Variety is the Spice of Life: A Microlongitudinal Study Examining Age Differences in Intraindividual Variability in Daily Activities in Relation to Sleep Outcomes

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Abstract

Objective. The relative importance of mean timing of daily activities versus intraindividual variability in the timing of daily activities in relation to health outcomes such as sleep has yet to be established. Furthermore, age-related changes in sleep could affect this relationship. The study objective was to examine the extent that intraindividual variability in the timing of daily activities is associated with sleep outcomes in younger and older adults.

Measures. A microlongitudinal observational study design was used with 14 consecutive days of diaries in community-dwelling younger and older adults. 50 younger and 50 older adults completed daily assessments of activities and sleep. Three activities (going outside, starting work, and eating dinner) and 5 sleep (sleep onset latency, wake time after sleep onset, number of awakenings, total sleep time, and sleep quality rating) variables were used in the analyses.

Results. Hierarchical regressions revealed variability in the timing of daily activities significantly predicted sleep, beyond mean timing of activities, for 4 of 6 models. Results differed depending on the type of activity and age group.

Discussion. Intraindividual variability, not mean timing of daily activities, best-predicted sleep outcomes. Variability was associated with positive sleep outcomes for older, but not younger adults.

Key Words: Circadian—intraindividual variability—microlongitudinal—older adults—sleep.

Many common behaviors, such as when we wake up, when we go outside, and when we first interact with another human being tend to become patterned over time (Monk, Flaherty, Frank, Hoskinson, & Kupfer, 1990). The rhythmicity of these daily behaviors mirrors patterns in underlying physiological rhythms (e.g., circadian cycles of sleep and wake, core body temperature, and hormonal fluctuations). Although substantial research has been devoted to the study of underlying physiological circadian rhythms, it can be argued that behavioral circadian rhythms warrant further interest as they are the rhythms most salient to us and, therefore, are amenable to change (Monk, 2010).

The level of regularity of behavioral rhythms is of interest as it has been associated with both positive and negative outcomes. Adverse consequences of greater regularity include feelings of boredom, burnout, and the inability to adapt to changing circumstances (Zisberg, Young, Schep, & Zysberg, 2007). Positive outcomes associated with higher levels of regularity in behaviors include improved functional and health outcomes (Bond & Feather, 1988; Clark et al., 2001; Hay et al., 1997; Zisberg, Gur-Yaish, & Shochat, 2010), lower levels of depression (Brown et al., 1996), and greater medication adherence (Wagner & Ryan, 2004). Given the tendency of many biological rhythms to exceed 24 hr when free of external environmental cues (e.g., morning light), behavioral circadian rhythms may serve an important role in entraining these underlying rhythms to the 24-hr clock. The present study examines one outcome associated with the regularity of behavioral activities—nocturnal sleep. Overall, higher levels of regularity in behavioral rhythms have been associated with better sleep outcomes for both younger and older adults. Specifically, more regularity in the timing of daily activities was associated with positive subjective estimates of the time to fall asleep, the efficiency of sleep, and sleep quality in older adults (Kennaway & Van Dorp, 1991; Zisberg et al., 2010) and better subjectively measured overall sleep in bereaved older adults (Brown et al., 1996). Similarly, younger adults classified as poor sleepers reported lower regularity of activities involving social engagement compared to good sleepers (Carney, Edinger, Meyer, Lindman, & Istrate, 2006), and greater regularity of behavioral rhythms was associated with better subjectively measured sleep in adult samples (Monk, Petrie, Hayes, & Kupfer, 1994; Monk, Reynolds, Buysses, DeGrazia, & Kupfer, 2003).

Overall, greater regularity in daily behavioral activities is associated with better sleep outcomes in both younger and older adults. However, age differences in the relationship between behavioral rhythms and sleep may exist given age differences in the level of behavioral rhythms.
and differences in underlying physiological rhythms. For example, levels of regularity appear to increase with age across the lifespan (Monk et al., 1997) such that older adults are more regular in the timing of daily events compared to younger adults. Even within younger age groups, it appears that regularity increases with age (Monk et al., 1994, 2006). Increased levels of behavioral regularity with age may serve an adaptive function, compensating for decreased robustness of underlying physiological rhythms (Monk et al., 1997). As a result, the association between behavioral regularity and sleep may not be uniform across the lifespan.

