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Variability in Self-Reported Normal Sleep Across the Adult Age Span

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Abstract

Objective: Illustrate the importance of examining both within- and between-person differences in sleep across the adult age-span. **Method:** Two weeks of sleep diary data were analyzed for 592 normal sleepers ranging in age from 20 to 96 years. Variability in total sleep time (TST), nighttime awakenings (NWAK), sleep-onset latency (SOL), and wake time after sleep-onset (WASO) was examined overall and by age, sex, and race. Multilevel models described the extent to which self-reported sleep varied within- and between-individuals across the two-week period. Multiple regression analyses tested for age, sex, and race differences in intra-individual variability. **Results**: Night-to-night differences in sleep within the same individual generally exceeded differences between individuals for TST, SOL, and WASO. The amount of intra-individual variability in TST and NWAK decreased with older age. Further, the degree of reduction in variability in TST associated with age depended on sex and race, with young Black females showing the greatest variability. In general, females tended to have more intra-individual variability in SOL and NWAK than males, while race differences were complicated by high variability between-Blacks. **Discussion:** To truly assess and understand individual differences in the sleep of older adults, future research needs to take into account night-to-night variability (including what makes sleep vary from one night to the next), in addition to average sleep.

Keywords: sleep, intra-individual variability, age-related change

Introduction

Poor sleep is a significant problem for older adults, with almost half of adults aged 65 years and older reporting difficulties sleeping on several nights of the week (Foley et al., 1995). There are also changes in sleep architecture occurring across adulthood. Sleep becomes lighter with age and shifts between sleep stages more frequent (Ohayon, Carskadon, Guilleminault, & Vitiello, 2004), with older adults experiencing more awakenings and more time awake (Lichstein, Durrence, Riedel, Taylor, & Bush, 2004; Ohayon et al., 2004). The sleep phase of older adults advances, leading to sleep-onset and wake-up times several hours earlier than desired (Myers & Badia, 1995). Despite these age-related changes in sleep structure, poor sleep is not an inevitable result of aging. Instead, this increased prevalence of sleep disturbance in older adults is related to the higher levels of medical comorbidities (e.g., chronic pain) and other life events (e.g., retirement, loss of spouse) that accompany aging. Given the myriad of potential influences on older adults' sleep and the negative consequences that sleep problems have on their health and functioning, there is a need for more research and interventions focused on this population.

The purpose of this study is to examine intra-individual variability (IIV) in sleep, or the extent to which sleep varies from night to night, across the adult age span. Most research on sleep averages values across several nights or uses a single-point estimate of habitual sleep. However, this may not be an accurate representation of a person's sleep and could overlook valuable information about age-related change processes. Developing normative values of IIV in sleep will provide baseline levels of short-term variability that can increase our understanding of how pathological sleep patterns develop and/or resolve at different stages of life. There is already an important role for psychologists in the delivery of behavioral treatments to improve sleep (e.g., multi-component cognitive behavioral interventions for insomnia; Morin et al., 2006). Given the unique nature of sleep in older adults, there is a role for clinical geropsychologists who are already skilled in recognizing the biopsychosocial influences affecting such a dynamic process in late-life. However, in order to develop and deliver efficacious interventions to this population, we need a complete understanding of sleep across the lifespan, which includes short-term variability. In fact, a required geropsychology competency is an understanding of normative and successful aging (Molinari, 2012).

Furthermore, there may be functional implications of sleep variability that influence psychological and physical health of older adults. For instance, greater IIV in sleep has been associated with increased stressful life events (Mezick et al., 2009), negative affect (Fuligni & Hardway, 2006), depression and suicidal ideation (Bernert, 2009), and poor sleep quality (Carney, Edinger, Meyer, Lindman, & Istre, 2006), and nightly fluctuations in sleep have been linked to subsequent daily fluctuations in mood and health complaints in community samples (Fuligni & Hardway, 2006; McCrae et al, 2008). Daily changes in sleep duration are also associated with worse cognitive functioning in older adults (Gamaldo, Allaire, & Whitfield, 2010). Finally, the amount of nightly variability seems to be independent of aggregate measures of sleep. A study of napping behavior in community-dwelling older adults found that day-to-day variability in naptime was predictive of medical morbidity while average nap duration was not (Dautovich et al., 2012). Therefore, sleep variability may be a potential target for geropsychology interventions.

Although studies have documented IIV in objective measures of sleep in the general adult population (Knutson, Rathouz, Yan, Liu, & Lauderdale, 2007; Mezick et al., 2009; Tworoger, Davis, Vitiello, Lentz, & McTiernan, 2005; van Hilten et al., 1993), little is known about age differences in IIV. Two studies failed to find age effects on objective measures of sleep variability (Mezick et al., 2009; van Hilten et al., 1993). However, both study samples were limited to the higher end of the age span and age differences may exist outside of these ranges. A study looking at sleep-wake patterns in healthy adult males found that younger males (19-26 years) showed more day-to-day variability in the timing of their sleep schedules (times entering and leaving bed) than older males (59-74 years; Kramer, Kerkhof, & Hofman, 1999). If younger adults have more variability in the timing of their sleep schedules, they will likely exhibit greater variability in other sleep parameters (i.e., sleep-onset latency, TST) as well.

