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Wandering Minds and Aging Cells

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Abstract

Many ancient contemplative traditions believe presence of mind promotes greater longevity, a belief that is hard to test. Scientific evidence suggests that mind wandering predicts unhappiness, whereas presence in the moment predicts well-being. It is important to test whether a tendency toward mind wandering is associated with biological measures of longevity beyond self-reported measures of well-being. Telomere length has recently emerged as a proxy measure of biological aging and correlate of severe stress. We assessed the association between telomere length and tendency to be present versus tendency to mind wander in 239 healthy women. Those who reported high mind wandering had shorter telomeres, consistently across immune cell types (granulocytes, lymphocytes), than did those who reported low mind wandering, even after adjusting for stress. Telomere length varies widely between adults, and these findings suggest that presence of mind may explain some of these differences. A present attentional state may promote a healthy biochemical milieu and, in turn, cell longevity.

Keywords

aging, telomere length, mind wandering, mindfulness, presence, experiential avoidance

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> The secret of health for both mind and body is not to mourn for the past, worry about the future, or anticipate troubles but to live in the present moment wisely and earnestly.
>
> —Buddha

Mind wandering is the common mental state whereby task-oriented thoughts are hijacked by internally generated, unrelated, or "wandering" thoughts, usually with little meta-awareness of this process (Schooler et al., 2011). Studies of mind wandering may provide new insights into mental and physical health, and the link between the two. William James, in his examination of the "stream of consciousness," pointed to mind wandering as a defining aspect of self: "The faculty of voluntarily bringing back a wandering attention, over and over again, is the very root of judgment, character, and will. No one is *compos sui* (master of oneself) if he have it not" (James, 1890, p. 424). Mind wandering, which tends to fill almost 50% of our mental time, appears to be intricately tied to well-being and predicts daily unhappiness (Killingsworth & Gilbert, 2010). Conversely, negative mood is linked to increased mind wandering, as shown experimentally (Smallwood, Fitzgerald, Miles, & Phillips, 2009).

The antithesis of mind wandering might be thought of as the ability to sustain focus on the moment. Present focus has often been studied as part of the larger multidimensional construct of mindfulness, as defined in Western science. Mindfulness includes paying attention to the moment, with intention and without judgment, and "disengaging oneself from strong attachment to beliefs, thoughts, or emotions," which in turn is predicted to reduce suffering and promote well-being (Ludwig & Kabat-Zinn, 2008). Indeed, training in the ability to be more mindful is consistently related to improvements in psychological well-being and physical health, typically as self-reported health measures (Grossman, Niemann, Schmidt, & Walach, 2004).

The belief that presence of mind is intricately linked to well-being and longevity has roots in many ancient contemplative traditions. For example, living according to certain Buddhist principles, including fostering a present orientation through meditation, is thought to allow one to live to 100 years (Gethin, 2001). In Taoism, meditation training is thought

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to increase longevity and in some cases to promote immortality through increasing life force (Olson, 2003). Beyond the studies on mindfulness and health, no studies have directly examined whether mind wandering or presence of mind are associated with any objective measures of longevity. However, there are now several established measures of biological aging, notably telomere length, that make such a test possible.

We assessed the relationship of mind-wandering tendency to telomere length, an emerging biomarker for cellular and general bodily aging. Telomeres are the DNA-based caps that protect the chromosome termini. Telomeres typically shorten with age and psychological and physiological stressors, and telomere shortness predicts early disease and mortality (Lin, Epel, & Blackburn, 2011). Telomere shortness may be a useful marker of accelerated aging early in life as well, as violence exposure has been linked to telomere shortening in children (Shalev et al., 2012). Although links between telomere length and severe states of stress and clinical syndromes have now been well established, few studies have examined whether telomere length is associated with psychological processes such as mindfulness or mind wandering. A recent pilot study linked intensive meditation training to higher telomerase, the cellular enzyme that elongates and protects telomeres (Jacobs et al., 2011). In this study, we asked whether individual differences in the tendency toward mind wandering were associated with leukocyte telomere length (LTL), the mix of immune cells, and telomere length (TL) in specific immune cell types (lymphocytes and granulocytes). In other words, do people who spend more time fully engaged in the present and less time engaged in negative mind wandering have a slower rate of biological aging?

