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Age-related changes in frequency of mind-wandering and task-related interferences during memory encoding and their impact on retrieval

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During the performance of cognitive tasks such as memory encoding, attention can become decoupled from the external environment and instead focused on internal thoughts related to the appraisal of the current task (task-related interferences; TRI), or personal thoughts unrelated to the task at hand (mind-wandering; MW). However, the association between the frequency of these thoughts experienced at encoding and retrieval accuracy in young and older adults remains poorly understood. In this study young and older adults encoded lists of words using one of two encoding tasks: judging whether words are man-made/natural (objective task), or whether they are pleasant/neutral (subjective task). We measured the frequency of TRI and MW at encoding, and related them to retrieval accuracy in both age groups. We found that encoding task influenced the type of internal thoughts experienced by young, but not older, adults: young exhibited greater MW in the subjective vs the objective task, and greater TRI in the objective vs subjective encoding task. Second, across both tasks we found marked age-related decreases in both MW and TRI at encoding, and frequency of these thoughts negatively impacted memory retrieval in young adults only. We discuss these findings in relation to current theories of ageing, attention and memory.

Keywords: Mind-wandering; Task-related interference; Ageing; Memory; Attention.

During the performance of cognitive tasks, attention can become decoupled from the external environment and instead focused on one's internal train of thought (Christoff, 2012; Smallwood & Schooler, 2006). For example, participants may experience interfering thoughts related to the appraisal of the current task, (task-related interferences; TRI), or personal thoughts unrelated to the task at hand (mind-wandering; MW) (Smallwood, Davies, et al., 2004; Smallwood & Schooler, 2006; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011). Examples of the former are thinking about the difficulty or the length of an ongoing cognitive task, and examples of the latter are thinking about personally salient events that happened earlier in the day, or that may occur in the future. When MW and TRI occur during cognitively demanding tasks, they have been associated with reductions in task performance (McVay & Kane, 2010; Smallwood, Davies, et al., 2004; Smallwood & Schooler, 2006; Stawarczyk, Majerus, Maj, et al., 2011). Different

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theoretical accounts have been proposed to explain how such internal thoughts occur and why they negatively impact task performance. According to the resource competition hypothesis, MW reflects the activation of unresolved goals/current concerns and may occur automatically (without executive control) (Smallwood & Schooler, 2006). According to this perspective, the MW episode itself involves cognitive control processes; thus MW may compete with a primary cognitive task for limited cognitive resources (Smallwood, 2010; Smallwood & Schooler, 2006). On the other hand, according to the control-failure hypothesis, MW occurs during cognitive tasks following the failure of inhibitory executive control mechanisms to prevent their occurrence; however, the MW episode itself is conceived as independent of cognitive control processes, instead relying on the default-mode network (McVay & Kane, 2010).

Most studies investigating the relationship between MW frequency and task performance have used attention tasks, such as the sustained attention to response task (SART) (Smallwood & Schooler, 2006; Stawarczyk, Majerus, Maj, et al., 2011). In contrast, relatively little is known about the impact of MW and TRI during memory encoding on retrieval performance. Intuitively one would expect that MW would have a negative effect on memory encoding; most people have had the experience of having their minds drift away from ongoing external events (e.g., a boring lecture) to more ‘‘interesting’’ topics such as planning an event later in the day, which in turn results in poor or no recall of the external events that occurred during this time. A few studies have indeed found a negative association between MW and memory performance in young adults (Seibert & Ellis, 1991; Smallwood, Baracaia, Lowe, & Obonsawin, 2003; Smallwood, O’Connor, Sudberry, & Obonsawin, 2007; Smallwood, Obsonsawin, et al., 2003). For example, in one study three groups of participants received happy, neutral, or sad mood inductions, and then performed a memory recall task for letters (Seibert & Ellis, 1991). Following retrieval, participants were asked to list all the thoughts that they had had during the task. The happy and sad groups produced more task-unrelated thoughts relative to the neutral group, and the proportion of these thoughts was negatively related to recall performance in all three groups. On the other hand, to our knowledge no study has assessed the impact of TRI on memory performance.

In the current study we were interested in determining whether different encoding tasks might differentially affect the rates of MW and TRI during memory encoding, and whether the frequency of these thoughts may in turn negatively impact memory retrieval. A well-replicated phenomenon in the memory literature is that encoding tasks which encourage participants to attend to the semantic meaning of stimuli (‘‘deep’’ encoding) result in better memory for these stimuli relative to more ‘‘shallow’’ encoding tasks which instruct participants to attend to perceptual features (Craik, 1972, 2002). For example, commonly used semantic encoding tasks include making man-made/natural or living/non-living judgements on word or object stimuli. More recently it has been demonstrated that self-referential/subjective encoding tasks, such as judging whether adjectives are descriptive of oneself, or judging whether words are pleasant/neutral, also result in especially high performance on memory tasks (Rogers, Kuiper, & Kirker, 1977; Symons & Johnson, 1997). This mnemonic benefit is thought to result from elaboration and organisation of the encoding material through one’s self schema (Symons & Johnson, 1997).