Researchers have examined multiple facets of daily behaviors that could become rhythmic or patterned over time. After conducting a concept analysis of the rhythmicity of behavioral activities, Zisberg and colleagues (2007, p. 446) proposed that behavioral routines could be defined as “strategically designed behavioral patterns (conscious and unconscious) used to organize and coordinate activities along the axes of time, duration, social and physical contexts, sequence and order.” Accordingly, there are multiple facets of behaviors that contribute to the level of routinization experienced. The extent to which we engage in activities within the same timeframe, for the same duration, with other individuals present or absent, or in a similar sequence can influence the degree to which behaviors are regularized. The present study focuses on one facet of behavioral rhythms—the time of day that daily activities are performed. Rhythmicity in the timing with which we engage in specific activities has been associated with sleep outcomes. For example, regularizing the time we first get out of bed is used to promote better sleep (Bootzin, 1972; Spielman, Saskin, & Thorpy, 1987), the timing of daily exercise has been used to entrain the sleep/wake cycle (Yamanaka et al., 2010), and the timing of evening meals has been associated with the timing of sleep onset (Baron, Reid, Kern, & Zee, 2011). Furthermore, as light is thought of as the dominant environmental cue influencing underlying physiological rhythms (Mistlberger & Skene, 2004), it follows that the timing of first going outside (i.e., exposure to light) could be associated with sleep outcomes. What is less clear, however, is whether it is the time of day that activities are performed, or regularity in the timing of activities, that is most predictive of sleep outcomes. Accordingly, recent research has suggested that beyond the mean timing of events, intraindividual variability in timing is associated with negative health outcomes (Dautovich et al., 2012).

In summary, higher overall levels of regularity, and the timing of a small subset of activities, have been shown to be associated with sleep outcomes. However, the relative importance of mean timing of daily activities versus intraindividual variability in the timing of daily activities has yet to be established. Also, the association between variability of specific activities (e.g., exposure to light) and health outcomes warrants further investigation. Given age differences in the regularity of behavioral and physiological rhythms, regularity of activities should be examined in both younger and older samples.

The specific aim of this study was to examine to what extent intraindividual variability in the timing of specific daily activities (going outside, starting work or housework, and eating dinner) predicts subjective sleep outcomes (sleep onset latency, wake time after sleep onset, the number of awakenings, total sleep time, and sleep quality ratings) above and beyond mean differences in the timing of daily events in younger (18–30 years) and older adults (60–95 years). Innovations of this study include: (a) the use of microlongitudinal design (14 consecutive days of assessment); (b) the examination of mean timing and intraindividual variability in timing of specific activities; and (c) an examination of age differences. It was hypothesized that, given the proposed role of behavioral rhythms in synchronizing underlying physiological rhythms, variability in the timing of activities would predict sleep outcomes above and beyond mean timing. Specifically, higher levels of intraindividual variability in the timing of going outside, starting work or housework, and eating dinner would be associated with worse sleep outcomes for both younger and older adults.

**Methods**

**Participants**

Hundred community-dwelling adults participated in the study (50 younger and 50 older adults; see Table 1 for descriptive statistics). The younger adults were primarily female (72%), White (72%), average age of 19.88 (SD = 2.76), and reported less than one health condition on average (M = 0.34, SD = 0.69). The older adults were primarily female (60%), White (90%), average age of 67.81 (SD = 6.72), and reported more than one health condition on average (M = 1.24, SD = 1.25).

**Procedure**

Participants were recruited from the North Central Florida area and online. Recruitment materials consisted of flyers posted around the University of Florida and the community of Gainesville, FL, online advertisements in community classifieds such as Craigslist, announcements in undergraduate psychology courses from the University of Florida, the Undergraduate Psychology Research Pool, and mailings to individuals listed on the University of Florida’s Age Network Participant Registry.

