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The Natural Frequency of Human Prospective Memory Increases With Age

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Autobiographical memory (AM), the recollection of past experiences, and prospective memory (PM), the prospection of future events, are prominent components of subjective life, yet data on the frequencies of their occurrence are limited. Using experience sampling, we quantified the incidence of AM and PM in natural settings among various age groups. Individuals of all ages reported engaging in AM approximately 10% of the time. In contrast, whereas younger subjects recalled PMs as often as they recalled AMs, older subjects experienced PM twice as frequently. AM occurrence was positively correlated with PM occurrence, most strongly among younger individuals. AM and PM durations were also positively correlated and remarkably stable across age groups. Together, these data identify an age-associated shift in the temporal orientation of recollection and quantify the relationship between AM and PM. More broadly, this approach provides a quantitative foundation of AM and PM occurrence, a crucial yet largely unexplored dimension of recollection.

Keywords: autobiographical memory, future-oriented thought, prospective memory, episodic memory, experience sampling

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Adults readily engage in thoughts associated with the past as well as thoughts associated with the future. Recollection of personally experienced episodes, *autobiographical memory* (AM), and prospection of to-be-experienced events, *prospective memory* (PM), together enable an individual to cohesively recount his or her life story and effectively plan and deliberate. Despite a recent surge of research into these temporally distinct cognitive phenomena (e.g., see Berntsen & Rubin, 2012), empirical data of their naturalistic occurrence are scarce. Nonetheless, this knowledge is necessary to address basic yet long-standing questions about the temporality of episodic thought. Among typical adults, are some individuals more likely to ruminate on past events whereas others are more likely to imagine future experiences? Do older individuals spend more time reminiscing about their past at the expense of prospecting their future? Is there an age-associated shift in the temporal orientation of recollection?

The importance of these data is further emphasized by several studies that identify retrieval frequency as a meaningful dimension of memory. Self-reported measures of the occurrence of AM retrieval positively correlate with measures of retrieved content (Ritchie, Skowronski, Walker, & Wood, 2006; Walker, Skowronski, Gibbons, Vogl, & Ritchie, 2009). Likewise, experimental manipulations to enhance AM rehearsal increase a memory's perceived vividness and its associated detail (Nadel, Campbell, & Ryan, 2007; Svoboda & Levine, 2009). Frequent reminiscence may also moderate an age-related loss of memory content (Cohen, 1998), an age effect that can result in serious consequences (see, e.g., Cohen & Faulkner, 1989; Johnson, 1997). The frequency of PM recall is thought essential for effective planning. For example, without the aid of external reminders, the recall occurrence of a future intention is directly associated with remembering its execution (Kvavilashvili & Fisher, 2007). Moreover, imagining episodic detail associated with a future task can enhance resulting performance (Altgassen et al., 2014).

Naturalistic measurement of the occurrence of prospective recall may also clarify the prospective memory and aging paradox (e.g., Rendell & Craik, 2000). The paradox refers to a robust finding of age differences in completion rates of prospective memory tasks (i.e., remembering to perform an action within a specified temporal interval) depending on the context in which a given task is implemented; performance among younger adults is typically superior to that among older adults for tasks carried out in laboratory settings, whereas performance is superior among older adults for tasks carried out in naturalistic settings. Although questions of the mechanisms underlying this phenomenon remain open, certain explanatory factors have been proposed, including age- and setting-dependent changes in the frequency of thought related to the selected intention.

Previous studies measuring the incidence of subjective thoughts and experiences have typically used diary-based (Linton, 1986; Wagenaar, 1986) or experience-sampling techniques (Brewer, 1988; Csikszentmihalyi & Larson, 1987; Csikszentmihalyi, Lar-

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son, & Prescott, 1977; also see Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004). Both methods ask participants to record and annotate the occurrence of targeted experiences and are well-suited for use in natural settings. Diary entries are prompted by participants, demanding ongoing introspection, whereas experience sampling randomly prompts participants to evaluate the presence of a targeted experience solely at those prompted moments.

The current study, adapting prior experience sampling designs (Gardner, Vogel, Mainetti, & Ascoli, 2012), relied on mobile telephony for prompting participants (18 to 75 years old: $N = 106$) at random moments in their natural settings to document upon introspection if they were experiencing an AM or PM. If a call interrupted a memory, participants recorded its estimated duration. The proportion of sampled moments coinciding with a memory provides direct estimation of the amount of time engaged in AM and PM. Together, data of recall probability and duration permit calculation of recall frequency.

This approach differs in several ways from previous studies that quantified the naturalistic occurrence of mental states associated with past and future temporal periods. We adopted the classical definition of AM as recollection of temporally specific, personally experienced past episodes. Although PM, as defined here (the recollection of to-be-experienced future episodes), overlaps considerably with the recall or rehearsal of planned tasks (Kvavilashvili & Fisher, 2007; McDaniel & Einstein, 2007), it broadly encompasses the concept of future-oriented episodic thought (e.g., Addis, Wong, & Schacter, 2008; Addis, Musicaro, Pan, & Schacter, 2010; Atance & O'Neill, 2001; see Method section). We further emphasize that the current work measures the occurrence of these PM thoughts, which differs from studies that measured execution rates of specified intentions (or the number of distinct intentions); here, a thought of a particular future action or event was counted as a PM independent of the eventual occurrence of the episode.

