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When the Mind Wanders: Distinguishing Stimulus-Dependent From Stimulus-Independent Thoughts During Incidental Encoding in Young and Older Adults

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In recent years, several studies have indicated that healthy older adults exhibit a reduction in mind-wandering compared with young adults. However, relatively little research has examined the extent to which ongoing thoughts in young and older adults are dependent on environmental stimuli. In the current study, we assessed age-related differences in frequency of stimulus-dependent thoughts (SDTs) and stimulus-independent thoughts (SITs) during a slow-paced incidental encoding task. Based on previous research suggesting that older adults rely on external information to a greater extent than young adults, we hypothesized that ongoing thoughts in older adults may be more stimulus-dependent than in young adults. We found that although older adults reported overall fewer thoughts compared to young adults, they exhibited a reduction in proportion of SITs and an increase in proportion of SDTs. In both age groups, SDTs were more frequently about the past compared with SITs, while SITs were more frequently about the future. Finally, the extent to which both young and older adults reported SDTs, but not SITs, at encoding was positively correlated with how often they reported remembering thoughts at retrieval, and SDT frequency was positively correlated with overall performance on the memory task in older adults. Our results provide evidence that ongoing thoughts in older adults may be more dependent on environmental stimuli than young adults, and that these thoughts may impact performance in recognition tasks.

Keywords: aging, episodic encoding, mind-wandering, task-unrelated thought, memory

Participants frequently exhibit shifts in attention away from an ongoing cognitive task to self-generated thoughts and feelings (mind-wandering; Smallwood & Schooler, 2015). In recent years, several studies have indicated that healthy older adults report a reduction in mind-wandering during task performance (for review, see Maillet & Schacter, 2016). The purpose of the current experiment was to investigate the extent to which ongoing thoughts in young and older adults are dependent on environmental cues and how this may impact episodic memory.

Two main explanations have been put forth to explain age-related reductions in mind-wandering. First, based on the current concerns hypothesis (Klinger, 2013), it has been suggested that age-related reductions in mind-wandering may occur due to a shift in the relative saliency of the ongoing experimental task relative to self-generated thoughts. Supporting this proposal, there is evidence that older adults may have fewer nontrivial daily life current concerns compared with young adults (Parks, Klinger, & Perlmutter, 1988), and that older adults are more motivated and/or interested in experimental tasks compared with young adults (e.g., Jackson & Balota, 2012; Krawietz, Tamplin, & Radvansky, 2012; Maillet & Rajah, 2013). Additionally, older adults sometimes report a higher proportion of task-related interferences (thoughts about how well one is doing the task) compared with young adults, which may be due to them placing a higher importance on, or being more worried about, task performance than young adults (Frank, Nara, Zavagnin, Touron, & Kane, 2015; McVay, Meier, Touron, & Kane, 2013).

A second nonmutually exclusive idea is that age-related reductions in mind-wandering may be related to an age-related increase in reliance on the environment. Craik and colleagues (Craik, Routh, & Broadbent, 1983; Craik, 1986; Craik & Byrd, 1982) argued that older adults are particularly impaired in tasks that depend on self-initiated processing (self-generated cues, controlled processing) because these tasks rely on cognitive resources that decline with age. On the other hand, older adults exhibit reduced or no impairment in tasks that provide environmental support (environmental cues, hints; see also Lindenberger & Mayr, 2014). For example, age-related reductions in performance on memory tasks are usually highest during free recall, reduced in cued-recall, and absent in simple recognition tasks. In the same way that older adults exhibit greater reductions in free recall compared with cued recall due to the presence of an environmental cue only in the latter case, it is possible that ongoing thoughts in older relative to young adults may be more dependent on the environment (cued by a stimulus in the environment) rather than stimulus-independent (self-generated; Maillet & Schacter, 2016).

The extent to which ongoing thoughts in young and older adults are dependent on environmental stimuli has received relatively little attention in the mind-wandering literature. One of the most

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frequently used tasks in the mind-wandering literature is a go-no/go task involving meaningless stimuli (the digits 1–9, geometric shapes, meaningless letter strings) that are unlikely to themselves trigger thoughts. From a reduced cognitive resource standpoint, due to the requirement for constant attention (i.e., high resources needed to perform the task) and the lack of any meaningful stimuli in the task (i.e., little environmental cues for triggering thoughts), it is unsurprising that older adults report low levels of mind-wandering in these tasks (Giambra, 1989; Jackson & Balota, 2012; Jackson, Weinstein, & Balota, 2013; Zavagnin, Borella, & De Beni, 2014). In contrast, other studies have used tasks such as reading comprehension that involve meaningful stimuli (e.g., words, sentences) that may themselves be more likely to trigger thoughts. Some of these studies used thought probes forcing subjects to decide whether their thoughts were best classified as being on-task or mind-wandering (Jackson & Balota, 2012; Shake, Shulley, & Soto-Freita, 2015); in these studies, it is unclear in which category thoughts triggered by the text would be classified. In two other studies, thought probes that allow distinguishing the content of thoughts according to whether they are related to the text, or something unrelated were used. First, Krawiet, Tamplin, and Radvansky (2012) reported that while young adults reported a greater proportion of mind-wandering about themselves, older adults reported a greater proportion of mind-wandering about the text. Second, Frank, Nara, Zavagnin, Touron, and Kane (2015) found that while older adults reported a reduction in the frequency of thoughts that included "everyday things, current state of being, personal worries and daydreams," no age-related differences were observed for "reading-related images and thoughts corresponding to the content of the text." Although these two studies do not explicitly distinguish between thoughts cued by stimuli in the task and stimulus-independent thoughts, their results support the notion that ongoing thoughts in older adults may be particularly sensitive to task stimuli.