The study materials were completed online. After a brief introduction to the study, participants were screened for eligibility based on the following exclusionary criteria: (a) currently working shift work; (b) unable to complete study materials using a computer; (c) visual deficits that precluded participation (e.g., have severe self-reported difficulty reading the newspaper); (d) on vacation or planning to take a vacation during the study; (e) diagnosed with a dementia disorder; (f) diagnosed with sleep disorders other than insomnia (e.g., periodic limb movement disorder,
sleep apnea); (g) currently pregnant. If participants met the criteria for participating in the study, they completed the electronic informed consent approved by the University of Florida Institutional Review Board. Next, they completed baseline surveys online (i.e., the demographic and health questionnaire). Participants received an email the following morning with the first of fourteen daily surveys consisting of several measures including the Social Rhythm Metric-17 and the Sleep Diary. They received the same email for the next consecutive 13 days. Based on Florida State rules prohibiting lotteries, the first 30 participants who completed the study were awarded $10 compensation (as opposed to a lottery at the end of the study). Undergraduate students who participated as part of the psychology research pool received research credit while undergraduate students who participated from higher-level psychology classes received extra credit.

Measures

Demographics and health survey.—This questionnaire collects information on demographics, sleep disorder symptoms, physical health, and mental health (Lichstein, Durrence, Taylor, Bush, & Riedel, 2003) and was administered prior to the start of the study. Health conditions that were assessed included: heart attack, cancer, AIDS, neurological disorder (e.g., Parkinson’s, seizures), breathing disorder (asthma, emphysema), urinary problems (kidney disease, prostate problems), diabetes, pain (arthritis, back pain, migraines), and gastrointestinal disorders (stomach, irritable bowels, ulcers, and gastric reflux).

Self-report sleep questions asked whether the participant had a sleep problem and if they or a bed partner noticed heavy snoring, difficulty breathing or gasping for breath, frequent leg jerks, restlessness before sleep onset, sleep attacks during the day, or paralysis at sleep onset. If they answered yes to any of these problems, they were asked to describe the problem and indicate how often and for how long the symptoms had occurred. Additionally, the participants were asked for the names of all medications they were currently taking and about any mental health concerns.

Social Rhythm Metric.—The Social Rhythm Metric (SRM-17; Monk et al., 1990) was completed each morning about the prior day’s activities. The SRM-17 is a scale designed to assess the extent to which an individual is regular or irregular on a daily basis in the timing of daily events.
Data was collected for the timing of 15 events: out of bed, first contact with another person, morning beverage, breakfast, first go outside, start work (including paid employment, school, housework, volunteer activities, child, or family care), lunch, afternoon nap, dinner, physical exercise, evening snack or drink, evening TV news program, another TV program, return home, and bedtime. Additionally, participants recorded the time they completed two activities of their choosing on a regular basis. The scale also assessed whether other individuals were present for each activity. Individuals recorded the clock time that the activity was completed and then indicated if they were alone, and if they were not alone, who else was present, and to what extent they were involved in the activity.

The SRM-17 has shown good test-retest reliability for older adults and adults (Monk et al., 1994). Additionally, the SRM-17 demonstrated good construct validity (Monk et al., 1990) and adequate criterion validity for adults (Monk et al., 1994).

Sleep Diary.—Sleeping behaviors were measured using a sleep diary that was completed upon awakening by participants. The sleep diary provided spaces for the individual to record information about napping behavior, bedtime, the amount of time to fall asleep, the number of awakenings, the total time spent awake during the night, wake up time, out of bed time, and sleep quality rating (Lichstein, Riedel, & Means, 1999). Sleep diaries have become a primary form of sleep assessment due to their ease of use, ecological validity, and reliability for assessing sleep (Lichstein et al., 1999).

The variables of interest for the present study that were derived from the sleep diary included: sleep onset latency (SOL; initial time from lights out until sleep onset); wake time after sleep onset (WASO; time spent awake during the night after initially falling asleep); number of awakenings (NWAK; the number of times you awaken during the night), total sleep time (TST; total time spent in bed minus SOL and WASO until final wake up); and sleep quality rating (SQR; a 5-point rating of the quality of sleep ranging from poor to excellent). These five variables represent distinct components of the sleep experience (e.g., unwanted wake time at the beginning [SOL] and during the night [WASO]; sleep fragmentation [NWAK]; sleep duration [TST]; and perception of sleep quality [SQR]). Additionally, these sleep variables represent the sleep experience at different time periods during the night—onset (SOL), during the night (WASO and NWAK), and overall sleep across the entire night (TST and SQR). Sleep variables were averaged across the 14 nights of data collection to create a mean for each sleep variable.