We hypothesised that semantic and subjective/self-referential encoding tasks might differentially affect frequency of MW and TRI. The Seibert and Ellis (1991) study described above demonstrated that pre-task conditions that bias participants towards themselves can increase rates of MW in a subsequent memory task. In this study we investigated whether the nature of the encoding task itself could modulate frequency of MW during the same task. Specifically, we hypothesised that participants would exhibit greater MW in a subjective (pleasant/neutral) vs an objective/semantic (man-made/natural) encoding task. On the other hand, it has been demonstrated that when an error is detected during task performance, participants may exhibit thoughts related to self-evaluation and performance (i.e., TRI), such as thinking about one’s ability or the difficulty of the task (Smallwood, Davies, et al., 2004). Since semantic judgements are objective (i.e., have a right and a wrong answer), we hypothesised that they might result in an increased frequency of TRI relative to a subjective encoding judgement. In addition we measured reaction times for the pleasantness and man-made/natural judgements to verify whether time on task could account for these differences in thought content. Finally we hypothesised that the frequency of internal thoughts during encoding would be negatively correlated with memory performance in young adults.

MIND-WANDERING AND TASK-RELATED INTERFERENCES IN OLDER ADULTS DURING MEMORY ENCODING

To our knowledge no study has assessed age-related changes in the frequency of MW and TRI during memory encoding tasks. Healthy ageing is associated with a reduction in episodic memory (Craik, 1991; Craik & Salthouse, 2000). It has been hypothesised that part of older adults' memory deficits might be due to a reduction in inhibitory control (Clapp & Gazzaley, 2012; Hasher & Zacks, 1988). For example, according to the inhibition deficit theory of ageing, older adults are less able than young adults to prevent irrelevant information from entering working memory (Hasher & Zacks, 1988). This results in increased attention being paid to information irrelevant to the current goal, to the detriment of goal-related information. This "mental clutter" is thought to be detrimental to encoding since less attention is focused on the relevant information to be encoded (Hasher & Zacks, 1988). Similarly it has been proposed that during working memory maintenance older adults are more susceptible to interference caused by both external (e.g., radio playing) and internal factors (e.g., MW) (Clapp & Gazzaley, 2012). Such accounts would predict an age-related increase in MW and/or TRI during memory encoding, due a reduction in the ability to inhibit these thoughts, a result which would support the control failure hypothesis of MW (McVay & Kane, 2010).

However, another account of age-related deficits in memory tasks is that older adults have diminished attentional *resources* (Craik, 1983). For example, studies have shown that dividing the attention of young participants at encoding (and thereby reducing their available resources) results in similar deficits to those observed in older adults (Rabinowitz & Craik, 1982). Furthermore it has been demonstrated that age differences in memory tasks are reduced when a supportive environment which decreases attentional demands is provided (e.g., specific instructions to use a strategy) (Glisky, Rubin, & Davidson, 2001; Naveh-Benjamin, Brav, & Levy, 2007). Thus, if older adults have fewer attentional resources than young adults, they may use up more of these resources to perform a given task compared to young adults (Anderson, Craik, & Naveh-Benjamin, 1998), and have fewer resources available for MW, which would be consistent with the resource competition framework of MW (Smallwood, 2010; Smallwood & Schooler, 2006). Consistent with this view, age-related decreases in MW have been reported during vigilance, attention, and reading tasks (Giambra, 1989; Jackson & Balota, 2012; Krawietz, Tamplin, & Radvansky, 2012).

Thus in the current study we were interested in contrasting the predictions made by inhibition deficit vs the reduced attentional resources theories of ageing and memory. Specifically, we assessed how the nature of the encoding task would modulate thought content in older adults, and whether they would display an increase or a decrease in MW/TRI compared to young adults. First, we predicted that similarly to young adults, we would observe (1) greater MW in the subjective vs the objective task, due to this task biasing the participants' attention towards themselves, and (2) greater TRI in the objective vs the subjective task in older adults, due to this task having a performance-related component. Second, based on previous findings of an age-related decrease in MW during attention and reading tasks (Giambra, 1989; Jackson & Balota, 2012; Krawietz et al., 2012), we predicted that older adults would display a reduction in MW compared to young adults during memory encoding. On the other hand, we predicted that TRI might exhibit either no age-related change, or less of a reduction than MW. This is based on the common finding that older adults worry about their memory, and that negative attitudes and stereotypes may have a negative impact on their memory (Hess, Hinson, & Hodges, 2009; Levy, 1996; McDaniel, Einstein, & Jacoby, 2008). We reasoned that this might result in a shift of internal thought content during memory tasks away from MW to TRI in older adults (e.g., thinking about the difficulty of the task or about one's ability).

METHOD

Participants

A total of 31 young adults (age range: 18–32, mean: 22.6, 22 women) and 26 older adults (age range: 60–76, mean: 64.30, 15 women) participated in the study. One additional older adult was excluded because of a score of 21 on the Montreal Cognitive Assessment (MOCA; Nasreddine et al., 2005). All participants were French–English bilingual and reported no history of neurological or psychiatric disorders. The groups did not differ in education level (young mean: 15.19, $SD = 2.48$; old mean: 14.90, $SD = 2.56$; $p = .891$). The mean score on the mini mental status examination (MMSE; Folstein, Folstein, & McHugh, 1975) in older adults was 29.4 ($SD = 1.06$), and all of them scored 25 or higher. All participants had a score of 24 or higher on the MOCA, and there were no significant between-group difference in score on this test (young mean: 28, $SD = 1.77$; old mean: 27.08, $SD = 1.96$; $p = .067$).

Stimuli

The stimuli used in this experiment were 366 French nouns of 3–11 letters, taken from Desrochers and Thompson (2009) and the OMNILEX database (http://www.omnilex.uottawa.ca/scrServices.asp). The experiment was carried out in French, given that Montreal is a primarily French-speaking city. The words were split into four lists: two encoding lists of 122 words each, and two lists of 61 words each used as distractors at retrieval. Words in all lists were matched for frequency and imageability ratings. Half of the words in all lists represented man-made objects (e.g., pencil, computer, car), and the other half were natural (e.g., cat, apple, rose).