In the current study, we assessed age-related differences in the type of ongoing thoughts exhibited during an incidental encoding task for word and picture stimuli. Two features of typical incidental tasks led us to believe that this setting would promote more thoughts in older adults than is typically observed in the mind-wandering literature: (a) this task contains meaningful stimuli (words, pictures) that may trigger thoughts and (b) this task does not require sustained attention; rather, incidental encoding tasks typically contain intertrial intervals in between each encoding item (for similar argument, see O'Callaghan, Shine, Lewis, Andrews-Hanna, & Irish, 2015). This prediction is consistent with speculations in the episodic memory literature that older adults may exhibit an increase in thoughts cued by task stimuli compared with young adults at encoding (Healey, Hasher, & Campbell, 2013; Maillet & Rajah, 2014a), although this has never directly been tested. In the current study, we explicitly distinguished between thoughts cued by encoding stimuli (stimulus-dependent thoughts [SDTs]) and those that are not (stimulus-independent thoughts [SITs]) and tested the hypothesis that older adults would report an increase in SDTs. In contrast, previous findings of age-related reductions in mind-wandering in previous studies may be primarily attributable to a reduction in SITs.

Distinguishing SDTs from SITs is particularly interesting in the context of incidental encoding because of differences in how these thought types may support later retrieval. For instance, consider a participant having a memory of going to a jazz concert last weekend during an incidental encoding task. This thought is not intrinsically task-relevant or task-irrelevant if considered from the perspective of the subsequent memory retrieval task. This thought could turn out to be relevant if it was an SDT, that is, was triggered by one of the encoding stimuli (e.g., the word "saxophone") and is later used as evidence in the memory retrieval task that the participant did in fact see this word at encoding. For example, Gardiner, Ramponi, and Richardson-Klavehn (1998) reported that, when asked to describe what led them to recognize words at retrieval, participants frequently reported *involuntary remindings* that occurred at encoding. These remindings "appear to reflect occasions when the presentation of the word in the study list automatically triggered awareness of some personal memory from everyday life" (Gardiner et al., 1998, p. 5). Alternatively, this same thought of going to a jazz concert could be irrelevant to the memory test if it was not triggered by any external stimulus (i.e., is a SIT), and was instead internally triggered. Thus, in general, SDTs may be more likely than SITs to benefit later memory retrieval performance.

Note that although, to the best of our knowledge, no study in the mind-wandering literature has assessed the nature of ongoing thoughts during incidental encoding, many studies have done so during *intentional* encoding (Maillet & Rajah, 2013, 2014b, 2016; Seibert & Ellis, 1991; Smallwood, Baracaia, Lowe, & Obonsawin, 2003; Thomson, Smilek, & Besner, 2014). These studies have used either (a) periodic thought probes asking participants whether they were on-task/mind-wandering, or (b) retrospective questionnaires to assess task-irrelevant thoughts. In contrast, using an on-task/mind-wandering distinction during *incidental* encoding makes less sense, because the participant is unaware of the true nature of the task, and because the task does not involve sustained attention (i.e., it contains intertrial intervals in which it is unclear what being "on-task" would mean).

We view SDTs as being related but not identical to other concepts such as elaboration and task-related interferences. In the context of a memory task, SDTs may be viewed as a form of elaboration of the encoding stimuli, similar to elaboration obtained from performing incidental encoding tasks (i.e., levels of processing effects; Craik & Lockhart, 1972). Importantly, however, SDTs are not a requirement of the ongoing task (i.e., the participant is asked to perform incidental encoding judgments, but not to engage in SDTs), and the participant is unaware that such thoughts may impact later retrieval. In addition, the benefit of SDTs may critically depend on the nature of the task: although SDTs can potentially benefit performance in a slow-paced episodic encoding task by promoting elaboration of encoding stimuli, SDTs could hamper performance in a more fast-paced sustained attention task with no memory component by taking attention away from the task (see McVay & Kane, 2013; Plimpton, Patel, & Kvavilashvili, 2015). SDTs may also be related to the concept of task-related interferences (Smallwood et al., 2004; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011), in that both represent thoughts related in some way to the current task (SDTs are triggered by a stimulus in the task, whereas task-related interferences are thoughts about the appraisal of the current task). Similar to SDTs, task-related interferences may be triggered by a specific stimulus in the task (e.g., "I can't believe I responded that the word 'cow' is man-made"); however, they can also be triggered by the general task context (e.g., “I wonder how well I’m doing;” “I wonder if I should respond faster”). Moreover, the content of task-related interferences is necessarily about the task itself whereas the content of SDTs may be much broader, and may often contain instances of temporally distant thoughts about one’s personal life (e.g., the word “saxophone” triggering a memory of going to a jazz concert).

The Current Study

In the present study, participants incidentally encoded words and a corresponding picture while performing a man-made/natural judgment on each. Approximately once every minute, a thought probe asked subjects whether, in the moment directly preceding the thought probe, they had been exhibiting a SDT, a SIT, or no thought. All thought probes were presented during intertrial intervals. Half of the thought probes were presented 1.5 s after the offset of the last encoding stimuli, while the other half were presented 4 s after. At retrieval, participants performed an old/new task in which they were asked to distinguish previously presented items from novel lures. We hypothesized that (a) at encoding, young adults experience more SITs than older adults, while older adults experience more SDTs compared with young adults; (b) both age groups would be more likely to report SDTs when probed after a short delay than a long delay, and more likely to report SITs at the long relative to the short delay (see Seli, Carriere, Levene, & Smilek, 2013 for related findings); and (c) frequency of SDTs, but not SITs at encoding would be correlated with the extent to which participants report remembering thoughts at retrieval, and SDT may also be positively correlated with overall performance on the retrieval task itself.