Moreover, rather than probing general thoughts (Cameron, Desai, Bahador, & Dremel, 1977; Cameron, 1972; D'Argembeau, Renaud, & Van der Linden, 2011), including factual information (or recalled events not experienced first-hand), the current work sampled event-based recollections, which appear to be affected differently by aging (e.g., Addis et al., 2008; Addis et al., 2010; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). We also emphasized to participants to solely introspect and tally the specific mental state at the moment of a given prompt. This differs from previous studies asking participants to report the most recent stream of thoughts (e.g., Klinger & Cox, 1987), which may comprise many divergent mental states associated with more than one temporal period. Thus, our data should estimate more selectively the proportion of time engaged in recall of past and future experiences. Inclusion of memory duration estimates allows us to compute recall frequencies, enabling quantitative analysis of two distinct characteristics of memory occurrence: recall probability and rate.

In addition, previous studies have typically focused on college-aged subjects or experiences of a single temporal direction (D'Argembeau et al., 2011; Gardner et al., 2012; Klinger & Cox, 1987; Kvavilashvili & Fisher, 2007; Mace, 2004; Rasmussen & Berntsen, 2011; Schlagman, Kliegel, Schulz, & Kvavilashvili, 2009; Schlagman & Kvavilashvili, 2008). Important and novel aspects of the current work are the inclusion of subjects that represent a substantial portion of the adult life span and the focus on both AM and PM as targeted cognitive phenomena within the same study. This design enables direct comparison of AM and PM occurrence within and across younger and older subjects. Altogether, the current work characterizes the occurrence of AM and PM across the life span, providing a quantitative base of previously uncharted dimensions of human recollection.

Method

Experience Sampling

Participants ($N = 106$; age in years: 18–75, $M = 34.7$, $SD = 18.4$; 75% female) were enrolled in the experience sampling experiment from the George Mason University (GMU) student body (58%), faculty and staff (25%), and from the Northern Virginia community (17%). Within the community, recruitment advertisements were posted in local newspapers and at lifelong learning institutes. Undergraduates completed the study for course credit. All participants reported to be in good health without memory impairment, to live independently, and to own and regularly use a mobile telephone.

This experiment relied on mobile telephony for prompting participants at random moments during their normal daily activities to document, upon introspection, whether they were experiencing an AM or a PM at the time of a given call (Gardner et al., 2012). During an initial meeting with a researcher, participants were instructed verbally on the meaning of AM and PM with the aid of script hand-outs (included in the online supplemental materials). *AM* was defined as the recollection of an episode from the personal past specific to a particular time and place, for example, remembering your first job interview. The events recalled were emphasized to be contained in duration (less than 3 hr) to ensure their temporal specificity. *PM* was defined as the recollection of a task or event that is to occur in the personal future, for example, bringing to mind an intention to stop at the grocery store on your way home from work. More generally, PM could include first-person perspective thinking of future actions or events, for example, imagining the route you are going to take to arrive at the store. Before ending the initial meeting, participants were asked to apply these general classifications to various exemplar scenarios to ensure an understanding of the material. For PM classification, we did not place importance on the distinction between thoughts related to the formation of an intention, those related to the recollection of an intention, and musings of possible future events (whether it was the first time the event was called to mind or it was a repeatedly retrieved episode). Each participant provided demographic information and his or her mobile phone number to receive random prompt calls across days of participation.

A custom automatic-dialing program that used a stochastic-calling algorithm was designed for use with a computer modem to initiate the calls. The total number and temporal window of daily calls were predetermined by each participant to optimize their reception and minimize disruption of expected sleep patterns or other inappropriate time periods (e.g., classes). To avoid excessive customization, participants could only select continuous calling windows, which could differ only between weekdays and weekends. The precise timing of any given call was unknown to the participants, who were encouraged to assign the incoming number a distinct ringtone to identify each call more quickly; alternatively, caller ID was used.

Altogether, participants received calls (*M* = 219, *SD* = 96; range: 54–439) over the course of, on average, 19 days (*SD* = 7; range: 7–46) during their typical daily activities (between 6 a.m. and 12 a.m.). Each time prompted, participants were instructed to evaluate the concurrence of that call with an AM or PM. It was emphasized that participants evaluate only the ongoing mental state at that precise moment (i.e., the thought actually interrupted by the call), as opposed to thoughts preceding, elicited, or otherwise subsequent to the prompt. If participants detected the occurrence of AM or PM, they documented the specific type and its estimated duration in a pocket-sized data booklet provided at the initial meeting. Alternatively, a mark was recorded to indicate the absence of a memory at the time of that particular call. To facilitate classification decisions of sampled moments, the definitions and selected examples of AM and PM provided during the initial meeting were appended to the back of each data booklet. Duration estimations were subjective and instructed to be between 1 and 60 s. This restriction was applied to facilitate estimation of a unique episodic thought as opposed to a series of thoughts. On the occasion that a memory was perceived to be longer than 60 s, participants were asked to estimate the recall duration of the most recent unique event that composed the thought. All protocols were approved by the GMU Human Subject Review Board. Informed consent was obtained prior to participation.

The probability of recollection was calculated separately for each participant using Jeffreys' point estimate of probability (Jeffreys, 1961). This procedure was implemented to better estimate extreme outcomes while providing relatively small adjustments to the commonly used maximum likelihood point estimate. Specifically, the probability of recollection (PR) was estimated as $PR = (x + 0.5)/(n + 1)$, where x is the number of prompts that coincided with a memory and n is the total number of prompts received. The mean duration of recollection (DR) was calculated by doubling the mean time estimation for a given participant, assuming that, on average, the midpoint of a memory was interrupted by a prompt. The number of memories (NM) in a given temporal period (TP) was calculated for each participant as $NM_{TP} = PR \times TP/DR$, where TP/DR represents the total number of possible memories experienced in a temporal period. Taking the product of this value and the probability of recollection ($PR \times TP/DR$) captures the number of memories experienced in a specified temporal window, for example, memories per hour (MpH). It is important to note that because memory durations are based on participant estimations, recall durations and rates reported here are in terms of subjective (perceived) time. As such, the equation to calculate recall rates assumes that, for any one individual, the mean difference between actual and perceived memory durations does not appreciably vary according to memory type. The equation further assumes that, on average, any systematic difference between the actual and perceived duration of memories is similar to that found in other mental states. Although such assumptions have yet to be tested, the results presented here provide verifiable hypotheses on the subjective rate of AM and PM recall.