Some researchers theorize that greater regularity in older adults' sleep schedules is due to lifestyle changes that tend to occur with increasing age. Indeed, lifestyle regularity does increase with age (Monk et al., 1997) and greater lifestyle regularity is associated with better sleep quality (Monk, Reynolds, Buysse, DeGrazia, & Kupfer, 2003). Perhaps there is more heterogeneity in the daily schedules of younger and middle-aged adults as they balance work schedules with other family and life demands, and this continues into the night, leading to greater variability in sleep patterns. Furthermore, subsets of the older adult population may exhibit greater variability. Rowe, McCrae, Campbell, and colleagues (2008) found that older adult caregivers to persons with dementia had greater night-to-night variation in both objective and subjective sleep than non-caregiving older adults.

Finally, sex and race differences may exist in sleep variability, and may interact with age. Studies addressing sex differences suggest females have greater IIV than males in most measures of adult (Knutson et al., 2007; Mezick et al., 2009; van Hilten et al, 1993) and adolescent (Fuligni & Hardway, 2006) sleep. Studies have also addressed racial differences, reporting greater IIV in some measures of sleep for Blacks compared to Whites (Knutson et al., 2007), although results are not consistent across all sleep outcomes (Knutson et al., 2007; Mezick et al., 2009; Moore et al., 2011).

We used an existing epidemiological sample to examine variability in normal sleep across 14 days of sleep diaries. Any variable measured over time has at least two sources of variation: within-person and between-person. Therefore our first aim was to examine sources of variability in four aspects of self-reported sleep; total sleep time (TST), number of awakenings (NWAK), sleep-onset latency (SOL), and wake-time after sleep onset (WASO). Based on prior research documenting high IIV in sleep, we hypothesized that the majority of variability in all four sleep parameters would be due to within-person as opposed to between-person differences. Furthermore, the distribution/sources of variability were examined for three age groups (young, middle-age, and older adults) and by sex and race.

The second aim was to investigate individual differences and potential correlates of IIV. Specifically, we examined whether the amount of IIV in each sleep parameter differed by age, sex, or race. Consistent with prior research showing that regularity in sleep-wake behaviors increases (becomes less variable) with age, we expected IIV in TST to decrease with increasing age. However, because the average number of awakenings tends to increase with older age, we did not expect age-related changes in IIV in NWAK. Based on a few previous studies, we hypothesized that women and Blacks would exhibit greater IIV in self-reported TST and NWAK than men and Whites. Due to a lack of prior research on IIV in SOL and WASO, hypotheses were not made for these sleep parameters.

Method

Participants

This study used archival data gathered as part of an epidemiological survey of sleep and daytime functioning (Lichstein et al., 2004). A random-digit dialing procedure was used to recruit a stratified, randomly selected sample of adults from a county in the Southeastern United States. To ensure adequate sampling of sex and age, recruitment continued until at least 50 men and 50 women in each age decade were enrolled, beginning with ages 20-29 and ending with 80 and older. The county's population was predominantly White (47.3%) and Black (48.6%), though all ethnicities were included. Eligibility criteria included age (20+) and ability to speak/read English. Participants were compensated between $15 and $200 when they returned completed questionnaires. Males and older adults received larger payments because of recruitment difficulties. The many forms required of participants posed a differential burden to select groups, particularly older adults, thus compensation was incrementally graduated to recruit these groups. (Approximately 19% of sample received compensation greater than $100 and all were aged 60 and older.)

Measures

Demographics. Participant age, sex, and race were determined by self-report data on a health survey. For descriptive purposes, three age categories were used; young (20-35 years), middle-aged (36-64 years) or older (65-96 years) adults.

Sleep Diary. Self-reported sleep was assessed using sleep diaries (given in Lichstein et al., 2004) that participants completed each morning for 14 consecutive days. The present study used four nightly sleep measures: sleep-onset latency (SOL), wake time after sleep-onset (WASO), number of awakenings (NWAK), and total sleep time (TST) in minutes. The first three sleep measures were obtained directly from sleep diaries. TST was computed by subtracting total wake time during the night from total time spent in bed that night.

Potential Correlates. Mean levels of sleep were considered potential correlates of IIV in sleep since the amount of variability possible is dependent in part on the range of observed values for that parameter. A health survey form (Lichstein et al., 2004) collected additional demographic and health information used as covariates. Household education (highest number of years of education achieved for participant or spouse) was used as a proxy for socioeconomic status. Given that health impacts sleep, participants indicated all of the following categories in which they have health problems: heart disease, cancer, AIDS, hypertension, neurological disease, breathing problems, urinary problems, diabetes, gastrointestinal problems, and chronic pain. Affirmative responses were summed to obtain total number of physical health problems for each participant. The 21-item Beck Depression Inventory-II (BDI-II; Beck, Brown, & Steer, 1996) was used as a self-report measure of depression symptoms over the past two weeks. Participants rated each item 0-3 with a higher summed score representing more severe mood disturbance. Depression has been associated with poor sleep, thus total BDI-II scores were included as a covariate.

Procedure

Interested recruits were mailed packets containing informed consent, sleep diaries, and questionnaires about daytime symptoms/impairment. Participants received monetary compensation once they returned the completed packet (see Lichstein et al., 2004 for detailed methods).