Data Analysis

Selection of daily activities.—Daily activities were selected from the 17 daily activities of the SRM-17. An excessively large number of comparisons would have been required if all 17 activities were examined in the study (e.g., 17 activities × 3 sleep outcomes × 2 age groups). Consequently, a priori decisions were made to reduce the number of activities included in the analyses. First, the two activities that were personally specified by each individual were excluded from the analyses as they were not consistent across participants. Second, activities that were not conducted on a weekly basis by at least 75% of the participants were excluded (e.g., napping and exercise). Third, considerable research exists linking exposure to daylight, activity levels, and meals with sleep outcomes. As a result, activities representing these categories of behaviors that occurred across the day were selected for inclusion in the analyses: first time going outside, starting work or another activity (e.g., chores), and eating dinner.

Intraindividual variability and mean timing of daily activities.—Intraindividual variability in the activity variables was created by calculating the standard-deviation for each person’s timing of the outside, work, and dinner activities resulting in an intraindividual standard deviation (iSD). The first step in creating the iSD variables was to detrend the activities to control for any variations that were due to the effects of observing behaviors over time. Linear regressions were calculated for all participants with time (linear, quadratic, and cubic functions) as the independent variables and the activity variables as the dependent outcomes. The second step involved calculating the iSD for the activity variables using the time-independent residuals form the prior step. The resulting outside variability, work variability, and dinner variability variables consisted of a measure of within-person standard deviation that was independent of any influences of time. Additionally, mean-level values were calculated for the three activities resulting in measures of the mean time of day that the activity occurred for each individual (outside_mean, work_mean, and dinner_mean).

Analyses.—Multiple hierarchical regression analyses were run with activity variables predicting sleep outcomes. A multi-step, model building process was followed: Step 1) sex, number of health conditions, age group (younger or older), and mean activity level were entered; Step 2) variability in activity was entered; and Step 3) age group by variability in activity interaction was entered. Analyses were conducted separately for each activity (outside, work, and dinner) and sleep (SOL, WASO, NWAK, TST, and SQR) variable.

Results

Age Differences in Activity Variables

Independent samples t tests indicated that the mean timing of activities occurred significantly later in the day for younger adults compared to older adults (e.g., going outside, t(98) = 4.30, p < .001; beginning work, t(98) = 4.60,
p < .001; eating dinner, t(98) = 4.40, p < .001; see Table 1). There was significantly greater intraindividual variability in the timing of going outside, t(98) = 3.27, p = .002, and eating dinner, t(98) = 6.44, p < .001, for younger compared to older adults.

**Outside Activity Predicting Sleep Outcomes**

The third model with the age group by outside variability interaction predicting WASO was significant, $R^2 = .32$, $\Delta R^2 = .04$, $F(6, 93) = 7.18$, $p < .001$ and was a significant improvement over the prior models, $p = .03$ (see Table 2). Graphing the interaction effect revealed age differences with older adults experiencing longer WASO in association with greater variations in the time they went outside compared to younger adults (see Figure 1). For TST, the first model fit the best, $R^2 = .22$, $F(4, 95) = 6.74$, $p < .001$, with age group and mean outside time as significant predictors. For NWAK, Model 2 was the best fitting model, $R^2 = .32$, $\Delta R^2 = .08$, $F(5, 94) = 7.56$, $p < .001$, with number of health conditions, age group, and variability in outside time in association as significant predictors. The second model predicting SQR was significant, $R^2 = .19$, $\Delta R^2 = .04$, $F(5, 94) = 4.40$, $p < .01$ and was a significant improvement over the prior models, $p = .02$. Number of health conditions and outside variability were significant predictors of SQR. Timing of outside activity was not a significant predictor of SOL (outside mean, $p = .90$ and outside variability, $p = .96$).

In summary, being older was associated with spending more time awake during the night, less time asleep overall, and a greater number of awakenings. Having a higher number of health conditions was associated with a greater number of awakenings and lower sleep quality ratings. Going outside later in the day was associated with more total sleep time. Greater variability in the timing of outside exposure was associated with more awakenings at night, more time spent awake during the night, and lower sleep quality ratings. However, the association between time spent awake at night and variability was stronger for older adults.