In addition, we were also interested in assessing differences in three features of SDTs relative to SITs: temporal orientation, spontaneity, and pleasantness. First, when describing encoding thoughts that participants remembered at retrieval, Gardiner et al. (1998) used terminology (*involuntary remindings*) that emphasized a past-oriented focus. We thus hypothesized that SDTs would predominantly be past-oriented. In contrast, SITs may be driven primarily by current concerns, which tend to be primarily future-oriented (Baird, Smallwood, & Schooler, 2011; Cole & Berntsen, 2015). We thus hypothesized that unlike SDTs, SITs would have a future-oriented bias. Previous evidence concerning age-related differences in temporality of thought has been inconsistent (Gardner & Ascoli, 2015; Giambra, 2000; Jackson et al., 2013). We thus had no specific hypothesis regarding age-related differences in the temporality of SDTs and SITs.

Second, as mentioned earlier, the term *involuntary remindings* used by Gardiner et al. (1998) implies that SDTs occur spontaneously when seeing the encoding stimuli. In contrast, while mind-wandering is usually also thought to occur spontaneously, some evidence indicates that a significant proportion of mind-wandering episodes may be deliberate (e.g., Seli, Cheyne, Xu, Purdon, & Smilek, 2015; Shaw & Giambra, 1993). Thus, we hypothesized that a greater proportion of SDTs relative to SITs would be rated as spontaneous. Based on research indicating that older adults exhibit reductions in self-initiated processing (Craik et al., 1983; Craik, 1986; Craik & Byrd, 1982), we also hypothesized that older adults may be more likely to rate thoughts as occurring spontaneously than young adults.

Third, some evidence suggests that SITs may predominantly be of negative valence/associated with negative mood, perhaps because they are often directed toward concerns or worries (e.g., Killingsworth & Gilbert, 2010; Stawarczyk, Majerus, & D’Argembeau, 2013). We thus predicted that SITs may be rated as less pleasant than SDTs. Based on findings that older adults exhibit a positivity effect (Mather & Carstensen, 2005), we also expected that both SDT and SIT may be rated as more pleasant by older versus young adults.

Method

Participants

Thirty young adults (age range = 18–34; mean age = 23; 16 females) and 30 older adults (age range = 65–87; mean age = 71.1, 16 females) participated in the study. Young adults were recruited online through the Harvard Psychology study pool. This participant pool is not restricted to Harvard students, but is open to members of the Boston community. Five young participants were currently enrolled at Harvard University, 15 were enrolled in a college or university other than Harvard, five were not enrolled in a college or university, and five declined to answer. Older adults were recruited through advertisements in the Boston community. Participants did not report any history of neurological or psychiatric conditions. Older adults completed an extensive neuropsychological battery that included the minimental status examination (Folstein, Folstein, & McHugh, 1975), verbal fluency, the WAIS-III (Wechsler, 1997), the Wechsler Memory Scale (Wechsler, 1987), the California verbal learning test (Delis, Kramer, Kaplan, & Ober, 1987), and the Wisconsin card sorting test (Grant & Berg, 1948). Only older adults performing above accepted thresholds were asked to participate in the current study. The two age groups did not differ in education levels (young $M = 15.93$, $SD = 2.08$; old $M = 16.23$, $SD = 2.51$; $p = .62$). All participants completed the Montreal Cognitive Assessment Scale (MOCA; Nasreddine et al., 2005). Young adults scored significantly higher compared with older adults (young: $M = 28.07$, $SD = 1.57$; old: $M = 26.8$, $SD = 1.63$; $p = .003$, $d = 0.791$) but all participants had a score of 25 or higher.

Stimuli

A total of 324 pictures were selected from the Bank of Standardized Stimuli (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010; Brodeur, Guerard, & Bouras, 2014). The 324 pictures were split into three lists of 108. Two lists served as encoding stimuli, while the third was used as novel lures in the retrieval task. Items were counterbalanced in being assigned as novel lures. The ordering of items at encoding and retrieval was random. Half of the items in each list represented man-made objects (e.g., hammer) while the other half represented natural objects (e.g., cat).

Procedure

Participants first performed incidental encoding of 216 words. Below each word, there was a picture depicting that word (e.g., the word “Apple” presented with a picture of an apple). Each picture–word pair was presented for 4 s, followed by a blank screen for 4 s. Thus, the stimulus onset asynchrony was 8 s. Participants were asked to look at both the word and the picture, and to decide as quickly as possible whether they depicted a man-made or a natural object.

Approximately once every minute (every six to 10 encoding items), a thought probe appeared on the screen asking participants about what they had just been thinking about. There were 28 thought probes in total. Half the thought probes were presented 1.5 s after the offset of the preceding picture (short time interval), while the other half were presented 4 s after (long time interval). Four multiple choice questions were asked in the thought probe. First, was the participant: (a) having a thought that was triggered by one of the encoding stimuli (SDT); (b) having a thought that was not triggered by one of the encoding stimuli (SIT); or (c) having no thought. If the participants chose (a), they were also asked to specify which encoding stimulus triggered the thought. Second, was the thought spontaneous (a thought that popped into mind without any intention of doing so) or deliberate (a thought that participants intentionally had). Third, was the thought about (a) a past event, (b) a possible future event, or (c) had no temporal orientation. Fourth, how pleasant was the thought, on a scale of 1 to 5 (1 = *unpleasant*, 3 = *neutral*, 5 = *pleasant*).