Procedure

The experiment consisted of three phases: encoding, thought questionnaire, and retrieval. Participants went through each phase twice. Thus the order of tasks was: encoding 1, thought questionnaire 1, retrieval 1, encoding 2, thought questionnaire 2, retrieval 2. At encoding participants saw 122 words, presented one at a time for 1.5 seconds each. Words at encoding and retrieval were separated by a variable inter-trial interval (2.2, 3.4, or 5 seconds; mean 3 seconds) during which a central cross was presented. In one encoding phase participants were asked to judge whether each word was pleasant/neutral (subjective task), and in the other they were asked whether words were man-made/natural (objective task), and instructed to give their answer by pressing one of two buttons. Participants were told that a memory test would follow: therefore encoding was intentional. The order of encoding tasks was counterbalanced across participants. Immediately following each encoding phase, participants answered 15 questions taken from the thinking content section of the Dundee Stress Test questionnaire (Matthews et al., 1999) (translated into French). This questionnaire has been used by previous studies to assess MW and TRI retrospectively during a task (Barron, Riby, Greer, & Smallwood, 2011; Smallwood, O'Connor, & Heim, 2005; Smallwood, O'Connor, Sudberry, Haskell, & Ballantyne, 2004). Eight of these questions measured frequency of MW, while seven measured frequency of TRI. Each question appeared on the screen for 10 seconds, and participants were asked to rate the frequency to which they experienced each thought during the encoding phase on a 1 to 5 scale (1 = never, 2 = once, 3 = a few times, 4 = often, 5 = very often). The mean score for each question in young and older adults is presented in Table 1.

The retrieval phase started immediately following the administration of the thought questionnaire (approximately 3 minutes following encoding). Participants were presented with 183 words, one at a time, for 2.75 seconds each. Participants saw all 122 words they had seen at encoding plus 61 new words. They were asked to determine whether each word was old (previously seen at encoding) or new, as well as their confidence level, by pressing one of four buttons: 1 = Definitely old, 2 = Probably old, 3 = Definitely new, or 4 = Probably new (Dennis, Kim, & Cabeza, 2008; Duverne, Motamedinia, & Rugg, 2009). In the rest of this paper "Definitely new" and "Definitely Old" responses are referred to as high-confidence responses, while "Probably new" and "Probably old" responses are referred to as low-confidence responses. At the end of the experiment we administered a debriefing questionnaire, in which we asked participants to rate how difficult and interesting they thought the memory tasks were on a 1 to 10 scale.

Data analysis

Within-group outliers for MW, TRI, and retrieval Pr were identified by using a Z score cut-off of $\pm$ 3, separately for each task. Outliers on any of these three variables were excluded from all analyses on the corresponding task. For completeness we also calculated data point outliers

TABLE 1
Score on questionnaire for mind-wandering and task interferences, with standard deviation in parentheses

		Young adults		*Older adults*	
	Question	*Subjective encoding*	*Objective encoding*	*Subjective encoding*	*Objective encoding*
Mind-wandering	I thought about members of my family	2.36	1.77	1.58	1.80
	I thought about something that made me feel guilty	1.90	1.57	1.20	1.19
	I thought about personal worries	2.00	1.97	1.16	1.30
	I thought about something that made me feel angry	1.30	1.16	1.04	1.11
	I thought about something that happened earlier today	1.87	1.83	1.32	1.23
	I thought about something that happened in the recent past	1.83	1.83	1.16	1.24
	I thought about something that happened in the distant past	2.70	1.81	1.08	1.19
	I thought about something that might happen in the future	2.45	2.02	1.12	1.23
	Average Mind-wandering	2.05 (0.64)	1.79 (0.69)	1.21 (0.22)	1.29 (0.40)
Task interferences	I thought about how I should work more carefully	2.31	2.82	1.88	1.88
	I thought about how much time was left in the task	2.87	3.03	1.96	2.03
	I thought about how others have done on this task	1.40	1.73	1.36	1.46
	I thought about the difficulty of the task	2.03	2.41	1.76	2.00
	I thought about my level of ability	2.13	2.59	1.92	2.04
	I thought about the purpose of the experiment	1.87	2.21	1.64	1.65
	I thought about how I would feel if I were told how I performed	1.47	1.78	1.26	1.38
	Average task interference	2.00 (0.53)	2.36 (0.57)	1.68 (0.53)	1.78 (0.53)

across tasks for MW and TI (i.e., two values per participant), and between-group outliers. The Shapiro–Wilk test of normality was run on MW, TRI, and retrieval Pr scores for words encoded using the objective and subjective encoding tasks. A significant result ($p < .05$ corrected for 12 multiple comparisons) was taken as evidence of a non-normal distribution.

Between-group differences in response rate for the encoding, retrieval, and thought questionnaire phases were each assessed using two-way Age group by task mixed ANOVAs. The frequency of MW during encoding was assessed by averaging the score given on the eight questions measuring MW, separately for each task. The frequency of TRI during encoding was assessed by averaging the score given on the seven questions measuring TRI, separately for each task. A three-way Age group (young/old) by Thought type (MW/TRI) by Task (objective/subjective) mixed ANOVA was used to assess between-group differences in thought frequency at encoding. We used gender as a covariate in this analysis since our sample in both age groups included more women than men. Note that the frequency of MW vs TRI within a task in a single age group was not of interest in the current study, since this relies on the peculiarities of the questionnaire. Therefore only between-group differences in MW and TRI, as well as within-group differences in thought frequency between tasks, were of interest. A two-way Age group by task mixed ANOVA was used to assess between-group differences in encoding reaction time (RT). We used a significance threshold of $p < .05$ for all ANOVAs. When significant interactions emerged, we performed post-hoc tests corrected for multiple comparisons using a Bonferroni correction.