Measurement of mind wandering is a complex issue. Mind wandering is in part a stable cognitive trait that can be measured both in the lab and naturalistically. Mrazek, Smallwood, and Schooler (2012) found, as expected, that mind wandering is inversely related to attentional measures of mindfulness, as shown by self-report and behavioral measures. We measure self-reported "mind-wandering tendency" as the discrepancy between the tendency to be focused on tasks and the tendency to have thoughts about other things or being elsewhere. Mindfulness measures have previously been related to one's ability to accept situations and negative emotions rather than avoid them (Baer, Smith, & Allen, 2004; Sahdra, Shaver, & Brown, 2010), and thus we also examined whether the brief measure of mind-wandering tendency used here is related to these dispositions to avoid negative affect as well as other features of mindfulness from Buddhist and Western conceptualizations.

Severe distress may be an important confound in such a study of mind and cell. Perceived stress and depression are consistently associated with shorter TL (e.g., Epel et al., 2004; Puterman et al., 2010; Simon et al., 2006). We aimed to study mind wandering independent of distress and in relation to biological age (vs. chronological age). We therefore recruited a disease-free community sample of women who were interested in their health and were within a narrow range of chronological age (50–65 years), which minimized the effects of severe distress and age. We measured mind-wandering tendency and TL, as well as aspects of psychological distress and well-being (stress, depression, perseverative cognitions, and life satisfaction), because these latter factors could influence mind wandering and TL and serve as confounders. Perseverative cognition (i.e., rumination about the past and worries about the future), for example, is both driven by distress and a process that contributes to a wandering mind (Brosschot, 2010; Brosschot, Pieper, & Thayer, 2005; Lyubomirsky, Caldwell, & Nolen-Hoeksema, 1998).

Method and Measures

Between February and May 2010, we recruited 264 healthy midlife women (ranging from 50 to 65 years) from the San Francisco Bay Area, with online and paper advertisements. They volunteered for a study in which they would learn their own TL (this information was not given for several months after the self-report questionnaires were completed). The inclusion criteria included being a nonsmoker and being free from lifetime histories of cancer, including skin cancer, and autoimmune diseases. Women who had a history of cancer ($n = 18$), had missing data from self-reported mind-wandering questions ($n = 6$), or did not have a successful TL assay ($n = 1$) were excluded.

Measures

Mind-wandering and related measures. Here, we focus on a trait-like aspect of mind wandering based on self-report, which is presumably dependent on some level of meta-awareness in order to recall experiences. We examined items adapted from a recent mind-wandering study using smartphone technology. This study used experienced sampling assessments of presence of mind to predict happiness (Killingsworth & Gilbert, 2010). In this study, negative mind wandering predicted unhappiness more than positive mind wandering; therefore, we focused on negative mind wandering. Women answered questions on presence in the moment ("How often in the past week have you had moments when you felt totally focused on or engaged in doing what you are doing at the moment?") and lack of presence or negative mind wandering ("How often in the past week have you had any moments when you felt you didn't want to be where you are, or doing what you are doing, at the moment?"), rated on a 5-point scale from 1 (*never/very rarely true*) to 5 (*very often/always true*). Mean lack of presence was 2.40 ($SD = 1.09$), and mean presence in the moment was 4.13 ($SD = 0.73$). We calculated a composite score for mind-wandering tendency ("lack of presence" minus "presence in the moment"). Average mind-wandering tendency was −1.73 ($SD = 1.49$; indicating a mean tendency for greater presence), and scores ranged from −4.0 to 2.0.

Reliability. One-year follow-up data reveal a significant year-to-year correlation coefficient of .55 ($p < .001$), suggesting some stability in mind-wandering tendency for this two-item variable that focuses on past-week behavior. These stability results are similar to the test-retest correlation for the 10-item perceived stress scale in the current study, also taken one year apart, $r(211) = .60$.