**Work Activity Predicting Sleep Outcomes**

The first model best predicted TST, $R^2 = .30$, $F(4, 95) = 9.99$, $p < .001$, with age group, $p = .03$, and mean work time, $p < .001$, as significant predictors (see Table 3). The third model best predicted SOL, $R^2 = .24$, $\Delta R^2 = .10$, $F(6, 93) = 4.76$, $p < .001$, and was a significant improvement over the prior model, $p = .001$. Age group and work variability were significant predictors but these associations were qualified by a significant age group × work variability interaction, $p = .001$ (see Figure 1). Timing of work activity was not a significant predictor of WASO (work_mean, $p = .58$ and work variability, $p = .86$), NWAK (work_mean, $p = .23$ and work variability, $p = .91$), or SQR (work_mean, $p = .12$ and work variability, $p = .40$).

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Table 2. Hierarchical Multiple Regression Analyses Predicting Wake After Sleep Onset, Total Sleep Time, Number of Awakenings, and Sleep Quality Rating With Mean-level and Variability of Time Going Outside (N = 100)

| Variable            | Wake after sleep onset | Total sleep time | Number of awakenings | Sleep quality rating |
|---------------------|------------------------|------------------|----------------------|----------------------|
|                     | $R^2$ | $b$ | $SE_b$ | $R^2$ | $b$ | $SE_b$ | $R^2$ | $b$ | $SE_b$ | $R^2$ | $b$ | $SE_b$ |
| **Step 1**          |       |     |        |       |     |        |       |     |        |       |     |        |
| Sex                 | .23   | .63 | 4.36   | .22   | 11.34 | 12.84  | .21   | .06   | .23   | .18  | .11   |
| Health*             | .13   | 2.06 |       | -1.75 | 6.05  | .21*   | .10   | .15** | .05   |       |       |
| Age group           | 22.81*** | 4.90 |       | -40.75** | 14.44  | .69**   | .25   | .004  | .13   |       |       |
| Outside_mean        | .02   | .02  | .14*   | .06   |       |        | .001  | .001  |       |       |       |
| **Step 2**          |       |     |        |       |     |        |       |     |        |       |     |        |
| Sex                 | .28*  | .507 | 4.28   |       |     |        | .29** | .02   | .21   | .15  | .11   |
| Health*             | .84   | 2.03 |       | -3.39 | 6.04  | .25*   | .10   | .16** | .05   |       |       |
| Age group           | 24.31*** | 4.82 |       | -44.17** | 14.37  | .78**   | .24   | .03   | .12   |       |       |
| Outside_mean        | .01   | .02  | .17**  | .06   |       |        | .001  | .001  |       |       |       |
| Outside_variability | .08*  | .03  | -1.9   | .10   |       |        | .01** | .002  | .002  | .001  |       |
| **Step 3**          |       |     |        |       |     |        |       |     |        |       |     |        |
| Sex                 | .32*  | -4.91 | 4.19   |       |     |        | .30   | .03   | .21   | .15  | .11   |
| Health*             | 1.17  | 1.99 |       | -3.46 | 6.09  | .26*   | .10   | .17** | .05   |       |       |
| Age group           | 22.95*** | 4.75 |       | -43.86** | 14.56  | .75**   | .24   | .02   | .13   |       |       |
| Outside_mean        | -.004 | .02  | .17**  | .06   |       |        | .002  | .001  | .001  |       |       |
| Outside_variability | 1.14  | .10  | -1.4   | .34   |       |        | .001  | .005  | .000  | .003  |       |
| Age group ×         | 9.76* | 4.27 |       | -2.22 | 13.08 | .25    | .21   | .07   | .11   |       |       |
| outside variability |       |       |        |       |     |        |       |     |        |       |     |        |

Note. $b$ refers to unstandardized regression coefficients.

*Total number of classes of health conditions from the following list: heart problems, cancer, hypertension, neurological disorder, breathing disorder, urinary problems, diabetes, pain, gastrointestinal disorders, mental health disorder, and other.

*p < .05, **p < .01, ***p < .001.
In summary, being older was associated with spending less time asleep at night compared to younger adults. Starting work later in the day was associated with spending more time asleep at night for both age groups. Age differences were found for the association between variability in the timing of work and the time needed to fall asleep. Younger adults who were more variable in the timing of starting work took longer to fall asleep. Conversely, older adults who were more variable in the timing of starting work needed less time to fall asleep.