Statistical Analysis

The first set of analyses used multilevel modeling (MLM) to examine sources of variability in self-reported TST, NWAK, SOL, and WASO. MLM refers to a set of techniques focused on decomposing the variance across multiple levels of hierarchy (Bryk & Raudenbush, 1992; Hoffman, 2007). By accounting for dependence among repeated-measures from a single person, MLM takes advantage of all existing data points. Nightly sleep values from 14 days of measurement (Level 1) were nested within individuals (Level 2). This sample size exceeds Snijders and Bosker's (1993) minimum requirements for MLM (n=6 per Level 1 unit and N=10 for higher level units). For each sleep outcome, an unconditional (i.e., no predictors) random intercept two-level model was estimated using our normal sleeper sample. Separate unconditional random intercept models were also estimated for each subgroup: young, middle-age, older, males, females, Whites, Blacks.

Next, we calculated individual and group-level statistics for sleep diary data. Intra-individual means were calculated by averaging the individual's 14 nightly values for each sleep parameter. Intra-individual standard deviations (iSD) were also calculated across each individual's 14 nights of data to indicate the amount of variation from his/her mean across the two weeks. Correlational analyses were run to explore potential covariates.

Multiple regression analyses tested for age, sex, and race differences in nightly sleep variability. Separate hierarchical regression models were built for each sleep outcome, with iSDs as the dependent variable. Relevant control variables (often including mean values of that sleep variable) were entered in Step 1, independent variables (age, sex, and race) in Step 2, and potential interactions among three IVs of interest in Step 3. Nonsignificant control variables and interactions were removed from final regression models. Using statistical power of .80, probability of 0.05, and maximum 11 possible predictors, power analyses determined a minimum sample size of 122 was needed to detect a medium size effect ($f^2 = .15$).

Results

Sample Characteristics

See Lichstein et al. (2004) for details on the overall sample of 772 participants. To obtain our subsample of normal sleepers, 137 individuals were excluded for insomnia and 33 individuals for other sleep disorders (e.g., sleep apnea). Nine participants who identified themselves as belonging to a racial-ethnic group other than Blacks or Whites were excluded due to limited numbers. One additional participant was excluded due to invalid sleep diary data resulting in extreme values on outcome variables. Missing data was minimal and seemed at random, with the exception of education level, which was added to questionnaires shortly after data collection began.

The final sample of normal sleepers (*N* = 592) ranged in age from 20 to 96 years (*M* = 52.3, *SD* = 19.5). Household education ranged from 2 to 20 years (*M* = 14.5, *SD* = 2.9), with over half of participants reporting college coursework (Median = 14 years). Number of health problems ranged from 0 to 6 (*M* = .97, *SD* = 1.2). Although we excluded individuals with sleep disorders, 17% of this sample reported sleep complaints. Mean BDI-II score (*M* = 7.0, *SD* = 6.3) indicated minimal depressive symptoms. See Table 1 for breakdown by demographic group.

Sources of Variability in Self-Reported Sleep

Total variance in sleep across two weeks is composed of differences within a person in sleep values from one night to the next and differences between persons in average values (i.e., mean level of sleep). Using four unconditional MLM, total variance in TST, NWAK, SOL, and WASO was partitioned into within- and between-person variance (Table 2). All variance components were significant ($p < .001$), indicating significant variability among nightly measures of sleep within the same person, as well as significant variability in sleep between individuals.

Once statistical significance was established, actual values guided further interpretation. The intraclass correlation coefficient (ICC) was calculated in the first step of MLM (Bryk & Raudenbush, 1992). The proportion of total variation due to within-person differences was greater than variation due to between-person differences in the total sample for TST, SOL, and

WASO (Table 2). This means that night-to-night differences within the same individual exceed differences between individuals in these measures. For example, the ICC for TST is .38, indicating that 38% of the variability in TST was due to differences between individuals, and 62% of the variability in TST was due to due to night-to-night fluctuations within an individual. Directly comparing these variance components for TST (ratio of 1.66) indicates the nightly fluctuation in TST within individuals was more than 1.5 times the size of the variation between individuals. Ratios of within-person to between-person variance for SOL and WASO were slightly larger. The difference was minimal for NWAK.

Sources of variability by demographic group. Results of unconditional MLMs for each demographic group are also presented in Table 2. For TST, the ratio of variances decreases with increasing age. In the subsample of young adults, nightly fluctuation within-persons accounted for 72% of total variance compared to 48% for older adults. Females and Whites also had high ratios, indicating more of their variability in TST is due to nightly fluctuation within-persons than to differences between persons. Between-person differences in NWAK were actually greater than variability within-persons for older adults and males. However, there was still significant within-person variability for all demographic categories, with at least 40% of total variance attributed to night-to-night fluctuations in NWAK occurring within-persons. Within-person variability in SOL and WASO is higher than differences between-persons. Notably, for females, over 70% of the variance in WASO was attributable to nightly fluctuations within-persons. Middle-aged adults also had approximately 70% of variance in WASO due to within-person variability as compared to between-persons.

Sleep Characteristics

Intra-individual means and iSDs of each sleep parameter were calculated across all available nights of data per individual (Table 3). Examination of the sleep variables revealed several violations of normality, heteroscedasticity, and nonlinearity. Logarithmic transformations were conducted on mean NWAK, iSD NWAK, mean SOL, iSD SOL, mean WASO, and iSD WASO, which greatly improved the shape of each distribution and reduced heteroscedasticity and nonlinearity to an acceptable level (Tabachnick & Fidell, 2007).