Following the incidental encoding task, participants were asked to rate how interesting and difficult they thought the man-made/natural task was, and how difficult it had been for them to report their thoughts on a scale of 1 to 10. Participants were then informed that they would perform an old/new memory retrieval task (no participant reported being aware that a memory task would follow). Only the words, but not the accompanying pictures, were shown at retrieval. For each of 324 words, participants were asked to make one of the following four responses: (a) definitely old, (b) probably old, (c) probably new, or (d) definitely new. Henceforth, "definitely" responses will be referred to as high confidence responses, whereas "probably" responses will be referred to as low confidence responses. When participants responded that a word was "old" (options a or b), they were asked two additional questions. First, they were asked to rate on a 1–5 scale how well they remembered the picture presented alongside the word at encoding. Second, they were asked to rate on a 1–5 scale how well they could remember any thoughts they had when they initially saw this word at encoding. The retrieval task was self-paced.

Results

Encoding Accuracy and Reaction Time (RT)

Accuracy and RT data for the man-made/natural task are presented in Table 1. There was no between-groups difference in accuracy on the man-made/natural task at encoding, $F(1, 58) = 1.29$, $MSE = 0.002$, $p = .26$, $\eta_p^2 = .02$. Although RT on the man-made/natural task was numerically higher in older relative to young adults, this difference did not reach statistical significance, $F(1, 58) = 3.32$, $MSE = 182{,}871$, $p = .07$, $\eta_p^2 = .05$. After completion of the incidental encoding task, participants were asked how difficult and interesting they thought the man-made/natural task had been. There were no between-groups differences in difficulty ratings, $F(1, 58) = 0.37$, $MSE = 2.22$, $p = .55$, $\eta_p^2 = .01$, but older adults reported finding the task more interesting than young adults, $F(1, 58) = 7.51$, $MSE = 5.33$, $p = .01$, $\eta_p^2 = .12$.

Table 1
Incidental Encoding Data (mean, SD) in Young and Older Adults

	Young	Old
Man-made/natural accuracy	.98 (.06)	.99 (.01)
Man-made/natural reaction time	1,538 (403)	1,739 (451)
Interest in man-made/natural task	5.2 (2.19)	6.8 (2.42)
Perceived difficulty of man-made/ natural task	1.97 (1.54)	1.73 (1.44)
Perceived difficulty of reporting about one's thoughts	4.4 (2.2)	3.9 (2.34)

Encoding Thought Proportions

Following the encoding task, participants were also asked how difficult it had been to report about their own thoughts on the thought probes. There were no between-groups differences in difficulty ratings, $F(1, 58) = 0.72$, $MSE = 5.21$, $p = .40$, $\eta_p^2 = .01$.

An age group (young, old) by time interval (short, long) by thought type (SDT, SIT) ANOVA revealed a main effect of age group, $F(1, 58) = 6.61$, $MSE = 0.03$, $p = .01$, $\eta_p^2 = .10$, due to young adults reporting overall more thoughts compared to older adults. There was also a main effect of thought type, $F(1, 58) = 134.64$, $MSE = 0.07$, $p < .001$, $\eta_p^2 = .70$, due to participants reporting overall more SDTs relative to SITs. A significant time by thought type interaction, $F(1, 58) = 9.39$, $MSE = 0.02$ $p = .003$, $\eta_p^2 = .14$, indicated that while participants reported more SDTs at the short relative to the long time interval, $F(1, 59) = 5.25$, $MSE = 0.02$, $p = .03$, $\eta_p^2 = .08$, they reported more SITs at the long relative to the short interval, $F(1, 59) = 11.84$, $MSE = 0.01$, $p = .001$, $\eta_p^2 = .17$. Lastly, a significant thought type by age group interaction, $F(1, 58) = 37.32$, $MSE = 0.07$, $p < .001$, $\eta_p^2 = .39$, indicated that whereas young adults reported more SITs compared with older adults, $F(1, 58) = 59.97$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .51$, older adults reported more SDTs compared with young adults, $F(1, 58) = 12.05$, $MSE = 0.03$, $p = .001$, $\eta_p^2 = .17$. No other effects were significant (all $p > .25$).

When participants reported exhibiting an SDT, they were also asked to specify which word triggered the thought. Surprisingly, many SDTs (33% in young, 31% in old) were not triggered by the directly preceding stimulus, but instead triggered by one that occurred two or more stimuli ago. We will henceforth refer to SDTs about the directly preceding stimulus as 1-back SDTs, and all others as n-back SDTs. Proportion of 1-back SDTs, n-back SDTs, and SITs in young and older adults is presented in Figure 1. Because we had not a priori predicted that so many SDTs would be n-back SDTs, the following analyses are exploratory.

Eighty-seven percent of young adults and 73% of older adults reported exhibiting at least one n-back SDT. In these participants, the n-back thoughts were on average about stimuli that occurred 3.16 stimuli before the thought probe in young adults, and 3.66 stimuli before the thought probe in older adults. This age difference was not significant, $F(1, 46) = 2.12$, $MSE = 1.39$, $p = .15$, $\eta_p^2 = .04$.

