VARIABILITY IN SELF-REPORTED NORMAL SLEEP ACROSS ADULTHOOD

by

HALEY REBECCA DILLON

KENNETH L. LICHSTEIN, COMMITTEE CHAIR
MARTHA CROWTHER
NATALIE DAUTOVICH
JAMES D. GEYER
GIYEON KIM
BEVERLY E. THORN

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ABSTRACT

This study used archival data to examine variability in sleep diary measures across a two-week period. Data were analyzed for 592 normal sleepers (defined as absence of sleep disorder) ranging in age from 20 to 96 years. Variability was examined in four sleep diary parameters: total sleep time (TST), number of nighttime awakenings (NWAK), sleep-onset latency (SOL), and wake time after sleep onset (WASO) for the overall sample and by age, sex (male, n = 294, female, n = 298) and race (White, n = 415; Black, n = 177). Intraclass correlation coefficients were calculated from multilevel models to describe the extent to which self-reported sleep varied within- and between-individuals across the two-week period. Night-to-night differences in sleep within the same individual generally exceeded sleep differences between individuals for TST, SOL, and WASO. Multiple regression analyses were conducted to test for age, sex, and race differences in night-to-night, intra-individual variability (measured by the intra-individual standard deviation across nightly values for each individual). Results showed that 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 was dependent on sex and race. Although effect sizes were small, females tended to have more intra-individual variability in SOL and NWAK than males. Results of this study provide empirical support for considerable night-to-night variability in subjective sleep in the general population and should be taken into account in future research linking sleep with various psychological and physical health outcomes. Methodological implications regarding measurement/research design are also discussed.

DEDICATION

This dissertation is dedicated to my parents, whose unwavering love and support over the past 30 years brought me to where I am today. And to Brannon and my sister, who believed in me through every step of this journey.

LIST OF ABBREVIATIONS AND SYMBOLS

β	Standardized regression coefficient
B	Unstandardized regression coefficient
df	Degrees of freedom: number of values free to vary after certain restrictions have been placed on the data
F	Fisher's *F* ratio: A ration of two variances
f^2	Cohen's f^2 effect size
ICC	Intraclass correlation coefficient: between-persons variance divided by total variance (sum of between- and within- persons variance)
IIV	Intra-individual variability
iSD	Intra-individual standard deviation: standard deviation in an individual's sleep parameter across study nights
M	Mean: sum of a set of measurements divided by the number of measurements in the set
p	Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
r	Pearson product-moment correlation
R^2	Coefficient of determination
sr^2	Semi partial correlation coefficient
t	Computed value of *t* test
$<$	Less than
$=$	Equal to

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INTRODUCTION

Intra-individual variability (IIV) in normal sleep, or the extent to which sleep varies from night to night in the general population, has become a topic of increasing interest. Although it is recognized that collecting data across multiple nights yields more accurate and reliable estimates of sleep (i.e., Rowe, McCrae, Campbell, Horne, et al., 2008; Wohlgemuth, Edinger, Fins, & Sullivan, 1999), simply collapsing the multiple data points into averages may be overlooking valuable information. For instance, two individuals can have the same mean total sleep time, but exhibit very different sleep patterns, with either a narrow or wide range of sleep times from one night to the next. The extent of these nightly fluctuations in normal sleep may have implications for psychological and physical health outcomes in the general population. Recent research has shown that greater IIV in sleep is 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). Moreover, nightly fluctuations in sleep have been linked to subsequent daily fluctuations in mood, pain, and physical health complaints in community samples (Edwards et al., 2008; Fuligni & Hardway, 2006; McCrae et al, 2008).