Construct validity. We did not have multiple measures of mind wandering. We examined the construct validity of the mind-wandering scale (difference score of not in the moment and presence in the moment) by assessing relationships with scales that should conceptually be related to mind wandering. These included two measures that estimate the acceptance of current thoughts, emotions, and situations and the release from unhealthy mental fixations (Acceptance and Action Questionnaire; Hayes et al., 2004; and Nonattachment Scale; Sahdra et al., 2010), as well as a short mindful awareness measure (modified Acting With Awareness subscale of the Kentucky Inventory of Mindfulness Skills; Baer et al., 2004) as described in detail in the sections that follow. Bivariate correlations demonstrated satisfactory convergent validity and significant associations in the expected directions with the Acceptance and Action Questionnaire, $r(238) = –.53$, $p < .001$, with the Nonattachment Scale, $r(237) = –.53$, $p < .001$, and, to a slightly lesser extent, with the Acting With Awareness subscale, $r(239) = –.43$, $p < .001$. These associations provided support that the measure assesses a subset of mind-wandering tendencies: awareness and acceptance of the present versus avoidance of current situations, emotions, or unwanted thoughts.[1]

Acceptance and Action Questionnaire. The Acceptance and Action Questionnaire (AAQ; Hayes et al., 2004) assesses psychological inflexibility and experiential avoidance, such as unwillingness to accept negative feelings and emotions in everyday life and efforts to escape these experiences. It was predicted that greater experiential avoidance would be associated with greater mind wandering. Some example items are "My painful experiences and memories make it difficult for me to live a life that I would value" (reverse coded), "Worries get in the way of my success" (reverse coded), and "It's OK if I remember something unpleasant" (Cronbach's $\alpha = .83$).

Nonattachment Scale. The Nonattachment Scale (NAS; Sahdra et al., 2010) is designed to assess the Buddhist construct of *nonattachment*, defined as release from unhealthy mental fixations. High attachment to mental representations of self, others, and aspects of life in general (low scores on the NAS) indicates clinging and grasping for events and objects in a way that is thought to cause suffering, whereas high nonattachment (high scores on the NAS) implies lack of clinging to such representations. Higher scores on nonattachment are associated with more adaptive functioning. The full scale includes 30 items, but for brevity, we selected 10 items with the highest factor loadings and that tended to focus on acceptance of current experience (B. K. Sahdra, personal communication, December 2010). This was particularly useful for our goal of using the NAS and AAQ for establishing the construct validity of the mind-wandering measure. Although nonattachment is conceptually different from acceptance of (negative) experiences, the two constructs are theoretically related because accepting something difficult often involves letting go of one's resistance to it. Examples of the 10 items of the NAS that we selected include "I do not feel I need to escape or avoid bad experiences in my life," "I do not get 'hung up' on wanting an 'ideal' or 'perfect' life," "I find I can be happy almost regardless of what is going on in my life," "I can accept the flow of events in my life without hanging onto them or pushing them away," and "I find I can be calm and/or happy even if things are not going my way." Cronbach's α for the 10 items was .90.

Awareness. To measure awareness, we selected three items from the Kentucky Inventory of Mindfulness Skills Acting With Awareness subscale that most closely assess difficulty or ease with "engaging fully in one's current activity with undivided attention" (Baer et al., 2004). The three items were "When I do things, my mind wanders off and I am easily distracted," "I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted," and "When I'm doing something, I'm only focused on what I'm doing, nothing else." Cronbach's α was .74.

Potential psychological confounds

We used psychometrically validated measures to assess potential confounds affecting mind wandering and TL. We measured depressive symptoms, perceived stress, perseverative cognition, and life satisfaction, as described in the sections that follow. Psychological measures were retained in final analyses if they were related to LTL with $p \leq .20$.

Depressive symptoms. We used the nine-item Patient Health Questionnaire (Kroenke, Spitzer, & Williams, 2000), which asked participants to rate on a 4-point scale (0 = *not at all*, 3 = *nearly every day*) the extent to which, over the past 2 weeks, they had symptoms such as "Feeling bad about yourself or that you are a failure or have let yourself or your family down," "Trouble concentrating on things, such as reading the newspaper or watching television," and "Little interest of pleasure in doing things." Cronbach's α was .73.

Perceived stress. We used the 10-item Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983). Participants used a 5-point scale ranging from 0 (*not at all*) to 4 (*almost all the time*) to rate items such as "How often have you felt unable to control the important things in your life?" "How often have you felt nervous or stressed?" and "How often have you felt confident about your ability to handle personal problems?" (reverse coded). Cronbach's α was .87.