We recalculated the between-group ANOVA on thought type proportion, but this time separating SDTs into 1-back and n-back SDTs. Thus, it was an Age group (young, old) × Time (short,

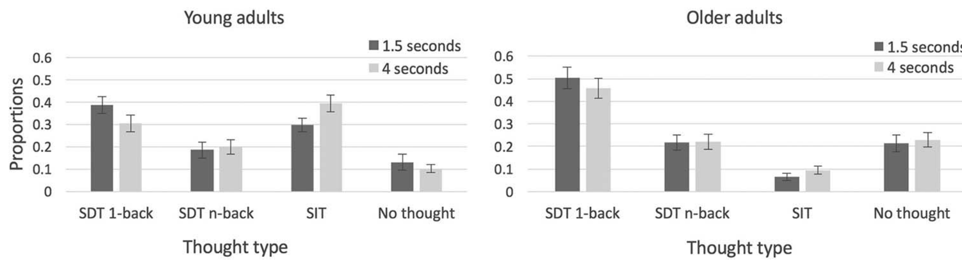

Figure 1. Proportion of responses on the thought probes (with standard error). SDT 1-back = stimulus-directed thoughts about the directly preceding stimulus; SDT n-back = stimulus-directed thoughts about stimuli that occurred two or more stimuli before the thought probe; SIT = stimulus-independent thought.

long) × Thought type (1-back SDT, n-back SDT, SIT) ANOVA. As before, there was a main effect of age group, a main effect of thought type, a Thought Type × Age Group interaction, and a Time × Thought Type interaction (all $p < .05$). The main effect of thought type was due to a higher proportion of 1-back SDTs compared with both n-back SDTs, $F(1, 59) = 22.53$, $MSE = 0.06$, $p < .001$, $\eta_p^2 = .28$, and SITs, $F(1, 59) = 22.99$, $MSE = 0.05$, $p < .001$, $\eta_p^2 = .28$, with no difference in proportion of n-back SDTs and SITs $F(1, 59) = 0.001$, $MSE = 0.04$, $p = .98$, $\eta_p^2 = 0$. In addition, post hoc tests revealed that both interactions reported in the previous ANOVA were driven by 1-back SDTs rather than n-back SDTs. For instance, the Thought Type × Age Group interaction was driven by an increase in 1-back SDTs in older relative to young adults, $F(1, 58) = 6.47$, $MSE = 0.04$, $p = .01$, $\eta_p^2 = .1$, and a decrease in SIT in older relative to young adults, $F(1, 58) = 59.97$, $MSE = 0.17$, $p < .001$, $\eta_p^2 = .51$, with no change in n-back SDTs, $F(1, 58) = 0.37$, $MSE = 0.03$, $p = .55$, $\eta_p^2 = .01$. Similarly, the time by thought type interaction was due to an increase in 1-back SDTs at the shorter relative to the longer interval $F(1, 59) = 6.54$, $MSE = 0.02$, $p = .01$, $\eta_p^2 = .10$, and an increase in SITs at the longer relative to the shorter interval, $F(1, 59) = 11.84$, $MSE = 0.01$, $p = .001$, $\eta_p^2 = .17$, with no change in 2-back SDTs, $F(1, 59) = 0.17$, $MSE = 0.01$ $p = .68$, $\eta_p^2 = .003$.

Previous studies have demonstrated that task interest is associated with mind-wandering in young and older adults (e.g., Krawietz et al., 2012; Shake et al., 2015). Moreover, in the current study, task interest was significantly higher in older relative to young adults, raising the possibility that age-related differences in proportion of SDTs and SITs may be accounted for by this variable. Within-group correlations indicated that task interest was not correlated with proportion of SDTs or SITs in either age group (all $p > .14$). We repeated the Age group (young, old) × Time (short, long) × Thought type (1-back SDT, n-back SDT, SIT) ANOVA with task interest as a covariate. As before, the main effect of thought type, the main effect of age group and the Age Group × Thought Type interaction were significant (all $p < .05$). In contrast, the time by thought type interaction was not significant, $F(2, 114) = 0.87$, $MSE = 0.02$, $p = .42$, $\eta_p^2 = .02$, indicating that this effect (the tendency of individuals to have more SDTs at the short time interval and more SITs at longer interval) was associated with task interest. No other effects reached significance.

In summary, the analysis of encoding thought types revealed three key results. First, both age groups are more likely to report a 1-back SDT a short time (1.5 s) relative to a long time (4 s) after the offset of the preceding stimulus, but more likely to report an SIT at a long relative to the short time interval—however, this effect disappeared when accounting for task interest. Second, irrespective of time point, older adults are more likely than young adults to be thinking about the directly preceding stimulus (1-back SDT), while young adults are more likely than old to be having a SIT. Third, older adults respond more frequently than young adults that they are not having any thought.

Characteristics of SDT and SIT

We assessed age-related differences in temporality, spontaneity and pleasantness of SDTs and SITs. Note that in this and all subsequent analyses in this article, SDTs combines both 1-back and n-back SDTs. This is because we had no a priori prediction regarding these thought types, and also because distinguishing 1-back and n-back SDTs would have reduced the amount of participants that could be included in the analyses (since not all participants reported each of these thought types). One young adult and 11 older adults did not report at least one SDT and one SIT. Thus, the analyses in this section were performed on a subsample of 29 young and 19 older adults. For temporality and spontaneity, we used proportions. For pleasantness, we used the average score per subject. Data for temporality, spontaneity, and pleasantness is shown in Table 2.

An age group (young, old) × Thought type (SDT, SIT) × Temporality (past, future) ANOVA yielded a main effect of temporality, $F(1, 46) = 10.68$, $MSE = 0.07$, $p < .002$, $\eta_p^2 = .19$, indicating that the proportion of past-oriented thoughts was higher than future-oriented thoughts. However, this main effect was qualified by a temporality by thought type interaction, $F(1, 46) =$

Table 2
Temporality, Spontaneity and Pleasantness Data (Mean, SD)

	Young		Old	
Temporality	SDT	SIT	SDT	SIT
% Past	.48 (.21)	.25 (.20)	.50 (.20)	.21 (.24)
% Future	.14 (.13)	.31 (.23)	.18 (.17)	.30 (.32)
% Atemporal	.38 (.21)	.44 (.25)	.32 (.22)	.49 (.36)
% Spontaneous	.73 (.21)	.66 (.26)	.79 (.27)	.69 (.38)
Pleasantness	3.4 (.47)	3.14 (.53)	3.56 (.58)	3.38 (1.06)

Note. These data are for a subsample of 29 young and 19 older adults that had at least 1 SDT and 1 SIT. SDT = stimulus-dependent thought; SIT = stimulus-independent thought.