Potential correlates. Bivariate correlations were conducted between iSDs for each sleep parameter, mean values of each sleep characteristic, and health and demographic factors (i.e., household education level, depression, physical health problems; see Table 4). Due to the large sample size, theoretical value was used in addition to statistical significance ($p < .01$) in determining which covariates to include in future analyses.

Multiple Regression Analyses Predicting Intra-individual Variability in Sleep

Age was treated as a continuous predictor and sex and race variables were dummy coded (sex: 0= male, 1= female; race: 0= White, 1= Black), so the reference group was white males. Continuous predictor variables were centered at their mean. Product terms were created to explore potential interactions among age, sex, and race.

Relation with variability in TST. Given research suggesting a relationship between depression and sleep variability (Bernert, 2009), BDI-II scores were entered in Step 1, explaining approximately 2% of the variance in iSD TST, F (1,590) = 10.68, p =.001. Importantly, adding the set of demographic variables (age, sex, and race) in Step 2 increased variance explained by almost 14%, F (3,587) = 31.65, p < .001. Adding interaction terms further increased variance explained, $\Delta R^2 = .02$, F (4,583) = 3.78, p = .005. Results of the final regression model predicting variability in TST were significant, F (8,583) = 15.55, p < .001 (Table 5). BDI-II remained significant in the final model.

The significant 3-way interaction indicates that the relationship between age and IIV in TST depends on both sex and race. Tests of simple slopes revealed a significant effect of age on TST variability for all race and sex categories (white males, white females, black males, black females), all $p < .05$. Slope difference tests (see Figure 1) revealed a difference in slopes for Black and White females, $t(588) = -2.73$, $p = .006$, such that with increasing age, the amount of variability in TST decreases at a greater rate for Black females compared to White females (significant age × race interaction for females). There was also a significant difference in simple slopes for White females and White males, $t(588) = 2.69$, $p = .007$, with the amount of variability in TST decreasing with age at a greater rate for White males than for White females (significant age × sex interaction for Whites). Given that the interaction of sex and race is conditional on age, the significant sex × race interaction in Table 5 only applies to the mean age of the sample (M = 52 years). Figure 1 illustrates this effect at the mean age, showing that the sex difference in variability in TST only pertains to Blacks, with Black females showing greater iSD TST than Black males. White males and females show similar iSD TST at mean age. Further examination of the graph reveals differences in TST variability between demographic groups at lower and higher ages in the sample.

Relation with variability in NWAK. When predicting IIV in NWAK, mean NWAK and education were entered as covariates in Step 1 and accounted for 33% of the variance, F (2,500) = 122.56, $p < .001$. Entering age, sex, and race in step 2 provided a 9% increment in explained variance, F (3,497) = 25.76, $p < .001$. The full model accounted for 42% of the variance in iSD NWAK, $F(5,497) = 71.77$, $p < .001$ (see Table 5). Mean NWAK was the strongest predictor, accounting for 34% of the total variance. Household education explained < 1% of the variance, with more education associated with greater IIV in awakenings. Age and sex were also significant, with females reporting more IIV in NWAK than males, and the amount of IIV decreasing with increasing age. In the presence of other variables, race was not associated with variability in NWAK. There were no interactions among demographic variables.

Relation with variability in SOL. Mean SOL was entered in Step 1 of the model predicting iSD SOL and explained a significant amount of variance, $R^2 = .56$, $F(1,590) = 742.0$, $p < .001$. Adding the set of demographic variables further increased explained variance by 2%, $F(3,587) = 9.03$, $p < .001$. The full regression model was significant, $F(4,587) = 199.85$, $p < .001$ (see Table 5). There were no interactions among demographic variables. Mean SOL remained the strongest predictor, accounting for 53% of the total variance. Age and sex each accounted for approximately 1% of variance, with younger age and female sex associated with greater IIV in SOL. Race accounted for < 0.5% of variance in the full model. The direction of the race effect suggests that Whites have more night-to-night variability in SOL than Blacks, which is inconsistent with average values of iSD SOL for each race (in Table 3). Furthermore, comparison of the regression coefficient for race with the zero-order correlation of race and iSD SOL shows opposite signs. Given the significant association between Black race and mean SOL and the high correlation between mean SOL and iSD SOL, a suppression effect is likely.

Relation with variability in WASO. Based on bivariate correlations and previous research, mean WASO, BDI, and number of health problems were entered in Step 1 of the model predicting iSD WASO. This step accounted for 74% of the variance, $F(3,588) = 564.91$, $p < .001$, but mean WASO was the only significant predictor. Adding demographic variables in Step 2 increased variance explained by 2%, $F(3,585) = 17.12$, $p < .001$. Given the nonsignificant contribution of BDI and health problems to the prediction of iSD WASO, these covariates were removed and we reran the full model. There was no change in variance explained from the first to the second model, suggesting that the elimination of BDI and health problems did not reduce the model's predictive utility. This final model was significant, $F(4,587) = 472.10$, $p < .001$ (see Table 5), accounting for 76% of total variance in iSD WASO. After controlling for mean WASO, age was the only other significant predictor in the model. There were no interactions among demographic characteristics.

Discussion

In this sample of normal sleepers, there was considerable IIV in subjective sleep across a two week period. The amount of within-person variance in TST, SOL, and WASO generally exceeded between-person differences in these measures, while the two sources of variance were similar in size for NWAK. These results are consistent with research using objective measures of sleep (Knutson et al., 2007; Mezick et al., 2009; Tworoger et al., 2005; van Hilten et al., 1993).