All participants recorded at least one memory over the course of sampling. However, 4 participants (3.8% of total) did not report both an AM and a PM. Thus, for these participants, duration estimates were not provided for both memory types. On such occasions, given the robust correlation between AM and PM duration (see Results section), the hourly recall rate for the memory type with an absent duration was calculated by using the mean recall duration of the other memory type from that individual, adjusted on the basis of the linear fit between AM and PM in the aggregate data. When applicable, this same procedure was used to assess recall rates across sampling intervals (i.e., within and across days of participation; see Table S1 in the online supplemental materials). None of the conclusions or statistical significance of the results changed by including or excluding these computed data points.

Participant measures of recall probability, duration and hourly rate greater than three times the interquartile range (IQR) above the 75th percentile or less than three times the IQR below the 25th percentile were considered outliers and excluded from analysis. To account for potential changes in recall across the life span, this procedure was applied separately to distinct age intervals: 18–19 (n = 28), 20–29 (n = 33), 30–39 (n = 10), 40–49 (n = 7), 50–59 (n = 10), and 60–75 (n = 18) years of age. Data from 2 participants were excluded for PM probability (and consequently PM MpH; 1.8% of total), from 5 participants for AM MpH (4.7% of total), and from 3 participants for PM MpH (2.8% of total). Two participants did not provide duration estimates of either memory type restricting their inclusion to probability analysis.

Regression analysis was used to statistically test the effect of age on each measure of recall. Subsequently, age effects were further explored using the six age groups as described to identify outliers. Such division revealed an increase in the probability of PM recall among participants 50–59 (*M* = 18%, *SD* = 12%, *Mdn* = 15%, Cohen's d = 0.77) and 60–75 (*M* = 22%, *SD* = 18%, *Mdn* = 14%, d = 0.89) years old compared with participants in younger age groups (*M* = 10%, *SD* = 6%, *Mdn* = 9%). Measures of AM recall probability and duration, and PM duration were not meaningfully altered across age groups (data not shown). Thus, to describe the magnitude of age effects on recall, participants were divided into two age ranges (18–49 years old: *M* = 24.4, *SD* = 9.1, 73% female, n = 78; and 50–75 years old: *M* = 61.7, *SD* = 6.7, 79% female, n = 28).

The younger group comprised students enrolled at GMU (n = 61), GMU faculty and staff (n = 13), and individuals recruited from the local community (n = 4). The older group comprised GMU faculty and staff (n = 13), individuals enrolled in local lifelong learning institutes (n = 10), and those recruited from the local community (n = 5); 6 participants were retired or unemployed. It is important to note that all age effects reported here were unchanged when accounting for variation in these sampling pools. For instance, when comparing separately measures of recall across matched sampling pools (i.e., comparing younger and older GMU faculty and staff, and younger and older subjects recruited using local advertisements), older subjects showed an approximately twofold increase in the proportion of time engaged in PM (similar age effects to that found overall), whereas engagement in AM was equivalent. Although not from the same sampling pool, the same conclusions were reached when comparing data from younger students (enrolled at GMU) with those from older students (enrolled at lifelong learning institutes). Moreover, work status (currently working, unemployed or retired) was not associated with recall ($p > .10$). Together, these findings suggest that our results are not confounded by unintended or uncontrolled differences across participant pools.

Group sample sizes (younger age group: $n = 78$; older age group: $n = 28$) were reasoned to be sufficient on the basis of 100 random samplings of 28 younger participants, which produced comparable measures of recall probability (AM: $M = 10.1\%$, 95% CI [9.9%,10.3%]; PM: $M = 10.3\%$, 95% CI [10.2%,10.5%]), duration (AM: $M = 32.1$s, 95% CI [31.6s,32.6s]; PM: $M = 27.5$s, 95% CI [26.9s,27.9s]), and rate (AM MpH: $M = 13.4$, 95% CI [13.0,13.8]; PM MpH: $M = 16.9$, 95% CI [16.5,17.2]) to those reflecting recall across all younger participants (see Figure 1). In particular, upon comparison of each of the 100 samplings to the overall data, we found that between 0% and 2% ($M = 0.8\%$) were statistically different, depending on memory type and recall dimension (*M* Cohen's *d*: AM probability = 0.13, PM probability = 0.12, AM duration = 0.11, PM duration = 0.14, AM MpH = 0.13, PM MpH = 0.11). This analysis is not definitive for recall probability, given the difference in variability between younger (AM coefficient of variation [CV] = 0.63; PM CV = 0.59) and older (AM CV = 0.88; PM CV = 0.76) participants. However, the consistency of the probability of AM recall across all ages, paired with the magnitude of the effect of age on the probability of PM recall ($d = 0.87$; see Results) and the difference between AM and PM recall probability within older individuals ($d = 1.00$), more than overcomes any underestimation of the sufficient number of older participants.

Altogether, these factors supported the decision to terminate data collection for inclusion in the current work made subsequent to regularly performed data analysis, which invariably yielded equivalent conclusions based on relative group comparisons to those reported here. Moreover, we emphasize that the reliability of within-subject assessment is also ensured by the large numbers of recorded probes and days of participation per individual. In comparison, for example, using a similar sampling procedure, Klinger & Cox (1987) reported an average of 49 probes per participant, which is approximately three times less than the mean number of prompts recorded in our older age group.