Retrieval performance was assessed using the index Pr (% of hits −% of false alarms). We calculated Pr separately for high-confidence retrieval judgements (Pr-H) and for low-confidence retrieval judgements (Pr-L). Between-group differences in retrieval Pr and retrieval RT were each assessed by conducting a two-way Age group (young/old) by Task (objective/subjective) mixed

ANOVA with post-hoc T-tests. Stepwise multiple regressions were used to assess the relationship between retrieval Pr (dependent variable) and MW and TRI (independent variables), separately for each task and age group.

RESULTS

Data from two young participants were unavailable for the objective task due to computer malfunction. One young participant was identified as having a TRI score 3.22 standard deviations higher than other young adults on the subjective task. The same young participant was also identified as a between-group outlier, and a data point outlier. Thus this participant was excluded from all analyses involving the subjective task. One older adult was identified as having a MW score 4.16 standard deviations higher than other older adults on the subjective task. This participant was not a between-group outlier, given young adults' higher MW rates. Still, since multiple regressions were done within group, we excluded this participant from all analyses involving the subjective task. Finally, one older participant was identified as a between-group outlier on Pr-H in the objective task ($z = 3.01$). However, since this participant was not a within-group outlier ($z = 2.65$), we included him in all analyses (note that his exclusion would not have impacted the significance of the group by task mixed ANOVA on Pr scores, the ANOVAs on encoding data, or the multiple regressions). Thus all statistical analyses were based on a sample of 30 young and 25 older adults in the subjective task, and 29 young and 26 older adults in the objective task. The Shapiro–Wilk test was significant for MW in both the subjective ($p < .001$) and the objective ($p < .001$) tasks in older adults, indicating that the MW scores were not normally distributed in this group. This caveat is addressed in a later section. The Shapiro-Wilk test did not reach significance ($p < .004$) for TRI or Pr-H in older adults, or for any variable in young adults.

Encoding results

Young adults responded to 99% ($SD = 1\%$) of trials in both the subjective and objective encoding tasks. Older adults responded to 98.42% ($SD = 1\%$) of trials in the subjective task and 98.99% ($SD = 1\%$) in the objective task. A two-way age group by task mixed ANOVA revealed there was no main effect of task, $F(1, 53) = 0.811$, $p = .372$, or age group by task interaction, $F(1, 53) = 1.571$, $p = .551$), but there was a group main effect, $F(1, 53) = 4.94$, $p = .03$, on response rates. Encoding RT results are listed in Table 2. A two-by-two mixed ANOVA revealed no significant main effects for group, $F(1, 51) = 0.951$, $p = .334$, or task, $F(1, 51) = 0.205$, $p = .653$, and no significant group by task interaction, $F(1, 51) = 0.310$, $p = .580$, in RT. Accuracy in the man-made/natural (objective) encoding was high in both groups (Young: 93.87%, $SD = 0.033$; Old: 94%, $SD = 0.039$; $p = .884$).

TABLE 2
Mean reaction time (RT), in milliseconds with standard deviation in parentheses

Behavioral Measure	*Young adults*		*Older adults*	
	Subjective task	*Objective task*	*Subjective task*	*Objective task*
Encoding RT	1249 (221)	1214 (235)	1184 (142)	1192 (187)
Retrieval RT	1457 (270)	1603 (197)	1574 (242)	1708 (276)

Young adults responded to 29.75 ($SD = 0.65$) questions of the Dundee Stress Test assessing frequency of MW and TRI, while older adults responded to 29.16 questions ($SD = 1.25$) (out of 30). This age difference reached significance, $T(1, 51) = 2.196$, $p = .033$). Mean RT for responses to the Dundee Stress Test questions was significantly faster in young adults (mean = 3902 ms, $SD = 509$) compared to older adults (mean = 4320 ms, $SD = 848$), $T(1, 51) = 2.199$, $p = .032$, although both groups responded well within the time limit for each question (10,000 ms).

A three-way Group by Task by Thought type mixed ANOVA revealed a main effect of group, $F(1, 51) = 29.636$, $p < .001$, a Task by Thought type interaction, $F(1, 51) = 11.425$, $p = .001$, and a third level interaction, $F(1, 51) = 11.558$, $p = .001$. These effects remained significant when gender, encoding RT, or retrieval RT was included as a covariate. The main effect of group was due to young adults exhibiting a significantly greater amount of internal thoughts compared to older adults overall. The third level interaction was due to a significant second level Task by Thought type interaction in young, $F(1, 27) = 20.197$, $p < .001$, but not in older adults ($p = .988$). In young adults this second level interaction was due to young adults exhibiting more MW during the subjective vs the objective task, $T(27) = 3.40$, $p = .002$, but more TRI during the objective versus the subjective task, $T(27) = 2.60$, $p = .015$. These effects were significant after correction for two multiple comparisons ($p < .025$). On the other hand, in older adults there was no main effect of task, $F(1, 24) = 1.696$, $p = .205$, or task by thought type interaction $p = .988$).