There are many factors that contribute to sleep variability. Two core processes are thought to regulate the normal human sleep/wake cycle; the sleep homeostatic drive, which builds during wakefulness and declines during sleep, and the circadian system, which is largely independent of prior sleep and waking. Circadian rhythms operate on a roughly 24-hour schedule set by an endogenous biological clock. However, the circadian system can be influenced by exogenous factors such as behaviors and light exposure. This two-process model of sleep regulation (Borbely & Achermann, 2005) posits that the timing, duration, and structure of sleep each night is determined by the interaction of these homeostatic and circadian processes. This theory supports the idea that sleep is a dynamic process and likely to fluctuate as it adjusts to internal and external demands. Nonetheless, the degree to which normal sleep varies from night to night within a person has been an understudied topic that is the focus of this study.

In order to study variability in sleep, we must first be able to measure sleep itself. Sleep can be assessed objectively (e.g., polysomnography, actigraphy) or subjectively (e.g., self-reported estimates, daily sleep diaries). Both types of measurement yield quantitative values for a range of sleep parameters. Typical nightly sleep parameters include: sleep onset latency (SOL), wake-time after sleep onset (WASO), number of nighttime awakenings (NWAK), time in bed (TIB), total sleep time (TST), and sleep efficiency percent (SE; ratio of TST to TIBx100). However, objective measures do not always reflect the subjective experience of sleep and correlations between these two modes of measurement can differ based on demographic and sleep characteristics (Baker, Maloney, & Driver, 1999; Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008; McCrae et al., 2005). Accordingly, it is important for the literature to assess both aspects of sleep: subjective and objective sleep. Unfortunately, in the existing research on IIV in sleep, there is a lack of data on variability in subjective sleep.

The majority of research on IIV in normal adult sleep has used objective measures. Several studies have documented considerable night-to-night variability in the general adult population using actigraphic measures of sleep (Knutson, Rathouz, Yan, Liu, & Lauderdale, 2007; Mezick et al., 2009; Tworoger, Davis, Vitiello, Lentz, & McTiernan, 2005; van Hilten et al., 1993). These studies found that sleep differences within-individuals exceeded the differences between individuals in objective measures, which indicates that adults differ more from night to night than they do from each other (in regard to their sleep). Three of these studies reported quantitative values for the extent to which sleep varied over several nights of measurement. In a large sample of healthy, early middle-aged adults (ages 38-50 years), Knutson and colleagues (2007) found that across three nights of actigraphy data, TST varied by more than one hour and SOL by 30 minutes. Mezick et al. (2009) found similar variations in actigraphic measures of TST and sleep fragmentation across nine nights with an older adult (46-78 years) sample. Likewise, seven nights of actigraphy in an all-female sample (ages 20-40 years) revealed approximately one hour variation in TST, and less than 15 minutes variation in both SOL and WASO (Tworoger et al., 2005).

Much less is known about variability in adults' self-reported sleep. The extant research in this area has focused primarily on sleep patterns in insomnia (e.g., Buysse et al., 2010; Wohlgemuth et al., 1999) or on sleep-wake behaviors that are more voluntary in nature (i.e., bedtime, wake-up time, napping; Carney, Edinger, Meyer, Lindman, & Istre, 2006; Dautovich et al., 2012; Kramer, Kerkhof, & Hofman, 1999; Okun et al., 2011). However, Buysse et al. compared night-to-night variability in older adults with insomnia to older adults without insomnia and reported quantitative estimates of variability for both groups. Across two weeks of daily sleep diaries collected from the matched control group without insomnia (n =31), subjective SOL varied 21 minutes, WASO varied 17 minutes, and TST varied just over one hour (67 minutes). Although these values of subjective sleep variability are similar to estimates of variability in objective sleep, the sample size was small and limited to a matched control group of older adults. No studies have directly addressed IIV in self-reported sleep in the general population.