Younger and older participants received calls over an equivalent number of days (younger: $M = 18$, $SD = 6$; older: $M = 21$, $SD = 9$). In addition, although younger subjects typically elected to receive calls slightly later in the day, the temporal window of daily prompts was quite similar across groups. On average, younger subjects received daily calls from 11:30 a.m. until 9 p.m., whereas older subjects received calls from 10:15 a.m. until 7:45 p.m. In contrast, older participants generally elected to receive a fewer number of total calls (younger: $M = 247$, $SD = 89$; older: $M = 142$, $SD = 68$). However, there was not a significant relationship between these sampling variables (e.g., total days of participation, duration of daily calling window, total calls received, and calls received per day) and measures of recall in either age group (see Results; also see Table S1 in the online supplemental materials). Thus, although age-associated variation in the sampling schedule is present, it does not confound the findings of this work.

Questionnaire

A separate sample of 98 college-aged individuals (18–36 years old: $M = 21.0$, $SD = 4.0$; 60% female) was enrolled from the GMU student body. No participants reported memory impairment. Participants provided self-reported estimates of memory recall to assess whether measures collected using experience sampling were expected and reproducible by questionnaire. Participants were instructed on AM and PM classifications using the same procedure as described for experience sampling. Subsequently, participants were given a questionnaire that collected estimations of the proportion of time engaged in AM and PM, and typical recall durations and hourly rates (the text of the questions is provided in the online supplemental materials). In addition to collecting direct estimates of typical hourly recall rates, we also derived these values from the recall probabilities and durations reported in the same questionnaire (*derived memories per hour* [dMpH]) by using the same computation as described for the experience sampling data. All protocols were approved by the GMU Human Subject Review Board. Informed consent was obtained prior to participation.

Values greater than three times the IQR above the 75th percentile or less than three times the IQR below the 25th percentile for a given variable were considered outliers and excluded from data analysis. This resulted in removal of data from 3 participants for PM duration (and consequently PM dMpH; 3.1% of total), from 3 participants for AM MpH (3.1% of total), from 6 participants for AM dMpH (6.1% of total), and from an additional 2 participants for PM dMpH (2.0% of total). The remaining data were compared with those collected from the younger experience sampling age group (*M* age in years = 24.4, $SD = 9.1$, 73% female); results were equivalent when using a more precisely age-matched experience sampling population (18–36 range; data not reported).

Statistical Procedures

Bivariate regression was performed to evaluate correlation between measures of recall and participant age, and between AM and PM. Fisher's *z* transformation was applied to correlation coefficients for between-groups comparisons. Independent and paired samples *t* tests were conducted to assess differences between AM and PM recall within and across age groups, and across genders, sampling intervals, and collection methods. In cases of non-normal distributions, the Mann–Whitney *U* test and the Wilcoxon's sign-ranked test were applied. Cohen's *d* was calculated to estimate effect size for each group comparison. Statistical significance was interpreted by using the criterion of $p < .05$. Statistically significant correlations were corroborated by using data resampling procedures (Bishara & Hittner, 2012). False discovery rate correction was applied to control for spurious findings due to multiple comparisons (Benjamini & Hochberg, 1995). Statistical analyses were run with SPSS (IBM), Excel (Microsoft), and R (Dalgaard, 2008).

Results

The Naturalistic Occurrence of Prospective Memory Increases With Age

Each participant received on average 220 prompts over the course of 3 weeks (see Method section). Overall, participants experienced either an AM or a PM approximately 23% of the time (see Table 1; see also Figure S1 in the online supplemental materials). Moreover, participant age was correlated with the occurrence probability of PM recall ($r = .40$, $p < .001$) but not