Perseverative cognition (rumination). We used the 12-item Rumination subscale of the Rumination and Reflection Questionnaire (Trapnell & Campbell, 1999). Participants used a 5-point scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) to rate items such as "My attention is often focused on aspects of myself I wish I'd stop thinking about," "I always seem to be rehashing in my mind recent things I've said or done," "Sometimes it is hard for me to shut off thoughts about myself," and "Long after an argument or disagreement is over with, my thoughts keep going back to what happened." Cronbach's α was .93.

Life satisfaction. Life satisfaction was measured with the five-item Satisfaction With Life Scale, which assesses global judgments of satisfaction with one's life, such as "If I could live my life over, I would change almost nothing" and "The conditions of my life are excellent" (Diener, 1985). Cronbach's α was .89.

Telomere length. We measured LTL in all women and lymphocyte and granulocyte TL (Baerlocher, Vulto, de Jong, & Lansdorp, 2006) in a random subset of 55 women. Lin et al. (2011) summarized the measurement and basic and clinical science of TL for the social scientist. Lymphocyte and granulocyte TL was analyzed with Flow-FISH at Repeat Diagnostics, as described elsewhere (Baerlocher et al., 2006). Mean LTL was analyzed in Blackburn's UCSF Laboratory (Lin et al., 2010) with quantitative polymerase chain reaction (PCR), which is the most common method in the literature used for clinical and population-based studies. This method is associated with the gold standard Southern blot method (Aviv et al., 2011). This PCR TL measurement assay is adapted from the original published method by Cawthon (Cawthon, 2002; Lin et al., 2010). The method measures relative TL by comparing telomere to the single-copy gene ratio, also called the T/S ratio. For the PCR assay, the telomere thermal cycling profile consists of

> Cycling for T (telomic) PCR: denature at 96°C for 1 s, anneal/extend at 54°C for 60 s, with fluorescence data collection, 30 cycles. Cycling for S (single copy gene) PCR: denature at 95°C for 15 s, anneal at 58°C for 1 second, extend at 72°C for 20 s, 8 cycles; followed by denature at 96°C for 1 s, anneal at 58°C for 1 second, extend at 72°C for 20 s, hold at 83°C for 5 s with data collection, 35 cycles.

The primers for the telomere PCR are *tel1b* (5′-CGGTTT $(GTTTGG)_5$GTT-3′), used at a final concentration of 100 nM, and *tel2b* (5′-GGCTTG$(CCTTAC)_5$CCT-3′), used at a final concentration of 900 nM. The primers for the single-copy gene (human beta-globin) PCR are *hbg1* (5′ GCTTCTGACACAACTGTGTTCACTAGC-3′), used at a final concentration of 300 nM, and *hbg2* (5′-CACCAACTTCATCCACGTTCACC-3′), used at a final concentration of 700 nM. The final reaction mix contains 20 mM Tris-HCl, pH 8.4; 50 mM KCl; 200 µM each dNTP; 1% DMSO; 0.4× Syber Green I; 22 ng *E. coli* DNA per reaction; 0.4 units of platinum taq DNA polymerase (Invitrogen Inc.) per 11 microliter reaction; 0.5 to 10 ng of genomic DNA. Tubes containing 26, 8.75, 2.9, 0.97, 0.324, and 0.108 ng of a reference DNA (from Hela cancer cells) are included in each PCR run so that the quantity of targeted templates in each sample can be determined relative to the reference DNA sample by the standard curve method. Each concentration of the reference DNA is run as quadruplets, and samples are run as triplicates.

To control for interassay variability, eight control DNA samples from cancer cell lines (including 293T, H1299, UMUC3, and UMUC3 cells infected with a lentiviral construct containing the telomerase RNA gene to extent telomeres, harvested at various population doublings after infection) are included in each run. In each batch, the T/S ratio of each control DNA is divided by the average T/S for the same DNA from 10 runs to get a normalizing factor. This is done for all eight samples, and the average normalizing factor for all eight samples is used to correct the participant's DNA samples to get the final T/S ratio. The T/S ratio for each sample is measured twice, each time in triplicate wells. When the duplicate T/S value and the initial value vary by more than 7%, the sample is run a third time and the two closest values are reported. The interassay coefficient of variation for TL measurement was 4.3% for this study.

