014). Not all mind wandering is created equal: dissociating deliberate from spontaneous mind wandering. Psychol Res.

Seli, P, Cheyne, JA, Xu, M, Purdon, C, Smilek, D. (2015). Motivation, Intentionality, and Mind Wandering: Implications for Assessments of Task-Unrelated Thought. J Exp Psychol Learn Mem Cogn.

Shake, MC, Shulley, LJ, Soto-Freita, AM. (2015). Effects of Individual Differences and Situational Features on Age Differences in Mindless Reading. J Gerontol B Psychol Sci Soc Sci.

Shaw, GA, Giambra, L. (1993). Task-unrelated thoughts of college students diagnosed as hyperactive in childhood. Developmental Neuropsychology, 9(1), 17-30.

Singer, J. (1961). Some Characteristics of Adult Daydreaming. The Journal of psychology, 51, 151-164.

Singer, J, L., Antrobus, JS. (1970). Manual for the Imaginal Processes Inventory. Princeton, N. J.: Education Testing Service.

Smallwood, J. (2013). Distinguishing how from why the mind wanders: a process-occurrence framework for self-generated mental activity. Psychol Bull, 139(3), 519-535.

Smallwood, J, Schooler, JW. (2006). The restless mind. Psychol Bull, 132(6), 946-958.

Smallwood, J, Schooler, JW. (2015). The science of mind wandering: empirically navigating the stream of consciousness. Annu Rev Psychol, 66, 487-518.

Smith, RE. (2003). The cost of remembering to remember in event-based prospective memory: investigating the capacity demands of delayed intention performance. J Exp Psychol Learn Mem Cogn, 29(3), 347-361.

Spreng, RN, Schacter, DL. (2012). Default network modulation and large-scale network interactivity in healthy young and old adults. Cereb Cortex, 22(11), 2610-2621.

Staub, B, Doignon-Camus, N, Bacon, E, Bonnefond, A. (2014). Investigating sustained attention ability in the elderly by using two different approaches: inhibiting ongoing behavior versus responding on rare occasions. Acta Psychol (Amst), 146, 51-57.

Stawarczyk, D, Majerus, S, Maj, M, Van der Linden, M, D'Argembeau, A. (2011). Mind-wandering: phenomenology and function as assessed with a novel experience sampling method. Acta Psychol (Amst), 136(3), 370-381.

Stawski, RS, Mogle, J, Sliwinski, MJ. (2011). Intraindividual coupling of daily stressors and cognitive interference in old age. J Gerontol B Psychol Sci Soc Sci, 66 Suppl 1, i121-129.

Stevens, WD, Hasher, L, Chiew, KS, Grady, CL. (2008). A neural mechanism underlying memory failure in older adults. J Neurosci, 28(48), 12820-12824.

Takarangi, MK, Strange, D, Lindsay, DS. (2014). Self-report may underestimate trauma intrusions. Conscious Cogn, 27, 297-305.

Trunk, DL, Abrams, L. (2009). Do younger and older adults' communicative goals influence off-topic speech in autobiographical narratives? Psychol Aging, 24(2), 324-337.

Urry, HL, Gross, JJ. (2010). Emotion Regulation in Older Age. Current Directions in Psychological Science, 19(6), 352-357.

Uttl, B. (2011). Transparent meta-analysis: does aging spare prospective memory with focal vs. non-focal cues? PLoS One, 6(2), e16618.

Vannucci, M, Batool, I, Pelagatti, C, Mazzoni, G. (2014). Modifying the frequency and characteristics of involuntary autobiographical memories. PLoS One, 9(4), e89582.

Watson, D, Clark, LA, Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. J Pers Soc Psychol, 54(6), 1063-1070.

Wegner, DM, Zanakos, S. (1994). Chronic thought suppression. J Pers, 62(4), 616-640.

Zavagnin, M, Borella, E, De Beni, R. (2014). When the mind wanders: age-related differences between young and older adults. Acta Psychol (Amst), 145, 54-64.

Highlights:

- Frequency of mind-wandering and involuntary retrieval decreases with increasing age
- Evidence for relatively preserved spontaneous prospective memory retrieval
- Cognitive control, motivation and current concerns may contribute to age difference