Partitioning the variance in each demographic group revealed a pattern for age in TST and NWAK. For TST, younger adults had the highest within-person variance, followed by middle-age, and then older adults. In young adults, 27% of the total variance in TST was due to between-person differences, leaving 73% of variance from within-person fluctuations. This finding indicates that a young adult's TST on any given night is more likely to resemble the TST of another young adult than his/her own sleep on another night. In contrast, variance in TST for older adults was approximately the same for within- and between-person sources, suggesting that an older adult's TST for one night is just as likely to represent the TST of a complete stranger as it is his/her own sleep on another night. This trend for older adults to have less IIV was also apparent for nighttime awakenings and was significant in regression analyses predicting iSDs in TST and NWAK. Age effects for iSDs in SOL and WASO were attributed to statistical suppression.

There are several possible reasons that IIV in sleep may decrease with older age. First, some research has suggested the possibility of reduced homeostatic drive with increasing age (Dijk, Groeger, Stanley, & Deacon, 2010). Under normal conditions, short and disrupted sleep on one night leads to longer and more solid sleep on a subsequent night due to the accumulation of sleep debt and resultant increased sleepiness. Therefore, greater night-to-night variability in TST and NWAK of younger adults could reflect the existence of a stronger homeostatic sleep drive that leads to greater fluctuations in sleep as a mechanism of regulating one's sleep need.

Sleep patterns are also shaped by psychosocial and behavioral factors such as culture, values, environment and lifestyle. Thus, the reduced variability in older adults' sleep could reflect age-related changes in context, as many of the daily demands (e.g., work schedules, childcare responsibilities) that can disrupt sleep from one night to the next tend to decrease with age. It is also possible that older individuals have become better at regulating their responses to daily stressors so there is less impact on nightly sleep. Indeed, research shows that emotion regulation and problem solving improves with age (Blanchard-Fields, 2009). In line with this socioemotional selectivity theory (Carstensen, Isaacowitz, & Charles, 1999), shifting priorities, goals and motivations may lead older adults to become more selective in choosing to avoid activities or environments that increase stress or could interrupt their set sleep schedule.

Although effect sizes were small, our finding that females generally have greater IIV in sleep than males is consistent with previous research (Knutson et al., 2007; Mezick et al., 2009; van Hilten et al, 1993) and could indicate females' sleep is more vulnerable to external and environmental influences from one night to the next. As Tworoger and colleagues (2005) noted in their female sample, short-term variability in sleep could be due to hormonal fluctuations across the menstrual cycle. Additionally, females tend to experience other events (pregnancy, caregiving, menopause) throughout adulthood that can disrupt sleep through biological and behavioral mechanisms. An important finding regarding race is that Blacks had high variability both within- and between-persons, which is consistent with research showing Blacks are more likely to report extreme sleep durations (Hale & Do, 2007; Nunes et al., 2008).

Our results also support lifespan approaches to development that acknowledge how race and sex differences change with age. The amount of IIV in TST associated with age depended on both sex and race. Specifically, with increasing age, nightly variability in TST decreased at a greater rate for White males than for White females. Black females also showed a greater decrease in variability in TST with increasing age when compared to White females, with young Black females having more IIV than other groups. Variability may be particularly high due to social and lifestyle factors more common in young black females, such as earlier childbearing and high parity, which could lead to variation in caregiving demands from one night to the next. As a minority, young black females may be more likely to work multiple jobs/shift work and live in disadvantaged neighborhoods with environmental disruptions (e.g., noise). This finding that racial differences become smaller as females age further highlights the need to explore age-related changes in context that may affect sleep from night-to-night.

Finally, the degree of nightly fluctuation in sleep has clinical and theoretical importance in its own right. Variations in normal sleep could help explain the link between sleep and health, which is particularly relevant in the discussion of aging. For instance, greater IIV in sleep could indicate a dysregulated circadian pattern that has adverse effects on physiological processes (e.g., metabolic function). Preliminary support comes from findings that individuals with high IIV in sleep had elevated nocturnal norepinephrine levels (Mezick et al., 2009) and increased levels of inflammatory markers (Okun et al., 2011). Finally, variability in sleep may either lead to or be a marker of greater variability in other lifestyle/routine health behaviors (e.g., eating habits, physical activity) known to improve health and wellbeing. This line of research could lead to a greater understanding of the role variability plays in successful aging (Rowe & Kahn, 1996).

In light of our finding that TST variability differs by age, sex, and race, it would also be interesting to examine whether IIV plays a role in health disparities. Research has already begun exploring the impact of sociodemographic factors on habitual sleep and health, with a recent study documenting a stronger relation between extreme sleep duration and diabetes risk in Blacks compared to Whites (Zizi et al., 2012). Sleep duration is partly determined by hours available for sleep. Thus, short durations could mean sleep has been curtailed due to social pressures/stress, while longer durations could reflect extended sleep due to lack of daily activities or employment. While these are only two possible explanations, both could lead to poor health behaviors and decreased functioning. A more fine-grained analysis of factors leading to night-to-night variability in demographic groups could enhance understanding of such health disparities.