Research has also documented associations between variability in self-reported sleep-wake behaviors, sleep disturbance, and daytime functioning. For instance, studies with children and adolescents have linked irregular sleep schedules with behavioral problems and poor academic functioning (e.g., Acebo & Carskadon, 2002; Wolfson & Carskadon, 1998). Greater variability in bedtimes and rise times for college students is associated with poorer sleep quality (Carney et al., 2006). Another study with college students found that regularizing sleep-wake schedules led to improvements in sleep quality ratings and reductions in daytime sleepiness (Manber, Bootzin, Acebo, & Carskadon, 1996). Behavioral treatments for insomnia even recommend monitoring the regularity and variability of sleep behaviors to gauge adherence to treatment (Riedel & Lichstein, 2001), suggesting that consistent sleep patterns are optimal for good sleep and improved daytime functioning. Studying the consistency in sleep-wake behaviors is clearly important, as the timing of one's sleep schedule can contribute to the actual quantity and quality of one's sleep each night. However, there is a need for more research on the extent of IIV in other characteristics of sleep, such as SOL, WASO, and TST.

One compelling reason to examine IIV in sleep is that the amount of nightly variability seems to be independent of aggregate measures of sleep. Thus, sleep variability may have different consequences and associations with health and well-being than mean values of sleep. For instance, a recent 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). Additional support comes from a 14-day diary study with over 750 adolescents (Fuligni & Hardway, 2006). The researchers found that nightly variability in self-reported TST was just as important as average TST in explaining individual differences in anxiety, depression, and fatigue.

In addition to a lack of normative data on intra-individual variability in self-reported sleep, little is known about potential age, sex, and race-ethnic differences in sleep variability. Regarding sleep in general, research has documented fairly consistent changes in sleep structure and pattern across the adult age span. A meta-analysis of polysomnography data indicates that sleep becomes lighter with age and the shifts between sleep stages become more frequent (Ohayon, Carskadon, Guilleminault, & Vitiello, 2004). As a result, older adults experience more nighttime awakenings and arousals and the amount of time spent awake during the night increases with age (Lichstein, Durrence, Riedel, Taylor, & Bush, 2004; Ohayon et al., 2004). Circadian rhythm changes also occur with age and can affect the timing and resilience of the 24-hour sleep/wake cycle. For example, the sleep phase of older adults tends to advance, with typical sleep onset and wake-up times that are several hours earlier than desired (Myers & Badia, 1995).

Given the mean-level changes in sleep that occur with age, it is likely that IIV in sleep also changes with age. Two studies addressed this possibility using objective measures of sleep, and both failed to find age effects on sleep variability (Mezick et al., 2009; van Hilten et al., 1993). However, both study samples were at the higher end of the age span; with one sample ranging in age from 46-78 years (Mezick et al., 2009), and the other sample ranging from 50 to 98 years of age (van Hilten et al., 1993). As Mezick et al. noted, age differences may exist outside the age range in her sample, and future research should include younger and middle-age adults.

Another study compared self-reported sleep-wake patterns in older (59-74 years) and younger (19-26 years) healthy adult males (Kramer et al., 1999). The younger group showed more day to day variability in their sleep schedules (i.e., times entering and leaving bed) than the older males. If younger adults have more variability in the timing of their sleep schedules, they will likely exhibit greater variability in other sleep diary parameters (i.e., SOL, TST) as well. As previously mentioned, extensive nightly variation in bedtimes, wake-times, and time in bed could lead to analogous variation in TST from night to night.

Some researchers theorize that greater regularity in the sleep schedules of older adults is due to lifestyle changes that tend to occur with increasing age. Indeed, research shows that lifestyle regularity (i.e., keeping a more constant daily routine) increases with age (Monk et al., 1997) and that 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 (such as childcare, house/yardwork, social activities, etc), and this continues into the night, leading to greater variability in sleep patterns. 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 (i.e., SOL, TST, SE) than non-caregiving older adults. Although Rowe's findings do not address age differences in daily demands or sleep variability, they suggest that caregiving responsibilities could potentially influence variability of sleep patterns.