Results

Description of the sample

The final sample included 239 healthy midlife women (age $M = 57$, $SD = 4.4$, range = 49–66 years). Participants were highly educated, with 84% having a college degree or higher; 51% with a professional degree (doctorate, MD, or master's), 15% with some college, and 1% with a high school degree. They were of relatively high income (48% earned more than $100,000 per year, 32% earned between $50,000 and $100,000) and were mostly Caucasian (89% Caucasian, 6% Asian or Pacific Islander American, 3% Hispanic or Latina, 2% African American).

Level of stress. As expected, the sample experienced relatively low levels of stress. Their mean stress level was 12.11 ($SD = 5.121$), lower than the mean of a representative sample of U.S. women, which was 16.1 ($SD = 7.7$; Cohen & Janicki-Deverts, in press). A one-sample *t* test comparing this sample's mean stress level to the national representative mean was significant, $t(238) = -12.00$, $p < .001$. No participants scored in the range of extreme stress (2 *SD* above the population-based mean, a score of 32 or higher). In fact, only 15 participants scored 1 *SD* above the national representative average, confirming that this is a low stress sample.

Table 1. Pearson Correlations (Zero Order) Between Presence in the Moment, Lack of Presence, and Mind-Wandering Tendency (Composite Difference Score) with LTL, and Psychological Covariates

	Presence	Lack of presence	Mind-wandering tendency	Telomere length
Telomere length	.17**	–.14*	–.19**	—
Depression	–.27**	.42***	.45***	–.09
Perceived stress	–.23***	.57***	.53***	–.09
Rumination	–.33***	.42***	.47***	–.10
Life satisfaction	.20**	–.47***	–.44***	.05

Note: *df* = 238, except for depression, for which *df* = 196 because the questionnaire was added later.
*$p < .05$. **$p < .01$. ***$p < .001$.

Potential confounds to telomere length. We next tested the relationships among age, body mass index (BMI), and potential psychological confounds to determine any significant or nearly significant relationships with LTL (using a conservative alpha level, $p \leq .20$, as a cutoff). Bivariate correlations with LTL indicated that body mass index, $r(239) = –.16$, $p < .01$, perceived stress, $r(238) = –.09$, $p = .16$, and rumination, $r(239) = –.10$, $p = .12$, were the only three covariates that met the $p \leq .20$ criterion set forth to retain a covariate in the final regression models. Although age was not related to LTL within this restricted age range, it was used as a covariate in all final models given that, in theory and as evidenced by the majority of other studies including a range of ages, increasing age is significantly associated with declining TL.

Mind-wandering analyses. Lack of presence and presence in the moment were negatively related to one another, $r(239) = –.31$, $p < .001$, and each was related to LTL, $r(239) = –.14$, $p = .031$, $r(239) = .17$, $p = .008$, respectively. Given these relationships, it was unsurprising that greater mind wandering (the composite score) was also related to shorter LTL, $r(239) = –.19$, $p = .004$, as well as to specific subpopulation TL, lymphocyte TL $r(46) = –.41$, $p = .004$, granulocytes TL $r(46) = –.44$, $p = .002$.

Pearson correlations showed that mind-wandering tendency was related to psychological distress measures, including perceived stress, $r(238) = .53$, $p < .001$, depressive symptoms, $r(194) = .45$, $p < .001$, and rumination, $r(239) = .47$, $p < .001$, and to well-being (life satisfaction), $r(238) = –.44$. $p < .001$. The correlations with the individual measures of presence and lack of presence are shown in Table 1.

We tested two regression models, one with just age and BMI as covariates (Table 2, Model A) and the second with the potential confounds identified (Table 2, Model B). Each model identifies the beta weights of each individual factor at each step. The first regression with the age and BMI covariates (Model A) showed that mind wandering significantly predicted shorter LTL ($\beta = –.21$, $p = .002$), indicating a 46 base-pair decline for every unit change in mind wandering.