Previous studies have indicated that differences in task interest and task difficulty may account for age-related differences in MW frequency between young and older adults (Jackson & Balota, 2012; Krawietz et al., 2012). In the current study young and older adults rated the memory tasks as being equally difficult (young mean = 5.09, $SD = 1.81$; old mean; 5.26, $SD = 2.69$; $p = .788$). However, older adults rated the memory tasks as being significantly more interesting than did young adults (young mean = 5.29, $SD = 1.94$; old mean; 8.17, $SD = 1.49$; $p < .001$). Thus we ran an analysis of covariance (ANCOVA) to determine if the Age group main effect remained significant after accounting for task interest. This analysis revealed that although task interest accounted for some of the variance, the age difference in internal thoughts remained highly significant, $F(1, 48) = 16.291$, $p < .001$.

Given that internal thought frequency was assessed retrospectively following the encoding session (which lasted about 9.15 minutes) another possible explanation for the age-related reduction in MW/TRI frequency is that older adults failed to recall that they experienced these thoughts. To assess this possibility we examined age-related changes in MW/TRI frequency using only a subset of high-performing older adults. It has been demonstrated that a subset of the ageing population shows either no reduction or a very small reduction in memory compared to young adults (for a recent review, see Nyberg, Lovden, Riklund, Lindenberger, & Backman, 2012). In the current study we defined high-performing older adults as those performing within one standard deviation (SD) of the mean Pr-H of young adults in *both* retrieval tasks. A total of 10 older adults had a Pr-H within 1 SD of young adult's mean in the subjective task, and 9 older adults reached this criterion in the objective task. Of these, seven older adults performed within 1 SD in both the objective and subjective tasks; only these seven older adults were defined as high-performing. A two-way Group by task ANOVA on Pr-H scores confirmed that these high-performers scored as well as young adults in both retrieval tasks; there was no group main effect, $F(1, 33) = 0.909$, $p = .347$, or group by task interaction, $F(1, 33) = 0.629$, $p = .433$. Next we conducted a Group by Task by Thought type mixed ANOVA using this sub-sample of older adults and the full young adult sample. Similar to the ANOVA with the full older adult sample, a highly significant group main effect emerged, $F(1, 33) = 12.874$, $p = .001$, and there was also a Task by Thought type interaction, $F(1, 33) = 4.18$, $p = .049$, and a marginally significant Group by Task by Thought Type interaction, $F(1,33) = 3.092$, $p = .088$. In summary, high-performing older adults performed the memory tasks as well as young adults, but still exhibited reduced frequency of MW and TRI; thus it is unlikely that impaired retrieval can account for the age-related reduction in thought frequency that we observed in the full sample.

Retrieval results

Young adults responded to 99.8% ($SD = 1\%$) of the retrieval trials in the subjective task, and 97.3% ($SD = 2.7\%$) of the trials in the objective task. Older adults responded to 98.5% ($SD = 3\%$) of the trials in the subjective task and 99.2% ($SD = 1\%$) of the trials in the objective. A two-way age group by task mixed ANOVA revealed that there was no main effect of task, $F(1, 51) = 3.469$, $p = .068$, or age group, $F(1, 51) = 0.421$, $p = .519$, on response rates. However, there was a group by task interaction, $F(1, 51) = 10.655$, $p = .02$, due to young adults responding more often in the subjective task compared to the objective tasks, $T(1, 27) = 3.519$, $p = .002$, but older adults responding equally often in both tasks, $T(1, 24) = 1.04$, $p = .309$.

Retrieval RT are presented in Table 2. A two-way age group by task mixed ANOVA on RT revealed a significant effect of task, $F(1, 51) = 47.008$, $p < .001$, due to both groups responding faster in the subjective versus the objective task. There was also a main effect of age group, due to young adults responding faster overall, $F(1, 51) = 4.434$, $p = .04$. There was no group by task interaction, $F(1, 51) = 0.596$, $p = .444$.

The percentage of hits and false alarms for confident and non-confident responses in young and older adults are presented in Table 3. Retrieval Pr is also presented in this table. Pr-L was near 0 in both groups, indicating that low-confidence responses likely reflected guessing. Therefore assessment of retrieval performance

TABLE 3
Percentage of hits and false alarms for high and-low confidence responses with standard deviation in parentheses

	Young adults		*Older adults*	
Retrieval response	*Subjective task*	*Objective task*	*Subjective task*	*Objective task*
High confidence Hits	0.88 (0.08)	0.80 (0.11)	0.82 (0.11)	0.68 (0.14)
High confidence False alarms	0.06 (0.07)	0.11 (0.08)	0.16 (0.14)	0.17 (0.11)
High Confidence Pr	0.83 (0.10)	0.69 (0.12)	0.65 (0.17)	0.51 (0.15)
Low-confidence hits	0.04 (0.03)	0.07 (0.05)	0.04 (0.05)	0.07 (0.09)
Low-confidence false alarms	0.07 (0.06)	0.1 (0.08)	0.04 (0.06)	0.05 (0.06)
Low-confidence Pr	−0.03 (0.07)	−0.03 (0.08)	−0.01 (0.04)	0.02 (0.06)

focused only on high confidence (Pr-H) responses. A two-way age group by task mixed ANOVA on Pr-H responses revealed a significant main effect of task, $F(1, 51) = 62.066$, $p < .001$, due to both age groups performing better in the subjective versus the objective encoding task. There was also a main effect of group, $F(1, 51) = 32.146$, $p < .001$, due to young performing better than older adults overall. There was no group by task interaction, $F(1, 51) = 0.042$, $p = .839$.