Sex and race-ethnic differences in mean levels of sleep have also been documented. The literature has consistently shown that sleep complaints are more prevalent in woman than men (e.g., Lichstein et al., 2004; National Sleep Foundation, 2005). Unfortunately, research on sex differences in normal sleep has had conflicting results. Ohayon's meta-analysis of objective sleep data across the lifespan found that women had longer TST and SOL than men of the same age, although the effect sizes were small (Ohayon et al., 2004). A national survey using a single-point retrospective estimate of habitual sleep also found that women reported poorer sleep quality, but longer TST than men (National Sleep Foundation, 2005). However, Lichstein et al.'s (2004) study using 14 nights of sleep diary data did not find sex differences in average TST for normal sleepers. Although the women in this study did report more awakenings during the night, greater WASO, and worse sleep efficiency (SE), compared to men, the magnitude of these differences was still small. In summary, there seems to be a trend for women to self-report worse sleep than men, but the magnitude and direction of sex differences in quantitative values of sleep seem to depend in part on how sleep was assessed.

Research on racial-ethnic differences in sleep has grown considerably over the past 10 to 15 years. A recent meta-analysis examined the existing data on normal sleep in Blacks and Whites and concluded that Blacks slept worse on both objective and subjective measures of sleep (Ruiter, DeCoster, Jacobs, & Lichstein, 2011). Additionally, at least two studies have shown that when estimating habitual TST, Blacks are more likely than Whites to report extreme sleep durations (TST of less than 6 hours or TST longer than 8 or 9 hours; Hale & Do, 2007; Nunes et al., 2008). Given the increased mortality risks associated with short and long sleep duration (Grandner, Hale, Moore, & Patel, 2010), this finding could have important implications for understanding health disparities experienced by Blacks and other minority groups. However, many epidemiological studies, including the two just discussed, used retrospective estimates of self-reported sleep time. The validity of a single item question taken at one time point is still unknown, and responses are likely influenced by a host of other social and behavioral factors (Bliwise & Young, 2007). Thus, findings derived from single point estimates of sleep should be interpreted cautiously, as they might not fully represent the dynamic associations between sleep and health.

In addition to the research on average sleep parameters, a few studies have documented sex and race differences in sleep variability. Results from three studies using actigraphy measures of sleep suggest greater IIV for adult females compared to males (Knutson et al., 2007; Mezick et al., 2009; van Hilten et al, 1993). Importantly, even after controlling for average TST, Mezick and colleagues found that women had more night-to-night fluctuation in objective TST than men. Mezick et al. did not find differences between men and women in nightly variability in the degree of fragmented or disrupted sleep (as measured by actigraphy). Another study examined subjective estimates of TST across 14 days in a sample of adolescents (Fuligni & Hardway, 2006). Although both sexes were similar on average TST, adolescent girls had greater night-to-night variability in subjective TST than adolescent boys. Two of these studies also addressed racial differences in IIV. Knutson et al. (2007) reported that Blacks generally showed greater night-to-night variability in actigraphy measures than Whites, although the patterns were not consistent across each sleep parameter. Mezick et al. (2009) also used actigraphy data and found increased variability in sleep fragmentation for Blacks compared to Whites, but no differences in TST variability. A third study using actigraphy with a sample of adolescents found that adolescents identifying with the minority ethnicity (which consisted primarily of Blacks) had more night-to-night variability in TST than Whites (Moore et al., 2011). However, in contrast with the previously mentioned studies documenting sex differences in IIV in sleep, Moore and colleagues did not find differences between male and female adolescents in TST variability.

Given this evidence for age, sex, and racial differences in objective measures of sleep variability, further investigation of IIV in sleep is warranted. In particular, it is currently unknown whether subjective measures of sleep variability differ across the adult age span or by sex and race categories. Developing normative values of IIV across demographic groups will provide sleep researchers and clinicians with a baseline level of normal, short-term variability in sleep. In time, we can build on this knowledge to increase our understanding of how pathological sleep patterns develop at different stages of life. There may also be methodological implications of this study. If certain demographic groups tend to have greater nightly variability in their sleep than others, one night of data may not be enough to accurately represent their sleep. With the current interest and amount of research linking sleep with mortality and health outcomes, it is important that we take into account the sources of variability in normal sleep.