**Dinner Activity Predicting Sleep Outcomes**

The third model best predicted TST, $R^2 = .21$, $F(6, 93) = 4.19$, $p = .001$, and was a significant improvement over the prior model, $p = .04$ (see Table 4). Age group was a significant predictor, $p = .004$, however, this result was qualified by an age group × dinner variability interaction, $p = .04$. Graphing the interaction revealed that variability in the timing of dinner was associated with less total sleep time for younger adults and more total sleep time for older adults (see Figure 1). Timing of dinner was not a significant...
Table 3. Hierarchical Multiple Regression Analyses Predicting Total Sleep Time and Sleep Onset Latency With Mean-level and Variability of Time Beginning Work (N = 100)

| Variable                        | Total sleep time | Sleep onset latency |
|---------------------------------|------------------|---------------------|
|                                 | R²   | b     | SE b | R²   | b     | SE b |
| Step 1                          |      |       |      |      |       |      |
| Sex                             | .30  | 1.81  | 12.45| .13  | −.43  | 3.59 |
| Health*                         |      | −1.48 | 5.73 |      | 2.15  | 1.65 |
| Age group                       |      | −30.61*| 13.91|      | 8.80* | 4.01 |
| Work_mean                       |      | .24***| .06  |      | −.01  | .02  |
| Step 2                          | .30  | .41   | 12.74| .14  | −1.03 | 3.67 |
| Sex                             |      | −.89  | 12.73|      | −.10  | 3.49 |
| Health*                         |      | −.12  | 6.06 |      | .42   | 1.66 |
| Age group                       |      | −34.31*| 14.19|      | 11.49**| 3.89 |
| Work_mean                       |      | .22** | .06  |      | .01   | .02  |
| Work_variability                |      | −.42  | .30  |      | .24** | .08  |
| Age group × work_variability    |      | 16.54 | 12.51|      | −11.74***| 3.43 |

Note. b refers to unstandardized regression coefficients.

*Total number of classes of health conditions from the following list: heart problems, cancer, hypertension, neurological disorder, breathing disorder, urinary problems, diabetes, pain, gastrointestinal disorders, mental health disorder, and other.

*p < .05. **p < .01. ***p < .001.

Table 4. Hierarchical Multiple Regression Analyses Predicting Total Sleep Time With Mean-level and Variability of Time Eating Dinner (N = 100)

| Variable                        | Total sleep time |
|---------------------------------|------------------|
|                                 | R²   | b     | SE b |
| Step 1                          | .18  |       |      |
| Sex                             |      | 11.59 | 13.22|
| Health*                         |      | −.43  | 6.21 |
| Age group                       |      | −57.59***| 15.41|
| Dinner_mean                     |      | −.05  | .12  |
| Step 2                          | .18  |       |      |
| Sex                             |      | 11.73 | 13.28|
| Health*                         |      | −.24  | 6.25 |
| Age group                       |      | −54.70**| 16.93|
| Dinner_mean                     |      | −.06  | .13  |
| Dinner_variability              |      | .10   | .25  |
| Step 3                          | .21  |       |      |
| Sex                             |      | 12.21 | 13.06|
| Health*                         |      | −.16  | 6.15 |
| Age group                       |      | −49.50**| 16.84|
| Dinner_mean                     |      | −.05  | .12  |
| Dinner_variability              |      | −1.29 | .72  |
| Age group × dinner_variability  |      | 31.26*| 15.13|

Note. Only activity variables that were significantly associated with sleep outcomes in the bivariate analyses (Table 2) were entered into regression models. Hence, there is only one regression model for older adults predicting SOL. b refers to unstandardized regression coefficients and b* refers to standardized regression coefficients.

*Total number of classes of health conditions from the following list: heart problems, cancer, hypertension, neurological disorder, breathing disorder, urinary problems, diabetes, pain, gastrointestinal disorders, mental health disorder, and other.

*p < .05. **p < .01. ***p < .001.

In summary, variability in the timing of dinner was associated with less time spent asleep at night for younger adults, and more time spent asleep at night for older adults.

Follow-up Analyses

To further explore the associations between mean timing of going outside and starting work and longer total sleep time, bivariate correlations were run between mean timing of going outside and starting work, the time that individuals reported getting out of bed, and total sleep time. Later timing of going outside (r = .74, p < .001) and starting work (r = .81, p < .001) was significantly associated with later out of bed times. Later out of bed times were significantly associated with longer total sleep time (r = .49, p < .001).