Table 2. Multiple Regression Model Beta Weights for Mind Wandering Predicting Telomere Length

	Model A[a]		Model B[b]	
	β	*p*	β	*p*
Age	–.04	.56	–.07	.27
BMI	–.16	.01	–.17	.01
Perceived stress	—	—	.03	.72
Rumination	—	—	–.02	.79
Mind wandering	–.21	.001	–.21	.008

[a]Model A: Covarying age and BMI.
[b]Model B: Covarying age, BMI, perceived stress, and rumination.

For illustrative purposes (Fig. 1), we categorized mind wandering into three groups, based on participants' scores on the mind-wandering composite measure (difference score between mind-wandering and presence). High scores represent more mind wandering relative to presence; low scores represent less mind wandering relative to mind presence. We categorized the lowest two scores (–4, –3) as low mind wandering (33%), middle scores (–2 to 0) as moderate mind wandering (59%), and the highest two scores (1, 2) as high mind wandering (8%). As shown in Figure 1, the high and low mind-wandering groups had a difference of around 200 base pairs in TL. Based on cross-sectional relationships from numerous published articles showing average loss in TL per year, a metric commonly used, mind wandering was associated with an additional 4 to 5 years of cell aging between the two extreme groups. In addition, we calculated the regression results using the single items: In separate multiple regressions covarying for age and BMI, lack of presence and presence in the moment both independently significantly predicted LTL ($\beta = –.15$, $p = .02$ and $\beta = .20$, $p = .003$, respectively).

In Model B, we also included perceived stress and rumination as covariates. These factors, although strongly related to mind wandering, were not strongly related to LTL (*p* values approximately .15). Thus, it is unsurprising that their inclusion

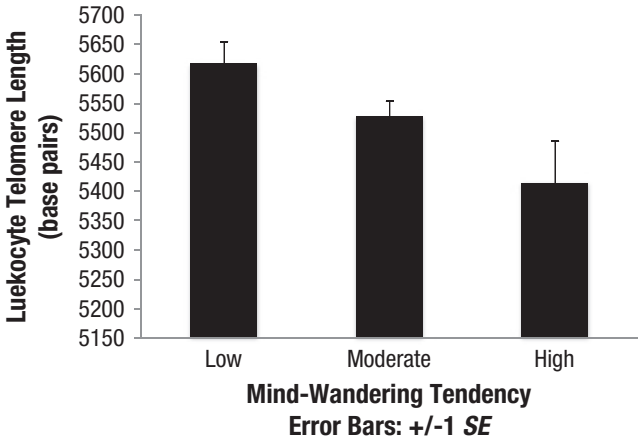

Fig. 1. Leukocyte telomere length by mind-wandering groups.

did not greatly affect the regression model results (Osborne & Waters, 2002). Mind-wandering tendency remained a significant predictor of LTL after controlling for all covariates and these psychological measures simultaneously ($\beta = -.21$, $p < .008$; Table 2).

Discussion

In the study of attention and consciousness, mind wandering is an important construct, defined as task-irrelevant thought and thus contrary to attentional focus on the present. Our findings suggest it may play a key role linking mental and physical health. We found a greater tendency to mind wander was related to shorter TL and thus, by inference, to accelerated cellular aging across immune cell types. These findings remained robust after adjusting for confounds. This result is significant because it represents a link between the wandering nature of the mind, a fundamental characteristic of human minds, and a fundamental indicator of the capacities for cell division and human health. Although we report merely an association here, it is possible that greater presence of mind promotes a healthy biochemical milieu and, in turn, cell longevity. If so, cognitive or meditative interventions that target executive function, such as attention and working memory, may promote less mind wandering, ultimately enhancing healthy human aging. The effect size appears meaningful. Those with the highest level of mind wandering had telomeres that were shorter by around 200 base pairs compared to those with the least mind wandering. Based on how many base pairs are lost per year according to cross-sectional studies by age, this would be equivalent to about 4 years of additional aging. Cross-sectional data suggest that telomeres decline slowly in adulthood, with a loss of around 30 to 60 base pairs per year on average. Therefore, it is traditional in telomere research to calculate effect sizes in terms of base pairs per year lost. We have done this to allow for comparisons with other papers. However, now that longitudinal studies are emerging, it is clear that individuals show dynamic change over shorter periods, not just losses but sometimes gains in TL (Epel, in press). Thus, any measure of base pairs lost per year is only a crude average across individuals.