The current study used an existing epidemiological sample to examine variability in normal sleep across 14 days of sleep diary data. Primary variables of interest were; SOL, WASO, NWAK, and TST. These four parameters were chosen as they represent important aspects of perceived sleep. SOL and WASO are commonly reported sleep complaints and have potential for wide variability within individuals. The number of nighttime awakenings (NWAK) is the best subjective measure of fragmented sleep. Sleep fragmentation can have negative effects similar to sleep deprivation (Bonnet & Arand, 2003) and was previously examined by Mezick et al. (2008). Finally, TST is the most common sleep parameter.

Any variable measured over time has at least two sources of variation: within-person and between-person. Therefore the first aim of this study was to examine the sources of variability in self-reported sleep parameters in a nonclinical sample of normal sleepers. Based on prior research documenting high intra-individual variability in sleep, it was hypothesized that the majority of variability in all four sleep parameters (i.e., SOL, WASO, NWAK, and TST) 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 adults, middle-aged adults, and older adults) and by sex and race.

The second aim was to investigate individual differences in this within-person variability. Specifically, we examined whether the amount of IIV in each sleep parameter differed by a person's age group, sex, or race. Due to a lack of prior research or theory on IIV in SOL and WASO, individual hypotheses were not made for these sleep parameters. However, specific patterns of IIV in TST and NWAK were hypothesized. Consistent with research showing that lifestyle regularity and regularity in sleep-wake behaviors increases with age, we expected the amount of variability in TST to also become more regular (i.e., less variable) with increasing age. However, because the average number of nighttime awakenings tends to increase with older age, we did not expect the amount of night-to-night variability in NWAK to change with age. We also expected sex and race differences in IIV in TST and NWAK. Based on a few previous studies, we hypothesized that women and Blacks would exhibit greater variability in self-reported TST than men and Whites. We expected this same pattern to hold for IIV in NWAK. Finally, several health and demographic factors (i.e., household education level, depression, physical health) that have been associated with mean-level sleep parameters were considered as potential correlates of IIV in normal sleep.

METHOD

This study used archival data gathered as part of the University of Memphis Sleep Research Project epidemiological survey of sleep and daytime functioning (Lichstein et al., 2004).

Participants

A random-digit dialing procedure was used to recruit a stratified, randomly selected sample of adults from Shelby County, Tennessee. 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 population of Shelby County, Tennessee is nearly equally distributed between African Americans and Caucasians, allowing a sufficient number of participants in these two racial groups. To obtain a broad sample, the only eligibility criteria were that the participant be at least 20 years old and be able to speak and read English at approximately a seventh grade level. All participants were required to make a two week commitment and respond to numerous self-report questionnaires sent to them by mail. As participants completed and returned the two weeks of data, they received monetary compensation between $15 and $200. Older adults and male participants received larger payments because of difficulties recruiting these participants.

Measures

The current study focused on demographic and sleep diary data. Self-report data on health, depression, and anxiety were explored as potential correlates of sleep variability. The database contained additional measures that were not utilized in this study (i.e. State-Trait

Anxiety Inventory, Fatigue Severity Scale, Epworth Sleepiness Scale, Stanford Sleepiness Scale, and Insomnia Impact Scale), but are discussed in Lichstein et al. (2004).

Demographics. Participant age, sex, and race were determined by self-report data provided on a health survey form (Appendix 1) that was included in the questionnaire packet. In addition to using age as a continuous variable, participants were classified into three groups based on their reported age; young (20-35 years), middle-aged (36-64 years) or older (65-96 years) adults. Participant sex was categorized as male or female. Two race categories were used in analyses; Blacks and Whites.