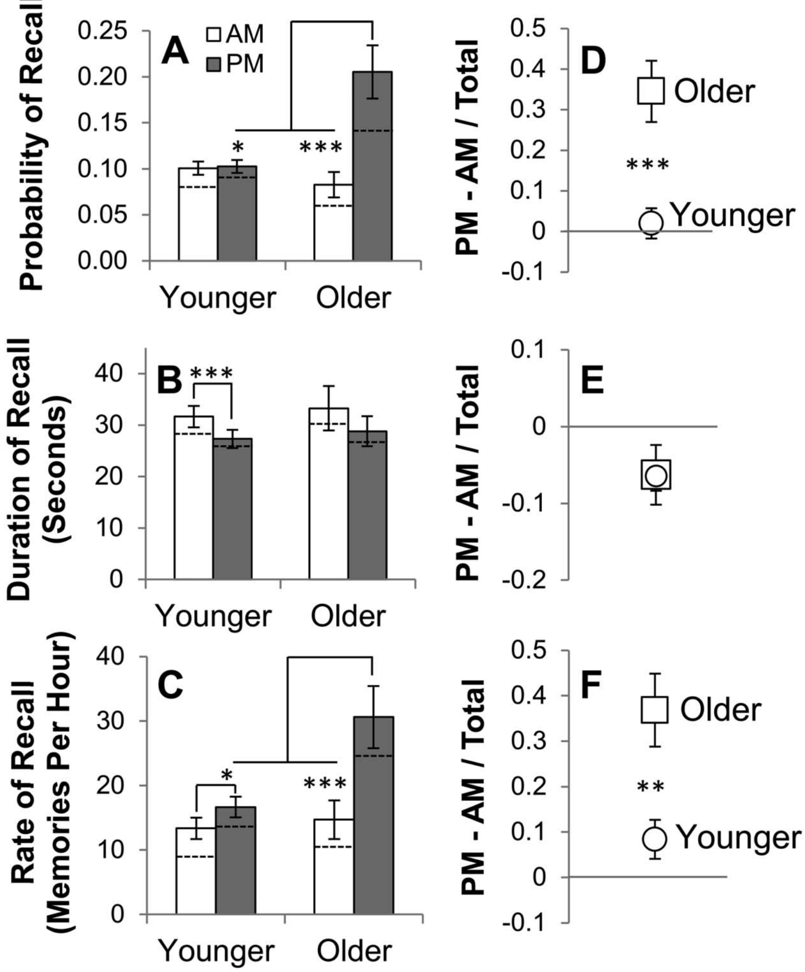

Figure 1. The probability and rate of prospection is increased in older adults. Panel A: Although the probability of autobiographical memory (AM) recall was equivalent to the probability of prospective memory (PM) recall in younger participants (age in years: M = 24, SD = 9), the probability of PM recall was enhanced in older participants (age in years: M = 62, SD = 7). Panel B: AMs were estimated to last slightly longer than PMs, showing no effects of age. Panel C: In general, the hourly rate of PM recall was higher than the rate of AM recall. However, this effect was strongest in the older age group, which experienced significantly more PMs. Panels D-F: These findings are further documented by the intrasubject difference between PM and AM recall. Data in all panels are presented as $M \pm SEM$. Dashed lines indicate median values. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$. For younger participants, AM probability: n = 78, PM probability: n = 76, AM duration: n = 77, PM duration: n = 76, AM memories per hour (MpH): n = 72, PM MpH: n = 73. For older participants, AM probability: n = 28, PM probability: n = 28, AM duration: n = 24, PM duration: n = 27, AM MpH: n = 27, PM MpH: n = 26.

of AM recall (r = −.11, $p > .10$). To further evaluate changes in recall across the life span, participants were separated into six age groups: 18–19 (n = 28), 20–29 (n = 33), 30–39 (n = 10), 40–49 (n = 7), 50–59 (n = 10), and 60–75 (n = 18) years of age. On the basis of this division, we observed an increase in the probability of PM recall among the 50–59 (M = 18%, SD = 12%, Mdn = 15%, d = 0.77) and 60–75 year old participants (M = 22%, SD = 18%, Mdn = 14%, d = 0.89) compared with that among younger individuals (M = 10%, SD = 6%, Mdn = 9%), whereas measures of AM recall probability and memory durations did not meaningfully differ across ages. Thus, for subsequent description of the magnitude of age effects on recall, participants were separated into two age groups: younger (M age in years = 24, SD = 9, range: 18–49, n = 78) and older (M age in years = 62, SD = 7, range: 50–75, n = 28; see Method section). Younger participants engaged in AM and PM equally often (~10% of the time; see Figure 1A). In contrast, older participants were more than twice as likely to experience a PM at the time of a prompt (M = 21%, Mdn = 14%), both when compared with younger participants ($p < .05$, d = 0.87) and relative to the likelihood of experiencing an AM ($p < .001$, d = 1.00; see Figure 1A).

Each memory, on average, was perceived to have started 15 s prior to a prompt, corresponding to an estimated subjective

Table 1
Naturalistic Measurements of Recall Probability, Recall Duration (in s), and Memories per Hour (MpH)[a]

Statistic	Total (AM and PM)			AM			PM		
	Probability	Duration	MpH	Probability	Duration	MpH	Probability	Duration	MpH
M	0.23	29.62	32.94	0.10	32.03	13.70	0.13	27.70	20.29
SD	0.14	16.33	27.02	0.07	18.86	14.40	0.11	15.38	18.25
Mdn	0.19	26.72	27.81	0.08	28.89	8.92	0.10	26.27	15.27
IQR	0.15	24.83	21.01	0.10	28.01	9.59	0.09	21.25	16.57
n	104	104	96	106	101	99	104	103	99

Note. The mean, standard deviation, median, and interquartile range (IQR) of autobiographical memory (AM) and prospective memory (PM) recall probability, duration, and rate displayed here are from data collapsed across all ages.
[a] For distributions of each recall dimension, see Figure S1 in the online supplemental material to this article.

duration of approximately 30 s (see Table 1 and Figure S1 in the online supplemental materials). Although recall durations were stable across age groups, the duration of AMs was mildly increased relative to PMs (younger group: $p < .001$, $d = 0.26$; older group: $p = .05$, $d = 0.24$; see Figure 1B). The within-subject mean and standard deviation of memory duration were positively correlated across all ages (AM: $r = .81$, $p < .001$; PM: $r = .71$, $p < .001$) yielding a stable CV (younger group: AM = 0.57, PM = 0.62; older group: AM = 0.57, PM = 0.66). Additionally, recall probability and duration were largely independent measures, as suggested by weak correlations across memory types and age groups (younger AM: $R^2 = 0.08$, PM: $R^2 = 0.04$; older AM: $R^2 = 0.01$, PM: $R^2 = 10^{-6}$). Measures of recall probability and duration permitted estimation of the number of memories experienced in a given temporal period (see Method section). The number of PMs, but not AMs, experienced per hour (MpH) was positively correlated with participant age (PM: $r = .40$, $p < .001$; AM: $r = .13$, $p > .10$). During any one subjective hour, younger subjects experienced slightly more PMs ($M = 16.6$, $Mdn = 13.9$) than AMs ($M = 13.3$, $Mdn = 8.9$; $p < .05$, $d = 0.24$; see Figure 1C). Older subjects displayed an equivalent rate of AMs ($p > .10$), but their hourly rate of PM recall was considerably higher ($M = 30.6$, $Mdn = 24.6$; $p < .05$, $d = 0.70$). In particular, one PM was estimated to occur approximately every 4 min in younger participants compared with one PM every 2 min in older participants. Analyzing the relative differences between AM and PM on an individual basis also revealed these same age effects on recall (see Figure 1D–1F).