40.43, $MSE = 0.05$, $p < .001$, $\eta_p^2 = .47$, indicating that while a greater proportion of SDTs were about the past relative to the future, $F(1, 47) = 64.20$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = .58$, there was no difference in proportion of SITs about the past relative to the future, $F(1, 47) = 1.52$, $MSE = 0.07$, $p = .23$, $\eta_p^2 = .03$. Also, while a greater proportion of SDTs relative to SITs were about the past, $F(1, 47) = 37.70$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = .45$, a greater proportion of SITs relative to SDTs were about the future, $F(1, 47) = 17.99$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = .28$.

An age group (young, old) × Thought type (SDT, SIT) ANOVA on spontaneity did not reveal any significant main effects or interactions (all $p > .09$). Similarly, an Age group (young, old) × Thought type (SDT, SIT) ANOVA on pleasantness ratings did not reveal any significant main effect or interaction (all $p > .09$).

Retrieval Performance

Retrieval trials were separated into two distinct categories: (a) words that participants had reported having an SDT about at encoding and (b) all other words. This was done because participants were asked to write down these words in the thought probes, and answer questions about SDTs related to them (i.e., temporal orientation, spontaneity, pleasantness). Thus, one would expect retrieval of these words to be especially strong, not because participants exhibited SDTs about them per se, but because these words received extra exposure compared to other words. The proportion of hits and false alarms, separated by confidence level (high, low), and for words with and without SDTs is shown in Table 3. As expected, high confidence hits were much more frequent for words about which participants had reported having an SDT at encoding in both young adults, $F(1, 29) = 154.28$, $MSE = 0.11$, $p < .001$, $\eta_p^2 = .84$, and older adults, $F(1, 29) = 175.58$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .86$. In all subsequent analyses involving retrieval data, we only analyzed those words about which participants did not report having SDTs.

Our a priori index of retrieval performance was "high confidence hits–high confidence false alarms." Using this index, there was no age-related difference in retrieval performance, $F(1, 58) = 0.88$, $MSE = 0.03$, $p = .35$, $\eta_p^2 = .02$. For completeness, we also calculated hits–false alarms (a) for low confidence responses, and (b) collapsed across confidence categories. Hits–false alarms for low confidence responses was higher in young relative to older adults, $F(1, 58) = 5.40$, $MSE = 0.01$, $p = .02$, $\eta_p^2 = .09$. Collapsed across confidence levels, age groups performed almost identically, $F(1, 58) = 0$, $MSE = 0.03$, $p = .98$, $\eta_p^2 = 0$.

Retrieval Ratings

When participants reported that a word was old, they were asked to rate the extent to which they could remember perceptual details about the picture associated with this word, and the extent to which they could remember any thoughts they had had while initially encoding this word. Two older adults reported reversing the order of retrieval response buttons (pressing "old" when they meant to respond "new" and vice versa). One older adult enquired about this in the middle of the retrieval task, while the other noted it after the task was completed. Retrieval accuracy could be calculated for these subjects after accounting for the reversal of button order. However, because they reversed the order of buttons, these two older adults gave retrieval ratings every time they responded that a word was new, rendering these ratings meaningless. Retrieval ratings for these two older adults were excluded, and hence, the following analyses are based on 30 young and 28 older adults. Table 4 presents these ratings in young and older adults. A two (young, old) × Two (perceptual details, thoughts) × Two (high confidence, low confidence) ANOVA revealed that all three main effects were significant. The type of detail main effect, $F(1, 56) = 23.98$, $MSE = 0.75$, $p < .001$, $\eta_p^2 = .3$, indicated that perceptual ratings were higher than ratings for thoughts. The confidence main effect, $F(1, 56) = 242.04$, $MSE = 0.63$, $p < .001$, $\eta_p^2 = .81$, indicated that ratings were greater for high relative to low confidence responses. Finally, the age group main effect, $F(1, 56) = 7.97$, $MSE = 1.33$, $p = .007$, $\eta_p^2 = .13$, indicated that ratings were higher overall in older versus young adults. Higher ratings in older relative to young adults on various subjective indicators of memory strength is a common finding in the literature (e.g., Johnson, Kuhl, Mitchell, Ankudowich, & Durbin, 2015; Rubin & Berntsen,

Table 3
Proportion of Hits, Misses and False Alarms (Mean, SD), Separated by Confidence Level in Young and Older Adults

	Old words			
	Young		Old	
	Words with SDT	All other words	Words with SDT	All other words
High confidence hit	.92 (.12)	.58 (.15)	.89 (.15)	.63 (.16)
Low confidence hit	.02 (.05)	.13 (.08)	.02 (.04)	.08 (.06)
Low confidence miss	.02 (.04)	.19 (.08)	.04 (.05)	.12 (.08)
High confidence miss	.04 (.07)	.10 (.09)	.05 (.11)	.17 (.15)

	New words	
	Young	Old
High confidence false alarms	.05 (.07)	.07 (.08)
Low confidence false alarms	.06 (.05)	.05 (.07)

Note. SDT = stimulus-dependent thought.