There are some limitations worth noting. Despite the stratified sampling procedure, the number of Black participants was still somewhat small compared to Whites, and other ethnicities could not be explored. Blacks also had greater amounts of variability in each sleep measure, both within- and between-individuals. As a result, the findings for Blacks are less reliable and should be interpreted with caution until replicated with other samples. Our sample was relatively healthy with low levels of depression, resulting in a restricted range on these covariates. Although education was assessed, other possible confounds were not included (e.g., income, employment, marital status, and caregiving/parenting responsibilities).

This study addresses a largely neglected, but potentially very important topic in the literature on aging and sleep. Our novel statistical approach allowed us to examine sleep variability in two different ways, by separating the overall variance in a measure into within- and between-person sources, as well as exploring age, sex, and race differences in net IIV. A particular strength of this study was the sample's wide age range, which takes a developmental lifespan approach to sleep. The use of self-report data from a community sample allowed us to capture short-term variability as it occurs in an individual's natural sleep environment. These findings also highlight potential methodological issues to consider in research design (van Dongen et al., 2005 Appendix). For example, if Blacks truly have greater IIV in sleep, it may be necessary to collect more nights of data to provide an accurate representation of their sleep. However, given the high amounts of between-person variability found for Blacks in this study, it is imperative to have an adequate sample size of Blacks, especially if race differences are being explored.

Although older adults' sleep is less variable across nights than sleep in younger and middle-aged adults, there is still considerable night-to-night variability, highlighting the need to consider other factors which vary from day-to-day within older adults (e.g., mood, daily demands, sleep environment) and can affect sleep. Furthermore, we found significant heterogeneity between older adults in amount of IIV. Taken together with the higher prevalence of sleep disturbance in older adults and potential consequences of high variability in sleep, future research should explore long-term trajectories of such sleep variability. In addition to gaining a better understanding of how social and behavioral correlates of nightly sleep vary across adulthood, the use of approaches such as those discussed by Rocke and Brose (2013) can inform our understanding of older adults' adaptability and successful aging.

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Table 1

Sample Characteristics by Demographic Group (N = 592)

Group		*n* (%)	# Health problems *M (SD)*	BDI-II scores *M (SD)*	Years of Education *M (SD)*
Age	Young	187 (31.6)	.34 (.63)	7.5 (7.6)	14.9 (2.3)[a]
	Middle	225 (38.0)	.90 (1.1)	6.2 (5.3)	14.8 (2.6)[b]
	Older	180 (30.4)	1.7 (1.3)	7.6 (5.9)	13.8 (3.4)[c]
Sex	Male	294 (49.7)	.96 (1.2)	6.2 (5.5)	14.8 (2.8)[d]
	Female	298 (50.3)	.99 (1.2)	7.9 (6.9)	14.2 (2.9)[e]
Race	White	415 (70.1)	.99 (1.2)	6.4 (5.7)	15.0 (2.6)[f]
	Black	177 (29.9)	.94 (1.1)	8.5 (7.4)	13.2 (3.1)[g]

Note. BDI-II = Beck Depression Inventory-II. Age groups; young: 20-35 years, middle: 36-64 years, older: 65-96 years.
[a]*n* = 141. [b]*n* = 191. [c]*n* = 171. [d]*n* = 259. [e]*n* = 244. [f]*n* = 357. [g]*n* = 146.

Table 2

Estimates of Within- and Between-Person Variance in Sleep Parameters

Group		Within-person Variance component	Within-person % within	Between-person Variance component	Between-person ICC (% between	Ratio of within/ between
TST	Total Sample	5782.30	62.4	3478.96	37.6	1.66
Age	Young	8087.29	72.3	3095.64	27.7	2.61
	Middle	5500.50	64.6	3015.28	35.4	1.82
	Older	3737.12	47.6	4109.57	52.4	.91
Sex	Male	5182.84	58.2	3717.53	41.8	1.39
	Female	6376.44	66.2	3256.18	33.8	1.96
Race	White	5051.05	65.2	2692.10	34.8	1.88
	Black	7513.90	58.4	5352.90	41.6	1.40
NWAK	Total Sample	.95	51.7	.88	48.3	1.07
Age	Young	1.09	59.9	.73	40.1	1.49
	Middle	1.02	55.6	.81	44.4	1.25
	Older	.70	41.3	.99	58.7	.69
Sex	Male	.76	44.4	.95	55.6	.80
	Female	1.13	58.2	.81	41.8	1.40
Race	White	.97	53.4	.85	46.6	1.14
	Black	.87	48.6	.92	51.4	.95
SOL	Total Sample	324.37	67.6	155.82	32.4	2.08
Age	Young	256.17	66.5	129.10	33.5	1.98
	Middle	286.82	61.4	179.98	38.6	1.59
	Older	295.05	67.9	139.37	32.1	2.12
Sex	Male	185.15	59.7	124.91	40.3	1.48
	Female	373.27	68.3	173.30	31.7	2.15
Race	White	244.36	69.0	109.82	31.0	2.22
	Black	362.97	63.1	211.82	36.9	1.71
WASO	Total Sample	636.92	64.9	343.80	35.1	1.85
Age	Young	621.40	65.6	326.07	34.4	1.91
	Middle	639.99	69.6	279.81	30.4	2.29
	Older	687.12	62.1	419.40	37.9	1.64
Sex	Male	456.39	57.2	341.72	42.8	1.34
	Female	838.48	70.7	346.87	29.3	2.42
Race	White	582.40	66.8	289.40	33.2	2.01
	Black	804.20	62.7	478.51	37.3	1.68

Note. ICC = intraclass correlation coefficient; TST = total sleep time; NWAK = number of awakenings during the night; SOL = sleep-onset latency; WASO = wake-time after sleep onset; Variance components estimated from null multilevel models.