Relationship between thought frequency at encoding and retrieval Pr-H

Younger adults' results. In young adults, in the retrieval task for subjectively encoded stimuli, the correlation between Pr-H and TRI was −0.34 ($p = .065$), and the correlation between Pr-H and MW was −0.46 ($p = .01$). We conducted stepwise multiple regression to assess the effect of MW and TRI at encoding on retrieval Pr-H. The multiple regression analysis revealed that a reduced model with only MW provided the best fit for predicting Pr-H for subjectively encoded stimuli, $F(1, 29) = 7.613$, $p = .01$ (Adjusted R-square = 0.186). The addition of TRI did not significantly improve the fit of the model, T = 1.0110, $p = .321$. Figure 1a presents the regression results for the subjective task.

In the retrieval task for objectively encoded stimuli the correlation between Pr-H and TRI was −0.374 ($p = .046$), and the correlation between Pr-H and MW was −0.008 ($p = .966$). The step-wise multiple regression revealed that a model with only TRI provided the best fit for predicting Pr-H for objectively encoded stimuli, $F(1, 27) = 4.381$, $p = .046$ (Adjusted R-square = 0.108). Figure 1b presents the regression results for the objective task.

Older adults' results. In older adults, during the retrieval task for subjectively encoded stimuli, the correlation between Pr-H and TRI was −0.05 ($p = .810$), and the correlation between Pr-H and MW was −0.162 ($p = .438$). The multiple regression analysis did not identify a significant model for predicting Pr-H in the subjective task. During the retrieval task for objectively encoded stimuli, the correlation between Pr-H and TRI was 0.08

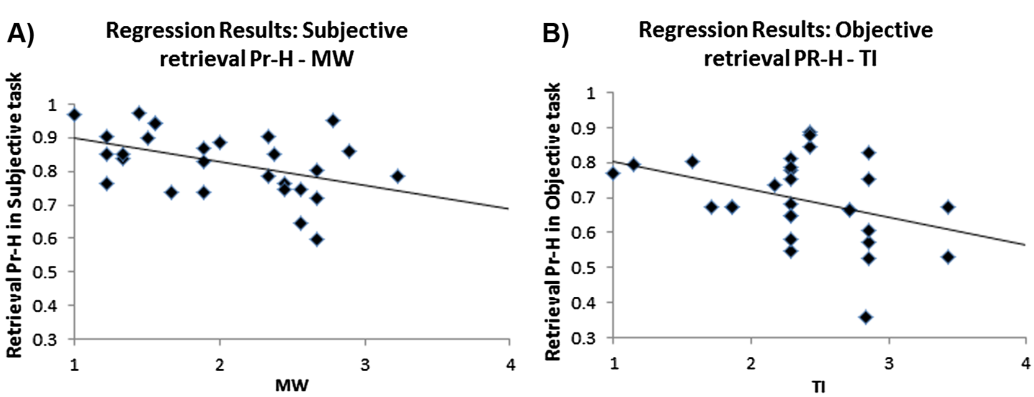

Figure 1. Regression results in young adults. A) This figure depicts a scatter-plot of subjective retrieval Pr-H (Y-axis) against mind wandering (MW; x-axis). The linear regression line is presented in black. B) This figure depicts a scatter-plot of objective retrieval Pr-H (Y-axis) against task-related interferences (TRI; x-axis). The linear regression line is presented in black.

($p = .696$) and the correlation between Pr-H and MW was 0.16 ($p = .445$). The multiple regression did not identify a significant model for predicting Pr-H in the objective task. However, as previously mentioned, the Shapiro–Wilk test was significant for MW in both the subjective ($p < .001$) and the objective ($p < .001$) tasks in older adults, indicating that the MW scores were not normally distributed. In the subjective tasks 9 older adults did not report MW, and in the objective task 12 older adults did not report any MW. Thus the lack of a relationship between MW and retrieval Pr in older adults may be due to a floor effect.

To address this issue we separated older adults into those who reported no MW versus those who reported at least one instance of MW (Smallwood, Baracaia, et al., 2003). Next we performed an independent sample *T*-test to assess whether those older adults reporting MW performed worse than those reporting no MW. In the subjective task 9 older adults reported no MW, and 16 older adults reported at least one instance of MW. There was no significant difference between the two groups in retrieval Pr-H (mean MW group = 0.67, $SD = 0.14$; mean non-MW group = 0.64, $SD = 0.18$; $p = .68$). In the objective task 12 older adults reported no MW and 14 reported at least one instance of MW. There was no significant difference between the two groups in retrieval Pr (mean MW group = 0.55, $SD = 0.13$; mean non-MW group = 0.48, $SD = 0.18$; $p = .27$). Thus, if anything, older adults reporting MW performed slightly better than those reporting no MW in this task.

DISCUSSION

The purpose of this experiment was to assess the frequency of MW and TRI during objective and subjective encoding tasks, and the impact of these thoughts on subsequent memory retrieval in young and older adults. First, we found that encoding task influenced the type of thought experienced by young, but not older, adults. Young adults exhibited greater TRI in the objective vs subjective encoding task, and exhibited greater MW in the subjective vs the objective task. Second, across both tasks we found a marked age-related decrease in both types of thoughts. There were no age- or task-related differences in RT at encoding, indicating that these difference in thought frequency emerged even if the two groups performed similarly in the encoding tasks. Third, we found that frequency of internal thoughts at encoding negatively impacted memory retrieval in young adults only. We first discuss the results in young adults, and next consider age-related changes in these relationships.