Recollection Is Stable Across a Variety of Conditions

Although considerable inter- and intra-subject variability was observed for all measures (see Table 1 and Figure S1 in the online supplemental materials), recall occurrence and duration were stable between genders ($p > .10$; see Table S1 in the online supplemental materials). Moreover, results were equivalent when measures were computed separately for the first and second half of sampled moments, either within a given day ($p > .10$) or across the length of participation ($p > .10$); similarly, there were no significant differences between weekdays and weekends ($p > .10$). In addition, neither the number of daily calls, nor the duration of the daily calling window affected recall measures in younger or older individuals ($p > .10$).

Measures of AM Are Positively Correlated With Measures of PM; A Relationship Selectively Altered With Age

As AM and PM were sampled within the same subject, we further assessed how these cognitive phenomena covary (see Figure 2). Notably, measures of AM were strongly and positively correlated with measures of PM (probability: $r = .58$, $p < .001$; duration: $r = .85$, $p < .001$; MpH: $r = .57$, $p < .001$) in the young to midlife participants. Moreover, the statistical significance of these results was unaltered when removing potential leverage points, as is shown in Figure 2C. The positive correlation between AM and PM duration was fully conserved in older participants ($r = .85$, $p < .001$; see Figure 2E). In contrast, the relationship between AM and PM occurrence appeared to be altered in the older group; although between-groups comparisons of correlation coefficients did not reveal statistically significant differences ($p > .10$), we noted a substantial age-related decrement in the variance explained by the correlation between memory types (older group, probability: $p = .06$, $R^2 = 0.14$, MpH: $p > .10$, $R^2 = 0.08$; younger group, probability: $R^2 = 0.34$, MpH: $R^2 = 0.32$; see Figure 2).

The Appearance of "Too High" Hourly Recall Rates Is Consistent With Bias Detected by Self-Reports

On first inspection, we, and the participants who requested their results, found the MpH rates computed from experience sampling measurements surprisingly high. To investigate this observation more extensively, we collected estimated assessments of recollection by questionnaire from a nonoverlapping sample of young adults (M age in years = 21, SD = 4, range: 18–36, n = 98). The goal was to determine the extent to which each of the experience sampling measures could be expected by intuitive introspection. Questionnaire estimates of the proportion of time engaged in AM and PM were equivalent to those measured with experience sampling ($p > .10$). In contrast, estimated values of memory durations were significantly lower: about two thirds of those reported during normal life ($p < .001$, $d = 0.56$; see Figure S2 in the online supplemental materials).

Together, these questionnaire estimates of recall probability and duration allow computation of a dMpH (see Method section). Whereas the autobiographical dMpH ($M = 20.2$, $Mdn = 10$) was slightly elevated compared to that observed naturalistically ($p >$

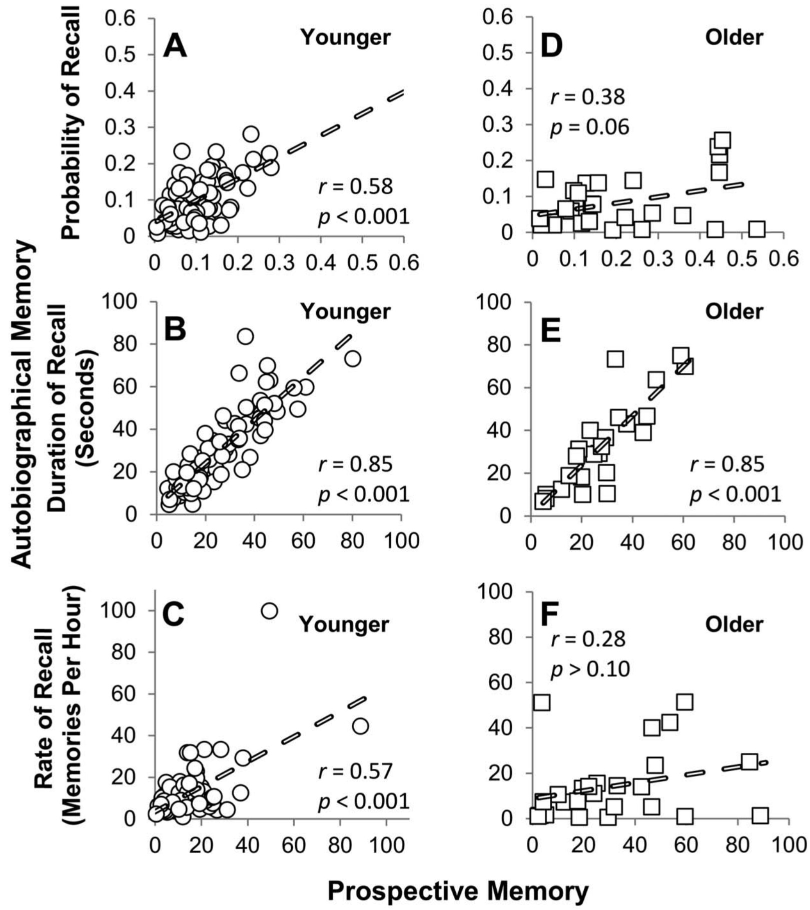

Figure 2. Measures of autobiographical recollection are positively correlated with measures of prospective recollection. Autobiographical memory (AM) and prospective memory (PM) recall probabilities (Panel A), durations (Panel B), and hourly rates (Panel C) were strongly and positively correlated in younger subjects (*M* age in years = 24, *SD* = 9). In older participants (*M* age in years = 62, *SD* = 7), whereas a similar correspondence was observed between AM and PM duration (Panel E), a relatively small amount of variation was explained by the correlation between AM and PM recall probability (Panel D) and by the correlation between AM and PM recall rate (Panel F). Dashed lines indicate best linear fits. For younger participants, probability: $n = 76$, duration: $n = 76$, memories per hour (MpH): $n = 70$. For older participants, probability: $n = 28$, duration: $n = 24$, MpH: $n = 26$.