Table 3

Means and Standard Deviations of Sleep Characteristics for Overall Sample (N=592) and Demographic Groups

	Overall	Age Groups			Sex		Race	
		Young[a]	Middle-age[b]	Older[c]	Males[d]	Females[e]	Whites[f]	Blacks[g]
Measure	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Mean TST	426.4 (62.4)	425.8 (60.7)	415.0 (58.5)	441.3 (66.1)	425.5 (64.0)	427.3 (60.9)	427.2 (55.2)	424.7 (76.9)
iSD TST	68.1 (33.9)	82.1 (37.1)	67.7 (30.7)	54.2 (28.2)	64.5 (32.4)	71.7 (35.1)	64.6 (29.6)	76.4 (41.3)
Mean NWAK	1.4 (.98)	1.1 (.90)	1.3 (.94)	1.7 (1.0)	1.3 (1.0)	1.4 (.95)	1.4 (.96)	1.2 (1.0)
iSD NWAK	.84 (.49)	.93 (.48)	.86 (.55)	.73 (.40)	.76 (.43)	. 92 (.54)	.86 (.48)	.79 (.51)
Mean SOL	18.6 (13.1)	18.5 (12.1)	18.2 (14.2)	19.1 (12.7)	17.1 (11.8)	20.0 (14.2)	16.4 (11.3)	23.7 (15.5)
iSD SOL	12.0 (11.7)	12.4 (10.1)	11.9 (12.4)	11.8 (12.5)	10.1 (9.5)	13.9 (13.3)	11.1 (11.0)	14.2 (13.0)
Mean WASO	18.4 (19.9)	15.6 (19.2)	16.8 (18.4)	23.2 (21.6)	16.4 (19.5)	20.3 (20.2)	17.5 (18.2)	20.6 (23.4)
iSD WASO	18.0 (18.1)	18.0 (17.4)	17.7 (18.2)	18.5 (18.6)	15.3 (15.0)	20.7 (20.3)	17.2 (16.9)	19.8 (20.4)

Note. Intra-individual means and intra-individual standard deviations (iSD) were calculated for each individual across all his/her available nights of sleep data. Thus, every individual had two measures for each sleep outcome: 1) a measure of his/her average sleep across the two weeks (mean), and 2) a measure of the amount of variation from his/her mean across the two weeks (iSD). Values are averaged across individual means or standard deviations.
TST = total sleep time; NWAK = number of nighttime awakenings; SOL = sleep onset latency; WASO = wake-time after sleep onset. All values reported in original units.
[a]*n* = 187. [b]*n* = 225. [c]*n* = 180. [d]*n* = 294. [e]*n* = 298. [f]*n* = 415. [g]*n* = 177.

Table 4

Intercorrelations Between Sleep Variables (iSDs and means) and Potential Covariates

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Mean TST	--													
2. iSD TST	-.06	--												
3. Mean NWAK[a]	.01	.03	--											
4. iSD NWAK[a]	-.02	.28**	.56**	--										
5. Mean SOL[b]	-.09*	.19**	.11**	.04	--									
6. iSD SOL[a]	-.08	.32**	.08*	.21**	.75**	--								
7. Mean WASO[a]	-.12**	.16**	.67**	.43**	.28**	.27**	--							
8. iSD WASO[a]	-.13**	.30**	.39**	.50**	.23**	.35**	.86**	--						
9. Age	.11**	-.35**	.24**	-.16**	.02	-.08*	.19**	-.00	--					
10. Sex	.02	.11**	.09*	.16**	.10*	.16**	.13**	.15**	-.04	--				
11. Race	-.02	.16**	-.13**	-.08	.26**	.16**	.00	.01	-.13**	.07	--			
12. BDI-II	.03	.13**	.14**	.05	.13**	.12**	.23**	.19**	.04	.13**	.15**	--		
13. Education[c]	-.12**	-.01	.04	.16**	-.22**	-.05	-.02	.04	-.20**	-.10*	-.29**	-.17**	--	
14. # Health problems	.05	-.07	.23**	-.03	.09	.06	.24**	.12**	.48**	.01	-.02	.22**	-.12**	--

Note. iSD = intra-individual standard deviation; TST = total sleep time; NWAK = number of nighttime awakenings; SOL = sleep onset latency; WASO = wake-time after sleep onset; BDI-II = Beck Depression Inventory-II; Sex was coded: 0 = male, 1= female; race coded: 0 = White, 1 = Black.
[a]LG10(X+1) transformation used in analyses. [b]LG10(X) transformation used in analyses. [c]$n = 503$.
$^{*}p < .05$. $^{**}p < .01$.