Young adults: Encoding task influences the content of ongoing thoughts

In the current study retrieval performance in young adults was greater when words had been encoded using a subjective versus an objective orienting task. These results are consistent with many other studies which have found that encoding stimuli using a subjective pleasantness judgement results in better memory retrieval compared to other semantic or perceptual judgements (Grady, Bernstein, Beig, & Siegenthaler, 2002; Leshikar & Duarte, 2012; Schott et al., 2011). Neuroimaging studies have demonstrated that this mnemonic benefit is mediated by increased activation in the medial prefrontal cortex (Leshikar & Duarte, 2012; Maillet & Rajah, 2011; Shrager, Kirwan, & Squire, 2008). Activation in this region during successful encoding has also been observed during self-referential encoding tasks, such as judging whether adjectives are descriptive of oneself (Macrae, Moran, Heatherton, Banfield, & Kelley, 2004). Relating material to oneself is thought to be an effective encoding mechanism due to the superior elaborative and organisational properties associated with the concept of self (Rogers et al., 1977; Symons & Johnson, 1997). Thus it is likely that performing a pleasantness judgement results in better memory relative to objective semantic encoding tasks because making such a subjective judgement involves greater elaboration and organisation of the encoding material through one's self schema (Leshikar & Duarte, 2012).

Studies in the MW literature have demonstrated that conditions that bias participants' attention towards themselves, such as mood induction or attention to personal goals increase rates of MW (Seibert & Ellis, 1991; Smallwood et al., 2011; Stawarczyk, Majerus, Maj, et al., 2011). In the current study we examined whether the nature of the encoding task itself (subjective versus objective) could modulate thought content in the same task. We found that this was indeed the case; young adults exhibited increased MW during the subjective versus the objective task. Thus it is possible that making pleasantness judgements, while being an effective way to encode information, also renders participants more prone to having personally salient thoughts about their past or their future. Furthermore, frequency of MW at encoding was negatively correlated with retrieval performance in the subjective task only, indicating that this increase in MW negatively affects memory. Thus, participants performing at a higher level in the subjective task may be those who are able to successfully encode words using the pleasantness judgement, without falling prey to MW that such a judgement can trigger. For example, rating the word "banana" as pleasant at encoding may trigger an internal thought that one should go to the supermarket following the experiment. While such a scenario likely results in effective memory for the word "banana", it is likely that the subsequent word may not be properly encoded if the participant's attention is not re-focused on the task. It will be important for future studies, particularly those using neuroimaging techniques, to examine the exact mechanisms by which MW at encoding negatively affects memory performance.

On the other hand, young adults exhibited greater TRI in the objective task versus the subjective task. The objective task, in contrast to the subjective one, had a right and a wrong answer (i.e., each word was either man-made or natural). Although the man-made/natural judgement is a relatively easy task, accuracy results for this encoding task show that errors were nevertheless frequent (average of eight per participant). Thus, given that there were a greater number of errors in the objective vs subjective *encoding task* and that *retrieval* performance was lower in the objective vs subjective task, one might argue that the objective encoding task was more difficult than the subjective encoding task. It is likely that this performance component accounts for the increase in TRI and the decrease in MW in this task. It has been suggested that when an error is detected, participants may exhibit thoughts related to self-evaluation and performance, such as thinking about one's ability or the difficulty of the task (Smallwood, Davies, et al., 2004). In addition, frequency of TRI during the objective task was negatively correlated with subsequent high confidence retrieval judgements indicating that they have a detrimental effect on stimulus encoding. These results are consistent with previous studies that have found that higher levels of TRI are associated with worse performance during cognitive tasks (Coy, O'Brien, Tabaczynski, Northern, & Carels, 2011; Smallwood, Davies, et al., 2004). For example, in one study (Smallwood, Davies, et al., 2004) young adults performed a SART task, and subsequently answered a questionnaire measuring MW and TRI. Participants were divided into low- and high-TRI groups and the high TRI group committed significantly more errors on the SART compared to the low-TRI group.

Orienting tasks at encoding such as the pleasantness judgement and the man-made/natural judgement used in the current experiment are ubiquitously used in behavioural and neuroimaging literatures of episodic memory (for reviews, see Craik, 2002; Kim, 2011; Symons & Johnson, 1997). Taken together, our results indicate that such orienting tasks affect the type of internal thoughts experienced by young adults. Furthermore, this modulation of internal thoughts is behaviourally meaningful, as demonstrated by negative associations with retrieval performance.

Older adults: Reduction in frequency of MW and TRI at encoding

Similar to the results obtained in young adults, older adults exhibited greater retrieval performance for words previously encoded using a subjective versus objective orienting task. As discussed above, this mnemonic benefit is thought to arise from the superior elaborative and organisational properties associated with using one's self schema during memory encoding. Our results are consistent with recent studies that have found that the self-referential effect in memory is preserved in older adults (Dulas, Newsome, & Duarte, 2011; Glisky & Marquine, 2009; Gutchess, Kensinger, & Schacter, 2010; Gutchess, Kensinger, Yoon, & Schacter, 2007; Hamami, Serbun, & Gutchess, 2011). For example, in one study (Hamami et al., 2011), older adults remembered adjectives better when they had been encoded in a self-encoding condition, versus commonness and lower/upper case encoding conditions.