Discussion

The main finding from the present study is that intradividual variability in the timing of daily activities better predicted sleep outcomes compared to the mean timing of activities for four out of the six significant models. Of the two models with mean timing significantly predicting sleep outcomes, going outside and beginning work later in the day was associated with longer total sleep time for predictor of SOL (dinner_mean, p = .28 and dinner_variability, p = .14), WASO (dinner_mean, p = .45 and dinner_variability, p = .13), NWAK (dinner_mean, p = .76 and dinner_variability, p = .34), or SQR (dinner_mean, p = .61 and dinner_variability, p = .70).
both younger and older adults. A possible explanation for the association between beginning these activities later in the day and longer total sleep time is that a greater window of opportunity for sleep is created with later start times for these activities. Consistent with this hypothesis, follow-up analyses revealed that individuals who began these activities later in the day reported getting out of bed later in the day. Furthermore, later rise times were associated with longer total sleep time.

As hypothesized, greater dysregulation of the timing of activities better predicted the majority of sleep outcomes compared to mean timing. However, the specific associations between variability in the timing of events and sleep outcomes differed depending on the activity and age group. For example, although greater dysregulation in the timing of going outside was associated with worse sleep outcomes, dysregulation of work and dinner timing was associated with better sleep outcomes for older adults. In terms of going outside, a greater number of awakenings during the night and worse sleep quality for younger and older adults, and significantly longer unwanted wake time during the night for older adults, was associated with greater variations in the first time outdoors. Light exposure has long been recognized as the dominant “zeitgeber” (Mistlberger & Skene, 2004), serving to synchronize our sleep–wake cycle with the light–dark phase. Brighter light exposure (e.g., 100,000 lux on a sunny day) is associated with outdoor light compared to dimmer exposure from indoor light (e.g., 1,000 lux). Dysregulation of this bright light exposure, especially first light exposure which plays a unique role in the circadian regulation of sleep (Mistlberger & Rusak, 2011), could understandably be associated with worse sleep. The age interaction indicating that older adults particularly experienced worse sleep with dysregulation of their outside exposure may reflect changes in the perception of light with age and degenerative processes that can diminish the amount and spectral composition of light input (Wirz-Justice, 2009).

Surprising age differences emerged when examining the association between dysregulation of work and dinner activities in relation to sleep onset latency and total sleep time. As mentioned in the introduction, there are age differences in the regularity of behavioral rhythms, with older adults typically being more regular compared to younger adults (Monk et al., 1997). Interestingly, higher levels of intraindividual variability in the timing of work and dinner activities was associated with poorer sleep outcomes for younger adults but not for older adults. Specifically, inconsistency in the time that younger adults first began work was associated with needing longer to fall asleep and inconsistency in the time that they ate dinner was associated with less total sleep time. The findings for younger adults are consistent with research showing higher levels of irregularity in behavioral rhythms are associated with poorer sleep outcomes (Carney et al., 2006). Given the documented association between poor mood and sleep (Nadorff, Fiske, Sperry, Petts, & Gregg, 2013; Peterson & Benca, 2011), it is possible that worse mood, and higher levels of stress and anxiety, often experienced by younger adult college students, could have contributed to poorer sleep outcomes for this age group. In fact, previous research has demonstrated that depressive symptoms account for some (although not all) of poorer sleep outcomes in relation to variability in the timing of activities (Carney et al., 2006). Further research is needed to account for the role of these variables in the association between variability in activity timing and sleep across age groups.

The finding that dysregulation of work and dinner times was associated with better sleep outcomes for older adults is less straightforward. Overall, prior research has revealed regularity in daily activities to be associated with better sleep outcomes (e.g., Zisberg et al., 2010). However, it is possible that for older adults, the association between regularity and outcomes such as nocturnal sleep is more complex and perhaps non-linear. First, in the present study, a lower number of health conditions was also predictive of better sleep outcomes. It is plausible that consistency in the timing of some activities for older adults could reflect poorer functioning, which, in turn, could be related to poorer sleep outcomes. For example, for older adults with functional limitations, meal times may be predicated on receiving assistance, which in turn could act to regulate this activity. Furthermore, older adults with functional impairments could have a reduced range of activities that is reflected in greater regularity in the timing of their work activities. In that case, greater regularity could be indicative of more health impairments, and, given the known association between poor health and poor sleep (Ohayon, 2002), also indicative of poorer sleep. Additionally, inconsistencies in the timing of work activities and meals could actually reflect a higher activity level resulting in varying meal times or more social engagements with other individuals. The participants in the present study consisted of community-dwelling older adults (vs. older adults in a retirement community in the Zisberg et al., 2010 study). Consequently, the sample from the present study may have consisted of a greater range of functional abilities (e.g., highly independent to requiring assistance).