Table 4
Retrieval Ratings (Mean, SD) in Young and Older Adults, Separated by Confidence Level

	High confidence	Low confidence
	Young	
Perceptual details	3.86 (.61)	2.29 (.78)
Thoughts	3.13 (.89)	1.75 (.75)
	Old	
Perceptual details	4.36 (.66)	2.49 (.99)
Thoughts	3.78 (1.07)	2.12 (.95)

2009; Rubin & Schulkind, 1997; St. Jacques, Montgomery, & Schacter, 2015) and may indicate that young and older adults are using the scales differently. Because of this age effect, we do not further discuss the results presented in this section. Instead, we collected these retrieval ratings to examine within-group individual differences, which we report next.

Regression Analyses Predicting Retrieval Ratings With Proportion of SDT and SIT

We hypothesized that the proportion of SDTs, but not of SITs, experienced at encoding would be positively correlated with the extent to which participants report remembering thoughts at retrieval. We thus performed within-group stepwise multiple regressions with encoding SDTs and encoding SITs as predictors, and ratings of thoughts during high confidence old responses at retrieval. Correlations between each predictor variable and the dependent variable, as well as details regarding stepwise regressions can be found in Table 5. In both age groups, the within-group stepwise multiple regressions indicated that proportion of SDTs was positively associated with higher ratings of remembering thoughts at retrieval; SITs did not significantly improve the fit of the regression model in either age group. Note that the specific words about which participants had reported having an SDT at encoding were excluded from these analyses. Thus this analysis does not indicate that when participants reported exhibiting SDTs at encoding, they also reported high ratings for thoughts for these same words at retrieval. Instead, this analysis indicates that the general tendency to exhibit SDTs at encoding was associated with a tendency to give higher rating for thoughts at retrieval, even after removing those specific words for which participants reported exhibiting thoughts about at encoding. We also assessed whether proportion of encoding SDTs and SITs (independent variables) was associated with perceptual details at retrieval (dependent variable). The within-group regression analyses did not reach significance—thus extent of perceptual details was not predicted by proportion of SDTs or SITs in either age group.

Finally, we examined whether proportion of SDTs and SITs at encoding predicted retrieval performance (high confidence hits–false alarms). In young adults, the within-group stepwise multiple regression with SDTs and SITs as predictors and high confidence hits–false alarms as the dependent variable was not significant. In older adults, a reduced model indicated that proportion of SDTs was positively associated with high confidence hits–false alarms; SIT did not significantly improve the fit of this model.

Discussion

In the current study, we assessed age-related differences in frequency and characteristics of SDTs and SITs during an incidental encoding task. There were no between-groups differences in task performance, either in the incidental man-made/natural task (both accuracy and RT), or in old/new retrieval (high-confidence hits–false alarms). Three novel findings emerged from this study. First, although

Table 5
Correlations, and Stepwise Regressions Analyses Predicting Retrieval Thoughts, Perceptual Details and High Confidence Hits–False Alarms Using SDT and SIT as Predictors

	Young adults			Older adults		
		r	p		r	p
Dependent variable: Retrieval thoughts						
Correlations	SDT	.46	.01	SDT	.47	.01
	SIT	−.17	.27	SIT	.01	.94
Stepwise regression	Excluded variable: SIT; $t = 1.07$, $p = .29$			Excluded variable: SIT; $t = .77$, $p = .45$		
	Final model: $F(1, 28) = 7.45$, $p = .01$, adjusted $r^2 = .18$			Final model: $F(1, 26) = 7.25$, $p = .01$, adjusted $r^2 = .19$		
Dependent variable: Retrieval perceptual details						
Correlations	SDT	−.13	.5	SDT	−.23	.23
	SIT	−.13	.51	SIT	.04	.85
Stepwise regression	Regression model n. s.			Regression model n. s.		
Dependent variable: High confidence hits–false alarms						
Correlations	SDT	.12	.52	SDT	.48	.007
	SIT	−.19	.32	SIT	−.08	.69
Stepwise regression	Regression model n. s.			Excluded variable: SIT; t = .549, $p = .587$		
				Final model: $F(1, 28) = 7.25$, $p = .007$, adjusted $r^2 = .205$		

older adults reported exhibiting "no thought" to a greater extent than young adults, they exhibited a reduction in proportion of SITs, but an increase in proportion of SDTs. Second, SDTs and SITs differed in terms of temporal orientation, but not in spontaneity or pleasantness. Third, SDTs at encoding were frequently remembered during the old/new retrieval task, and proportion of SDTs was positively correlated with overall performance on the memory task in older adults. We discuss each of these findings in turn.

We interpret the age-related reduction in SITs observed here as consistent with the reliable finding of reduced mind-wandering in older relative to young adults (Maillet & Schacter, 2016). However, consistent with some prior speculations (Healey et al., 2013; Maillet & Rajah, 2014a), older adults reported an increase in SDTs compared with young adults. Further inspection revealed the age-related increase in SDTs was due specifically to an increase in thoughts triggered by the directly preceding stimulus, rather than thoughts triggered by previously occurring stimuli. Previous studies have revealed that task interest is an important moderator of age-related differences in mind-wandering (Krawietz et al., 2012; Shake et al., 2015). In the current study, task interest was not related to proportion of SDTs or SITs in either age group. However, after controlling for task interest, the Time $\times$ Thought Type interaction indicating that SDTs were more frequent at a short relative to a longer time interval following the offset of the preceding stimulus (and vice versa for SITs) was no longer significant. Thus, while task interest was related to the content of thoughts as a function of intertrial interval length in the current task, it could not account for age-related differences in thought content.