Sleep Diary. Self-reported sleep was assessed using two weeks of sleep diaries (given in Lichstein et al., 2004; see Appendix 2). Participants were asked to complete the sleep diary upon awakening each morning for 14 consecutive days. The diary takes approximately 2 minutes to complete and respondents estimate the time they entered bed the previous night, number of minutes until falling asleep (sleep-onset latency), number of awakenings during the night, number of minutes spent awake after sleep onset, time of final morning awakening and exit from bed, and minutes spent napping the day before. Respondents also rate the perceived quality of the previous night's sleep on a 5-point scale from 1 (*very poor*) to 5 (*excellent*).

The current study included four daily sleep measures calculated from the 14 nights of sleep diary data: sleep-onset latency (SOL), wake time after sleep-onset (WASO), number of awakenings (NWAK), and total sleep time (TST) in minutes. Each night's SOL was obtained directly from the sleep diary, where participants recorded the number of minutes it took to fall asleep that night. Each night's WASO was also obtained from the sleep diary, where participants recorded the total number of minutes they spent awake during the night (from the time they first fell asleep until their final wake-up time the next morning). Each night's NWAK reflected the number of nighttime awakenings reported that night on the sleep diary. Finally, each night's TST was computed in a series of steps. First, time in bed (TIB) was calculated by subtracting the time participants got out of bed in the morning from the time participants entered bed the night before. Second, total wake time during the sleep period was the sum of SOL, WASO, and minutes spent awake in the morning (between final awakening time and the time participant exited the bed). Then, TST was calculated by subtracting total wake time at night from TIB. Additionally, individual level summary measures were calculated for each sleep parameter. Within-person means were calculated by averaging the individual's 14 nightly values for each sleep parameter. Within-person standard deviations were also calculated across each individual's 14 nights of data. This intra-individual standard deviation (iSD) represents the amount of short-term, nightly variation an individual has with regard to his/her own mean.

Potential Correlates. Mean levels of sleep were also considered as potential correlates of intra-individual variability in sleep. The amount of variability possible in a characteristic of sleep is dependent in part on the range of observed values for that sleep parameter. For example, an individual reporting between zero and 2 awakenings each night (for a mean NWAK of 1 across the two weeks) typically has a more limited range of values around the mean for which to fluctuate in comparison with an individual reporting mean NWAK of 5 across the two weeks. Thus, in order to help control for associations between means and the intra-individual standard deviations used as the outcome variables, for each sleep outcome, the corresponding mean level of that particular sleep characteristic was considered as a potential covariate in analyses.

The health survey form (see Appendix 1) collected additional demographic and health information (Lichstein et al., 2004) that was used as covariates in analyses. Education level was assessed by two questions in which participants indicated the total number of years of education achieved for themselves and for their spouse. The highest response was used to indicate the household education level, which served as a proxy for socioeconomic status. In light of research documenting interactive effects of race and SES on sleep (Patel, Grandner, Xie, Branas, & Gooneratne, 2010), education level was included as a control variable when appropriate.

Regarding physical health, respondents were asked to indicate all of the following categories in which they have health problems: heart disease, cancer, AIDS, high blood pressure, neurological disease (e.g., seizures, Parkinson's disease), breathing problems (e.g., asthma, emphysema), urinary problems (e.g., kidney disease, prostate problems), diabetes, gastrointestinal problems (e.g., stomach, irritable bowel syndrome, ulcers), and chronic pain (e.g., arthritis, back pain, migraines). For the ten categories, all affirmative responses were summed to obtain a total number of health problems for each participant. Given that certain health problems may contribute to a disruption in sleep patterns, total number of physical health problems was examined as a potential covariate of sleep variability.