One of the main goals of this study was to determine whether older adults exhibit an increase or a decrease in MW and TRI compared to young adults during memory encoding, and whether age differences in frequency of internal thoughts can account for retrieval deficits in older age. According to the inhibition deficit theory older adults are less able than young to prevent irrelevant information from entering working memory (Hasher & Zacks, 1988). Thus this theory predicts an age-related increase in internal thoughts during memory encoding which may result in a mental clutter detrimental to memory formation. On the other hand, it has been suggested that older adults exhibit reduced attentional resources at encoding (Craik, 1983); thus an alternate possibility is that older adults spend more of their resources than young adults on the encoding task, and have less resources available for MW or TRI (Smallwood & Schooler, 2006). Our results are more consistent with the latter possibility; we observed a marked age-related decrease in MW and TRI across both tasks. Furthermore, the encoding task did not modulate the frequency or type of internal thought in older adults, and frequency of MW/TRI did not correlate with retrieval performance. Note that these results are not necessarily inconsistent with the inhibition deficit theory; if older adults do not have the necessary resources available to generate internal sequences of thought during encoding, then there is no nothing to (fail to) inhibit.

Our hypothesis that the age-related decrease in MW may be replaced by TRI in older adults was not supported. Thus TRI may rely on similar cognitive/neural resources as MW, and both may be reduced in ageing during the performance of cognitively demanding tasks. For example, a recent neuroimaging study found that both TRI and MW are mediated by medial regions of the default-mode network, such as medial prefrontal cortex and posterior cingulate cortex (Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011). In addition, numerous studies have demonstrated age-related changes in default-mode network during memory encoding (Duverne et al., 2009; Duzel, Schutze, Yonelinas, & Heinze, 2011; Grady, Springer, Hongwanishkul, McIntosh, & Winocur, 2006; Leshikar, Gutchess, Hebrank, Sutton, & Park, 2010; Miller et al., 2008). Age-related changes in default-mode network may thus represent a common neural mechanism by which both TRI and MW are similarly reduced in older adults.

A limitation of the current study and of our interpretation that there is an age-related decrease in internal thoughts at encoding is that we assessed internal thoughts using a retrospective questionnaire, rather than directly probing participants for their thoughts during task performance. The main advantage of using a retrospective questionnaire is that task performance is uninterrupted; furthermore, constantly probing participants about their internal thoughts may cause them to monitor their thoughts to a greater extent (Smallwood & Schooler, 2006). Using a retrospective questionnaire also allowed us to easily compare MW and TRI rates. However, using a retrospective questionnaire also had disadvantages. First, using this method, we were unable to determine when during the encoding task MW/TRI occurred. Second, given that ageing is associated with reductions in memory retrieval, one explanation for the current findings is that older adults were less able to recall the nature of their internal thoughts compared to young adults. However, two results provide evidence against this interpretation. First, if this was the case, one would expect a *positive* relationship between MW/TRI and retrieval Pr-H, such that those adults with better memory also remember more instances of MW/TRI—this was not the case. Second, rates of MW/TRI were similarly reduced in a sub-group of high-performing older adults that performed the retrieval task as well as young adults. Finally, a recent neuroimaging study measured frequency of internal thoughts while participants were at rest, using a retrospective questionnaire (Mevel et al., 2012). This study reported no age-related differences in internal thought frequency; these results are consistent with our interpretation that reduced internal thought frequency in our study is due to reduced attentional resources during encoding, rather than due to the retrospective method of assessing MW.

Another possibility is that older adults might have been thinking about things that were not covered by the questionnaire (e.g., external distractions). Although we cannot exclude this possibility, our results are best considered along with findings from other studies using the SART or reading paradigms (Jackson & Balota, 2012; Krawietz et al., 2012). In these studies age-related changes in internal thoughts were assessed using the thought probe method; participants were randomly interrupted during task performance and asked whether they had been having thoughts unrelated to the task when they had been interrupted. The thought probe method eliminates reliance on memory, allows the localisation of internal thoughts to a particular point in a task, and is also more open-ended; participants can report any type of thought they had been experiencing. Using this method these studies have also reported an age-related decrease in internal thoughts during the SART and reading tasks (Jackson & Balota, 2012; Krawietz et al., 2012). Taken together, our results and those of others suggest that older adults exhibit a reduction in MW and TRI compared to young in different cognitive tasks, and when different thought sampling procedures are used.

Recent studies have highlighted the importance of considering task interest when examining age differences in MW frequency (Jackson & Balota, 2012; Krawietz et al., 2012). If older adults are more engaged in a task, they may be less likely to exhibit MW. For example, Jackson and colleagues (2012) reported that older adults found the SART to be more interesting than young adults, and task interest negatively correlated with self-reported MW frequency. Krawietz et al. (2012) reported that older adults exhibited less MW compared to young adults during text comprehension, but this age difference became non-significant when controlling for text interest. Consistent with these studies, in the current study older adults rated the memory tasks are significantly more interesting than young adults. However, age differences in MW and TRI frequency remained significant after accounting for this variable. Thus it is unlikely that task interest can fully account for the age-related decrease in internal thoughts observed during memory encoding. Rather, our results are more consistent with the view that the age-related decreases in MW and TRI are due to reduced attentional resources.

Conclusion

To summarise, our study revealed two key results. First, in young adults the orienting task affects the frequency and type of internal thoughts experienced; young exhibited more MW in the pleasantness task, and more TRI in the man-made/natural task. This modulation of internal thoughts is behaviourally relevant, as indexed by negative correlations between thought frequency and retrieval performance in both tasks. Second, older adults exhibit a marked reduction in the frequency of both MW and TRI at encoding. These results are most consistent with an account that memory encoding requires more resources in old versus young adults, leaving fewer resources available for the generation of internal thought.

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