It may seem puzzling at first glance that this study did not find significant relationships between TL and distress measures. This is in contrast to other studies showing significant links between perceived stress and TL. However, past studies tended to measure extreme states of stress (e.g., maternal caregiving, trauma exposure) or psychiatric conditions (e.g., depression) comparing clinical samples to controls, or in large population-based samples where there was a wide range of stress levels (as reviewed in Lin et al., 2010). Researchers who conducted past studies on distress and TL have often recruited samples based on high versus low stress or presence versus lack of psychiatric disorder and thus have more extreme ranges of stress exposures. For example, shorter TL has been found in people who are high-stress caregivers (Damjanovic et al., 2007; Epel et al., 2004) and in people with major depression (Hartmann, Boehner, Groenen, & Kalb, 2010; Simon et al., 2006), posttraumatic stress disorder (O'Donovan et al., 2011), and exposure to domestic violence (Humphreys et al., 2011) compared to those with low distress or no similarly stressful exposure. The healthy community sample in the current study was particularly high on education and had significantly lower stress levels compared to a nationally representative sample (as described in the Description of Sample section). Therefore, this sample is not designed for testing the relationship between high stress and TL, and thus it is not surprising that stress was only weakly related to TL. Given the low distress levels observed, this sample may be ideal for examining how a positive factor such as presence of mind may be functioning, but it is unclear if mind wandering would play as large a role in a sample with higher stress or lower education. In addition, it is unclear if this relationship would be altered later in life—when mind wandering (at least as measured by daydreaming) tends to decrease (Giambra, 1993) and telomeres also tend to be short. These findings may have limited generalizability and must be tested in larger samples across a range of distress levels and ages.

What are the drivers of mind wandering and its relationship to TL? It is possible that unhappiness, which can promote mind wandering, is playing a key role in both mind wandering and TL. In this study, we controlled for severity of distress (perceived stress) and the tendency to ruminate, which reduces but does not eliminate the likelihood of this explanation.

Regardless of overall levels of negative affect, it could be that one's relationship to unhappy thoughts matters. People's attempts to control aspects of experience, such as suppressing unwanted thoughts, can sometimes backfire, as part of ironic errors (Wegner, 2009). Trying to avoid unhappy thoughts can cause more distress. The mind-wandering tendency as measured here was, as predicted, related to the dispositional schemas of psychological inflexibility, attachment to maintaining positive affect, and avoiding negative affect. This type

of disposition may lead one away from unwanted thoughts or feelings in the present moment and feed subsequent mind wandering. It could also create fertile ground for more frequent or exaggerated threat appraisals of everyday hassles. Threat appraisals and associated physiological reactivity appear to promote aging of telomeres (Epel, 2009; O'Donovan et al., 2012; Tomiyama et al., 2012).

Alternatively, rather than being linked to more intense stress arousal states, a restless mind may simply leave the body in a less restful state chronically, suppressing the ongoing housekeeping and restorative functions of cell repair, leading to a low-grade accelerated aging process.

In future research, this novel association must be "unpacked," alongside both the measurement issues and the clinical implications. One of the major tasks is to better measure the different types of presence and mind wandering to see which are most closely associated with rate of aging. This would allow one to test this relationship, the mechanism, and possible reversibility in experimental and intervention designs.

Measurement of mind wandering is inherently challenging, in that it can be measured only indirectly. The many methods include self-report of tendencies, momentary thought sampling, cognitive task performance in controlled contexts assessing lapses in attention, and neurological activity measures. To further the study of state of mind—presence and mind wandering—it will be helpful to distinguish among the different definitions of presence and mind-wandering states and to use multiple measures.

We were limited to a brief self-report measure of presence and mind wandering in this study. A strength is that our self-report trait-like measure has significant test–retest reliability across a year, indicating that self-reported mind wandering as measured here may represent a generally stable tendency. Our measure of presence likely overlaps with the concept of flow (Csikszentmihalyi, Abuhamdeh, & Nakamura, 2005), which is focused attention and deep engagement, or absorption in present activities. Our composite measure also taps one aspect of negative mind wandering—that characterized by experiential avoidance. We did not measure positive mind wandering. Our composite measure of mind-wandering tendency is different from, and not simply the inverse of, the multidimensional construct of mindfulness, as discussed extensively elsewhere (e.g., Grossman & Van Dam, 2011). Our measure of recall over the past week is also different from lab-based measures and from momentary sampling methods in ways that need to be explored by using convergent measures in future research. It is possible that controlled, lab-based measures of mind wandering are tapping differences in basic executive function that may be only loosely related to the measure used here.