.10, $d = 0.37$), the prospective dMpH ($M = 36.0$, $Mdn = 24$) was more than twofold greater ($p < .01$, $d = 0.66$). In striking contrast, when gauging MpH directly, the same questionnaire participants estimated that they typically experience 3.7 ($Mdn = 2$) AMs and 5.4 ($Mdn = 4$) PMs each hour. These values are approximately 31% of those observed by experience sampling (AM: $p < .001$, $d = 0.94$; PM: $p < .001$, $d = 1.08$), and approximately 16% of the dMpH values computed (for the same participants) from questionnaire estimates of recall probability and duration (AM: $p < .001$, $d = 1.04$; PM: $p < .001$, $d = 1.09$). Questionnaire estimates of AM recall were positively correlated with estimates of PM recall (probability: $r = .53$, $p < .001$; duration: $r = .45$, $p < .001$; MpH: $r = .37$, $p < .001$; dMpH: $r = .36$, $p < .01$). Altogether, given the consistency of questionnaire estimates and naturalistic observations of recall probability and inconsistency of rate estimates, it is plausible that MpH values are underestimated by intuitive assessment. The striking incongruence between self-reported recall probability, duration, and rate may reveal the quantitative extent of this underlying cognitive bias.

Discussion

This research used experience sampling to measure the probability of AM and PM recall in younger (*M* age in years = 24, *SD* = 9) and older (*M* age in years = 62, *SD* = 7) participants. Additionally, we collected real-time subjective estimations of memory durations. Together, these measures permitted computation of recall rates. In this work, AM refers to recollection of temporally specific, personally experienced past episodes; PM refers to recollection of to-be-experienced episodes, which includes first-person perspective thinking of future actions or events (Atance & O'Neill, 2001). Thus, the resulting data provide a quantitative account, based on naturalistic measurements, of the everyday occurrence of past- and future-oriented episodic recollection among younger and older adults.

Younger participants engaged in AM and PM equally often (10% of the time). This result is consistent with prior studies showing equivalent proportions of general thoughts associated with past and future temporal periods (Klinger & Cox, 1987; however, also see Cameron et al., 1977). Extending this finding, we showed that, as the duration of a typical AM was slightly longer than that of a typical PM, the mean PM recall rate (~17/hr) was greater than the mean AM recall rate (~13/hr), in younger participants. Although these observed recall rates appear high, as corroborated by comparison with self-reports, self-reported recall probabilities were equivalent to those observed naturalistically. Taken together with questionnaire-based estimates of memory duration that were lower than those collected in real-time, we revealed a drastic internal incongruity between direct self-reports of recall rates (MpH) and recall rates derived from recall probability and duration estimates in the same questionnaire (dMpH). Altogether, these findings demonstrate the unreliability of intuitive assessment of recall occurrence that potentially explains why the naturalistic rate observations appear surprisingly high.

Naturalistic measures of AM occurrence were strongly and positively correlated with measures of PM occurrence. Thus, although it might be expected that some people are generally more future-planning whereas others are more past-mulling, these data, on average, do not support this notion. Rather, they suggest that, in general, some individuals experience more of both AM and PM, whereas others spend less time engaging in memories in both temporal directions. This result is consistent with the hypothesis that past and future episodic thought cooperate, for example, to support planning and decision making, at least in younger adults.

Although the probability of AM recall in older participants was equivalent to that in younger participants, older individuals engaged in PM twice as frequently (~21% of the time). Moreover, although AM recall occurrence was a good indicator of PM recall occurrence (and vice versa) in younger adults, the predictive power between memory types was considerably lower among older adults.

These observations are intriguing considering the changes in the temporal extents of one's personal past and future brought about by age. Specifically, the temporal period comprising the past expands with aging, whereas that comprising the perceived future shrinks. Thus, a priori, we might expect that older adults spend more time reminiscing past episodes at the expense of prospecting their future. On the contrary, our results suggest that though there does appear to be an age-related shift in the temporality of episodic recollection, the shift favors the future. Laboratory-based observations suggest that older adults recall PMs relatively restricted to the immediate future and AMs from a wider temporal range (Spreng & Levine, 2006). Therefore, we surmise that the foreseeable future of a typical older adult is comparatively dense with planned experiences, whereas his or her past is sparsely represented by autobiographical episodes. Research showing that older adults report fewer cued AMs compared with younger adults (Schlagman et al., 2009) also leaves open the possibility that recollection in older individuals comprises fewer unique, though well-rehearsed, memories. The fact that older (relative to younger) adults have a larger pool of retrievable past experiences, taken together with our finding of an equivalent AM recall rate across age groups, also suggests that on average the retrieval rate per AM is continuously lowered with increasing age; these data are in agreement with the notion that retrieval frequency may play an important role in age-related changes in episodic remembering (e.g., Cohen & Faulkner, 1989; Johnson, 1997; Levine et al., 2002).

What are the factors underlying the observed effects of age on memory frequency? In addition to potential age-related growth in the total number of planned occurrences, older adults may place a deliberate and comparatively greater focus on future events to ensure that intended actions are completed in a timely manner, which could result from (among other factors) task-related anxiety (Cockburn & Smith, 1994). This view relates to the hypothesis that older adults use external reminders more frequently than younger individuals (Cavanaugh, Grady, & Perlmutter, 1983; however also see Phillips, Henry, & Martin, 2008), and collectively these ideas suggest that older adults may be more likely to repeatedly rehearse thoughts pertaining to a given intention or future event. Research designs that couple experience sampling methods with content analyses of subjective experiences (e.g., Gardner et al., 2012) hold potential to evaluate this assertion.