Table 5

Final Multiple Regression Analyses Predicting iSDs in Sleep

Predicting iSD TST	B	*SE* B	β	*t*	*p*	sr^2	R^2
BDI-II	.646	.206	.120	3.135	.002	.01	
Age	-.727	.114	-.418	-6.366	.000	.06	
Sex	.464	3.07	.007	.151			
Race	-.051	4.15	-.001	-.012			
Age × Sex	.393	.160	.164	2.460	.014	.01	
Age × Race	.209	.210	.068	.992			
Sex × Race	12.139	5.67	.133	2.142	.033	.01	
Age × Sex × Race	-.732	.285	-.180	-2.570	.010	.01	.176
Predicting iSD NWAK[a]	**B**	***SE* B**	**β**	***t***	***p***	sr^2	R^2
Mean NWAK[a]	.377	.022	.619	17.069	.000	.34	
Education	.003	.001	.082	2.212	.027	.01	
Age	- .002	.000	- .291	-7.920	.000	.07	
Sex	.025	.008	.111	3.204	.001	.01	
Race	- .001	.009	- .005	-.147			.419
Predicting iSD SOL[c]	**B**	***SE* B**	**β**	***t***	***p***	sr^2	R^2
Mean SOL[d]	.897	.033	.756	27.027	.000	.53	
Age	- .002	.000	- .104	-3.836	.000	.01	
Sex	.058	.019	.084	3.041	.002	.01	
Race	- .046	.022	- .060	-2.140	.033	.00	.577
Predicting iSD WASO[e]	**B**	***SE* B**	**β**	***t***	***p***	sr^2	R^2
Mean WASO[e]	.848	.020	.884	42.810	.000	.74	
Age	- .004	.000	- .167	-8.083	.000	.03	
Sex	.031	.018	.035	1.705			
Race	- .018	.020	- .018	-.898			.763

Note. Values for individual predictors reflect fully partialed values from final regression model. iSD = intra-individual standard deviation; TST = Total sleep time; *sr* =semi-partial correlation coefficient; BDI-II = Beck Depression Inventory-II; NWAK = number of nighttime awakenings; SOL = sleep onset latency; WASO = wake-time after sleep onset; Sex is coded as 0=male, 1=female; Race coded as 0=White, 1=Black. All continuous predictor variables are centered at the mean.

[a]LG10(X+1) transformation used on iSD NWAK and mean NWAK. [c]LG10(X+1) transformation used on iSD SOL. [d]LG10(X) transformation used on mean SOL. [e]LG10(X+1) transformation used on iSD WASO and mean WASO.

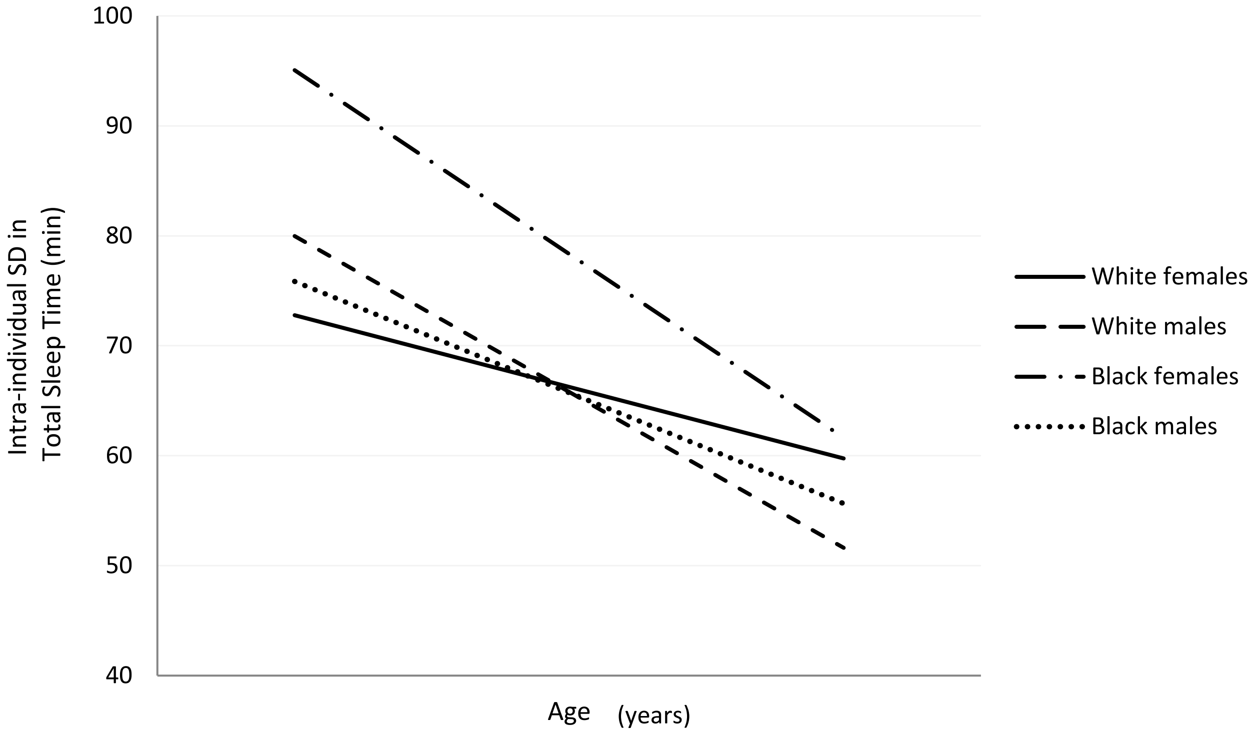

Figure 1. Three-way interaction of age × sex × race on variability in TST. Simple regression lines for intra-individual standard deviation (iSD) in TST are plotted at one standard deviation above and below the sample's mean age. TST = total sleep time