Several other factors could explain why older adults report an increase in SDTs compared with young adults. First, extending predictions of the reduced cognitive resources theory (Craik et al., 1983; Craik, 1986; Craik & Byrd, 1982), it may be that ongoing thoughts in older adults are more dependent on stimuli in the immediate environment, rather than being self-generated. Second, stimuli may be more likely to spontaneously trigger thoughts in older relative to young adults, perhaps because older adults have more life experiences than young adults. Other possibilities are that older adults have more SDTs because they have fewer competing current concerns than young adults (Parks et al., 1988) which may primarily manifest as SITs, or because older adults use SDT as a way to stay on-task during intertrial intervals.

In both age groups, proportion of encoding SDTs, but not of SITs, was positively associated with the extent to which participants reported remembering thoughts (but not perceptual details) at retrieval. This finding may indicate that in both age groups, the words presented at retrieval acted as cues for SDTs experienced at encoding. In addition, in older adults only, we found that frequency of encoding SDTs was positively correlated with later retrieval performance. These findings provide evidence that encoding SDTs are an important feature that older adults may use in memory tasks to decide if a word in old or new (see also Hashtroudi, Johnson, & Chrosniak, 1990). One possibility as to why this correlation was only found in older adults is that the recognition stimuli themselves are a sufficient basis for decision in young adults whereas older adults benefit more from the extra information provided by evoked SDTs.

SDTs and SITs also differed in their temporal orientation: Whereas a higher proportion of SDTs were about the past relative to SITs, a higher proportion of SITs were about the future. Environmental stimuli thus appear to primarily trigger past-oriented thoughts. This may be an important mechanism that helps individuals relate the current environmental situation to similar situations they have encountered in the past, which may in turn help guide appropriate action (e.g., Preston & Eichenbaum, 2013). In contrast, SITs did not have a temporality bias—SITs were equally likely to be about the past and future, and a greater proportion of SITs relative to SDTs were about the future. Compared with SDTs, it is possible that a greater proportion of SITs were triggered by current concerns, which tend to be future-oriented (Cole & Berntsen, 2015; Klinger, 2013).

The temporality of SDTs and SITs was remarkably similar in young and older adults. Few prior studies have examined age-related differences in temporality of thought. Using retrospective questionnaires regarding daydreaming in everyday life, Giambra (2000) found that whereas young adults had more daydreams about the future relative to the past, older adults had more daydreams about the past relative to the future. In contrast, using daily life experience sampling, Gardner and Ascoli (2015) reported that while young adults were equally likely to have past and future-oriented thoughts, older adults were more likely to have future versus past-oriented thoughts. Finally, in an online study involving a sustained attention task, Jackson et al. (2013) reported that a group of "older adults" (mean age between 56 and 57 years) reported a decrease in both past- and future-oriented thoughts relative to atemporal thoughts compared with young adults. To our knowledge, the present study is the first laboratory study to assess temporality of thought in a group of individuals aged 65 and above. We found no age-related differences in temporality of either SDTs and SITs. Taken together, these studies present inconsistent evidence for age-related differences in temporality of thought. Future studies are required to determine if there are precise conditions in which temporality of thought may be altered with age.

We also did not find any age-related differences in spontaneity of thought. In both age groups, a majority of both SDTs and SITs were rated as occurring spontaneously. However, we note that there was a slight trend for SDTs to be more spontaneous than SITs (p = .095). Many participants reported difficulty in determining whether some of their thoughts were spontaneous or deliberate. So far, the distinction between spontaneous/deliberate thoughts has been used in tasks requiring sustained attention (Seli et al., 2015; Shaw & Giambra, 1993). In these tasks, it may be easier for participants to determine whether they were intentionally having thoughts that were unrelated to the task. On the other hand, in the current study, thought probes occurred during intertrial intervals in which there was no specific task to perform—it may have been harder in this scenario to make this distinction. We also did not find age-related differences in pleasantness of SDTs or SITs. In both age groups, thoughts were rated as slightly above neutral valence.

In summary, our results suggest that during incidental encoding, it is important to distinguish between SDTs and SITs. We would like to emphasize that although our study highlights that SDTs at encoding can be beneficial in old/new retrieval tasks in older adults, it is unlikely that this pattern generalizes to all memory tasks. For instance, in source memory tasks (Johnson, Hashtroudi, & Lindsay, 1993), participants are asked to remember in which context a particular encoding stimulus was observed (e.g., was a word seen on the left/right of the screen, in small or large font, in the color blue or the color red, etc.). In such tasks, it is unlikely that SDTs are beneficial. That is, being reminded of a jazz concert one went to when seeing the word "saxophone" may help one to remember that the word "saxophone" is old, but not whether it was seen on the left or right of the screen.

Depending on their specificity, SDTs may be equally unhelpful in a task where encoding stimuli and novel lures at retrieval are very similar to each other. For example, the thought about the saxophone mentioned above may help one to remember that a picture of a saxophone was seen, but may be unhelpful in a memory task involving multiple different pictures of saxophones in which successful retrieval requires remembering very specific perceptual information about the original stimulus (SDTs could even lead to false alarms in such a paradigm). Hashtroudi, Johnson, and Chrosniak (1990) have similarly argued that thoughts and feelings may not be as reliable as perceptual and contextual details and suggested that an overreliance on thoughts and feelings in older relative to young adults may contribute to reduced performance in some memory tasks (see also Maillet & Rajah, 2014a). Finally, we note that our study used a slow design typical of event-related functional MRI studies (one word every 8 s). It is unclear how frequency of SDTs and its relation to performance would be altered in a fast paced study (e.g., one word every 2 s). In such a design, one could imagine that an encoding SDT, while it may benefit retrieval of the word that triggered it, could potentially hurt retrieval of subsequent words in the encoding list if attention is not brought back to the task. Future studies are needed to better understand the conditions under which SDTs may help or be detrimental to performance in memory tasks, particularly in older adults.

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