Reducing negative mind wandering has potential as a focus of interventions. A brief period of mindful breathing acutely reduces mind wandering (Mrazek et al., 2012). There is strong evidence that third-generation mindfulness-based clinical interventions can be effective across affective disorders. For example, empirically validated clinical interventions have used presence and mindful acceptance of negative affect as a key active ingredient to successfully reduce clinical symptoms and distress (Bieling et al., 2012; Hayes, Luoma, Bond, Masuda, & Lillis, 2006; Lynch, Trost, Salsman, & Linehan, 2007). Present-focused attention and reductions in negative mind wandering may also be important for good physical health, which is our focus here.

A few studies have examined mental training and telomerase activity as a proxy for cell aging. Brief training in a yogic meditation over 4 months and intensive meditation over 3 months were both associated with higher telomerase activity (Jacobs et al., 2011; Lavretsky et al., 2012). Whether these reduce the rate of telomere shortening and whether the key mechanism is reduced mind wandering are not known and need to be tested directly.

To assess the potential utility of this mind wandering–cell health relationship, researchers could apply short-term attentional training interventions and assess how they affect mind-wandering tendencies. It may be helpful to focus on high-functioning, low-stress respondents such as those in the sample studied here to minimize the potential confounding effects of high levels of negative affect. If the relationship between presence of mind and cellular aging processes is causal, one could expect short-term improvements in markers of cellular stress responses and health, such as gene expression toward lower inflammation and oxidative stress, and increases in telomerase. Interventions that last at least several months can also assess changes in TL, which is slower to change than telomerase.

There is a vast divide between mind wandering and cell aging, and understanding any causal mechanistic links between the two could provide a better understanding of the mind–body relationship. At the least, this finding opens the door to new questions about the experiential aspect of the flow of thought and why this appears to be tied to fundamental cell biology. Which aspects of mind wandering matter the most? Both presence of attention and negative mind wandering were related to TL with similar magnitude. Are there underlying etiological factors driving this relationship, such as differences in brain connectivity, aspects of executive function such as working memory, affective states, or one's relationship to affect, in the form of high experiential avoidance of negative states?

We have mostly posed models in which mind wandering is driving physiology and cell aging. However, we should also consider that there may be recursive relationships among brain function, mind-wandering tendency, and peripheral rate of aging that starts early in life. Trait-like mind wandering and cell age do not arise in the moment but are likely results of development, learning, and historic and current exposures. TL is now conceptualized as a marker that holds memory for life experiences such as early prenatal stress exposure, abuse or neglect in childhood, and adult trauma and chronic stress exposures, but it is also protected by positive exposures such as social connection (Puterman & Epel, in press). Early

childhood exposures shape both TL and executive functioning such as attention, memory, and emotion. For example, it appears that early life stressors, either prenatal or during childhood, shape both brain connectivity toward poorer executive function and greater stress reactivity (Davidson & McEwen, 2012), and this could affect tendency toward mind wandering. Because childhood is the period when trajectories for executive function as well as TL are set, it may be revealing to study these relationships early in life.

In summary, despite the limitations of the current study, self-reported attentional state appears important to immune cell aging. A highly wandering mind may indicate a more rapidly aging body. Future studies are needed to replicate and further demonstrate the generalizability and mechanism of this novel relationship.

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Declaration of Conflicting Interests

E. Epel, J. Lin, and E. Blackburn are cofounders of Telome Health, Inc., a telomere measurement company.

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Note

1. We did assess the correlations between telomere length and the measures used for convergent validity of mind wandering, although this was not the goal of the study and these were not planned analyses. Telomere length was not significantly associated with any of these measures: Acceptance and Action Questionnaire, $r(239) = .08$, $p = .25$, Acting With Awareness items, $r(240) = .07$, $p = .30$, nor with the Nonattachment Scale, $r(238) = .10$, $p = .11$.

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