Alternatively, or additionally, our findings may result from age-related changes in the occurrence of mind wandering. Mind wandering refers to the engagement in stimulus-independent thought unrelated to the task at hand and is a prominent feature of subjective experience (Killingsworth & Gilbert, 2010). Several findings suggest that thoughts associated with these wandering states are typically future oriented (Baird, Smallwood, & Schooler, 2011; Smallwood, Nind, & O'Conner, 2009), and linked to autobiographical planning (Baird et al., 2011; Cohen, 2013; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011). Age effects on the occurrence of mind wandering have been predominantly evaluated in studies carried out in the laboratory and in studies that used retrospective self-reports (Giambra, 1979; Giambra, 1989; Jackson & Balota, 2012). These studies suggest that the occurrence of off-task thought is decreased in older participants. Given these results, we should expect that differential engagement in mind wandering across the life span does not explain our results; whether these previous findings translate to natural settings, however, largely remains an open question. As task demand is thought to regulate the frequency of task-unrelated thought (Smallwood et al., 2009; Smallwood & Schooler, 2006), if older and younger adults differentially engage in practiced, habitual, or cognitively demanding activities in natural settings, a proportional adjustment in their rates of mind wandering would be predicted. In line with this hypothesis, older (compared with younger) adults have reported experiencing less stress related to daily events (Schnitzspahn, Ihle, Henry, Rendell, & Kliegel, 2011) and were more likely to be engaged in automatic activities during recall of a planned action (although they reported higher levels of concentration associated with those activities; Kvavilashvili & Fisher, 2007). We suggest that naturalistic measurement of the frequencies of PM thoughts (associated with unique in addition to rehearsed future experiences) as they relate to task focus and activity engagement, among younger and older subjects, is also a valuable future endeavor that may clarify age-dependent changes in prospective recollection.

Our work may be relevant to studies of the aging and PM paradox, a finding that performance of prospective memory tasks (i.e., remembering to perform an action within a specified temporal interval) is generally impaired in older individuals compared with younger individuals in laboratory settings but superior in natural settings (e.g., Rendell & Craik, 2000). Several factors have gained traction as to account for these findings, for example, age- and setting-dependent changes in task motivation and the difficulty level of everyday activities (Aberle, Rendell, Rose, McDaniel, & Kliegel, 2010; Kvavilashvili & Fisher, 2007; Niedźwieńska & Barzykowski, 2012; Schnitzspahn et al., 2011). Adding to this research, the current work suggests that the frequency at which older adults engage in future-oriented thought may also contribute to their enhanced naturalistic PM task performance. These factors (e.g., the degree of focus on future events, demand of ongoing activity, and task motivation) are not mutually exclusive and likely interact to regulate completion rates of prospective memory tasks. Future testing to tease apart their individual influences on the timely execution of intentions in natural settings is warranted.

Previous accounts of the occurrence of AM or PM are scarce and variable. Several diary-based studies have concentrated on the occurrence of involuntary AM (memories that pop into one's mind without conscious effort) predominantly in younger subjects. Reported averages of the frequency of these memories have varied from just a few in a typical day (Mace, 2004; Schlagman et al., 2009; Schlagman & Kvavilashvili, 2008) to more than 20 (Rasmussen & Berntsen, 2011). In addition, Schlagman et al. (2009) suggested that the involuntary AM recall rate was moderately decreased among older adults. Rasmussen and Berntsen (2011) sampled both involuntary and voluntary (those deliberately retrieved) AMs, reporting that 29 memories in total were retrieved in a single day. Using a diary study, D'Argembeau et al. (2011) estimated 59 general future thoughts (not necessarily tied to a particular event) occurred daily. Kvavilashvili and Fisher (2007) found that for a single PM task, participants reported on average two recollections of the intention each day; a relatively high proportion of these thoughts occurred temporally proximal to the intention's execution.

Although it is evident that the current study's estimates of retrieval frequencies are considerably higher than those provided by the diary method, making precise rate comparisons across studies is difficult, particularly because these previous designs did not include temporal estimates of daily participation (and were varied in their focus). Further confounding meaningful comparison, our measures of memory duration were based on participant time estimation, and thus, values representing recall duration and consequently rate are in terms of perceived time.

Other methodological distinctions that could account for a portion of this variability relate to the demand placed on participant introspection to document the occurrence of targeted thoughts, and how each thought is segmented. In particular, diary methods require subjects to continually monitor their thoughts in order to capture all targeted experiences, conceivably leading to some degree of underreporting. It is intriguing that in a lab-based study that used random thought probes to measure the incidence of mind wandering, Schooler, Reichle, and Halpern (2004) demonstrated that participants were unaware of their engagement in these wanderings approximately 13% of the time, indicating intermittent lapses in meta-awareness; it is unclear, however, if these sampled thoughts would have passed entirely without being reported. It is also plausible that interrupted thoughts that are later revisited may be reported as a single tally in a diary (likely depending on the temporal delay). In contrast, when random prompts to sample momentary subjective experiences (e.g., as employed in our protocol) are used, these same thoughts are more likely to contribute to a computed occurrence rate as separate and distinct events.

Considering the variability among estimates of the prevalence of subjective thought (cf. Cameron, 1972; Cameron et al., 1977; D'Argembeau et al., 2011; Gardner et al., 2012; Klinger & Cox, 1987; Kvavilashvili & Fisher, 2007; Rasmussen & Berntsen, 2011; Schlagman et al., 2009), we find it important to further emphasize several methodological choices of the current design and their implications (for a full discussion, see online supplemental materials). Nonetheless, the main conclusions of this work, based on relative comparisons between memory types within and across age groups, should be robust to these choices. Thus, the reported naturalistic account of the probability, duration, and rate of AM and PM recall across the life span offers an important quantitative foundation of rarely studied dimensions of human memory.

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