A second explanation for the association between variability in work and dinner times and positive sleep outcomes in older adults is that variations in timing could effect the components of the two-process model of sleep: (a) the homeostatic build-up of sleep debt; and (b) the circadian-dependent arousal signal (Borbely, 1982). Some older adults experience a decreased drive to sleep with age, due in part to decreased activity during the day coupled with increased napping. As a result, they do not build up a sufficient sleep debt across the day, resulting in poorer sleep at night. Variability in the timing of work events (whether outside the home or through within home activities) could have
an activating effect, increasing alertness and subsequently the drive to sleep, resulting in shorter sleep onset and longer total sleep time. Additionally, variability in dinner times could impact the circadian component of the two-process model of sleep. There is considerable evidence for age-related changes in the circadian rhythms underlying sleep. Older adults tend to have earlier circadian phases often accompanied by undesirable early morning awakening and more awakenings (Ohayon, 2002). Variations in dinner times, an activity occurring later in the day, whether due to a change in schedule or socializing, could have a stimulating effect that maintains alertness for longer into the evening period and results in greater evening light exposure. As a result, bedtimes in older adults who are experiencing an undesirable phase advance of their sleep–wake cycle could become better aligned with the light–dark cycle, which, in turn, serves as the main zeitgeber of sleep. Importantly, the association between dysregulation of work and dinner times and better sleep outcomes in older adults is a novel outcome and is in need of replication in future independent studies.

In summary, the association between variability in the timing of activities and sleep depended on the type of activity and age group. Variability in exposure to light was universally associated with worse sleep outcomes for both younger and older adults (although older adults experienced even worse sleep). Furthermore, variability in activities not associated with bright light such as starting work or eating dinner was associated with better sleep outcomes for older adults. The implications for these findings include a need to assess the regularity of daily activities in the treatment of poor sleep. Current interventions address the time of day of specific activities (e.g., napping earlier in the day, avoiding heavy meals or exercise late at night; Perlis, Jungquist, Smith, & Posner, 2008). The present results highlight the need to also consider the level of dysregulation of daily activities and the unique role that type of activity may play in promoting sleep outcomes (e.g., activities involving exposure to light vs. indoor activities).

There are several strengths of the present study including the assessment of multiple daily activities, the inclusion of a younger and older adult sample enabling age comparisons, and the use of a microlongitudinal design. By using repeated measures of daily activities, both mean levels and intraindividual variability could be calculated and, consequently, compared. Limitations of the present study include the use of a convenience sampling method resulting in a sample that may have limited generalizability (e.g., the younger adults primarily represented a narrow demographic of college students). Additionally, gender and race was not balanced across age groups. Also, conclusions cannot be drawn regarding the directionality of the relationships between daily activities and sleep outcomes. It is possible that overall poorer nocturnal sleep could have led to increased variability in daily activities for younger adults and decreased variability for older adults. Additional studies are needed to replicate the finding that dysregulation of daily activities may be associated with positive sleep outcomes in older adults. Finally, in contrast with earlier studies (e.g., Zisberg et al., 2010), the use of daily sleep diaries and the longer version of the Social Rhythm Metric in the present study may have enabled the recording of greater variability in daily activities and sleep outcomes. Future research would benefit from inclusion of objective sleep indices (e.g., actigraphy or polysomnography) in addition to subjective measures of sleep as complementary approaches to measurement can provide a more complete picture of sleep (Williams, Kay, Rowe, & McCrae, 2013).

In conclusion, intraindividual variability in the timing of daily activities was predictive of more sleep outcomes in both younger and older adults compared to the mean timing of daily events. Interestingly, age differences were found in the relationship between intraindividual variability of daily activities and sleep outcomes with intraindividual variability appearing to be more adaptive for older adults.

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Conflict of Interest
None of the authors have any conflicts of interest to disclose.

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