Symptoms of depression have been associated with sleep disturbance and may be related to sleep variability as well. The Beck Depression Inventory-II (BDI-II; Beck, Brown, & Steer, 1996), a 21-item self-report questionnaire, was used to measure cognitive and behavioral symptoms of depression experienced over the past two weeks. Participants rated each item from 0- 3 with a higher summed score representing more severe mood disturbance. Beck and colleagues (1996) reported a Cronbach's alpha of .92 for an outpatient sample. Total scores on the BDI-II were examined as a potential correlate of sleep variability.

Procedure

Participants were recruited through a random-digit dialing procedure. The sampling protocol consisted of pairing valid, three-digit telephone prefixes with computer-generated random four-digit numbers. Undergraduate research assistants called the list of random numbers, disqualifying businesses and organizations. When a person answered, the research assistant read a brief script to deliver information about the study and assess interest. Recruiting continued until at least 50 men and 50 women returned data in each age decade. Interested recruits were mailed a packet containing informed consent, two weeks of daily sleep diaries, and several questionnaires about daytime symptoms and impairment. Participants were instructed to begin completing the sleep diary immediately and to complete the rest of the packet in one sitting at the end of the 2-week period. Participants returned the completed sleep diaries and questionnaires by mail in a pre-addressed, stamped envelope. Upon receipt of the data, participants received monetary compensation (more complete details on methods can be found in Lichstein et al., 2004). The original study was supported by National Institute on Aging grants AG12136 and AG14738, by Methodist Healthcare of Memphis, and by the Center for Applied Psychological Research, Department of Psychology, University of Memphis, part of the State of Tennessee's Center of Excellence Grant program (Lichstein et al., 2004).

Statistical Analysis

The first set of analyses used multilevel modeling to examine the sources of variability in self-reported TST, NWAK, SOL, and WASO. Multilevel modeling 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 (e.g., 14 nights of sleep diary data), multilevel analyses allow us to take advantage of all existing data points. Nightly sleep values from the 14 days of measurement (Level 1 variables) were nested within individuals (Level 2 variables) in multilevel analyses. For each of the four sleep outcomes, an unconditional (i.e., no predictors) random intercept two-level model was estimated using the entire sample of normal sleepers. Results yielded estimates of within-person and between-person variation which were then placed in a ratio to describe the relative magnitude of each source of variation. To examine the distribution of each source of variability within demographic groups, we estimated separate unconditional random intercept models for each subgroup (i.e., young, middle-age, older, males, females, Whites, Blacks).

The presence of multiple levels in these analyses complicates the determination of power, as both levels must be taken into consideration. (The greater the sample size at Level 1, the more reliable your measures of within-person fluctations are, while the greater the sample size at Level 2, the more reliable are your measures and predictions of individual differences.) For basic multilevel analyses with two levels, Snijders and Bosker (1993) recommend a minimum sample size of n = 6 per Level 1 unit and a minimum of N = 10 for higher level units. This study's sample exceeds these minimum size requirements with approximately 14 cases per Level 1 unit nested within 593 individuals as Level 2 units. Thus, there should be adequate power to detect an effect using multilevel analyses.

Next, we calculated individual and group-level statistics for the sleep diary data. As stated, means and standard deviations were calculated for each individual across his/her 14 nights of sleep values, and these summary measures were averaged across individuals to obtain group statistics. Intra-individual standard deviations (iSD) for each sleep parameter were used to quantify the amount of nightly, within-person variability in that sleep characteristic. The iSDs for TST, NWAK, SOL, and WASO were reported for the total sample of normal sleepers and for each age, sex, and race category. To examine potential correlates of intra-individual variability in sleep, correlational analyses were run among the iSDs and mean level of each sleep parameter and other health and demographic factors (i.e., household education level, depressive symptoms, and physical health problems).

Lastly, multiple regression analyses were used to test for age, sex, and race differences in nightly sleep variability. Separate hierarchical regression models were built for each sleep characteristic (TST, NWAK, SOL, and WASO), with iSDs of these sleep variables serving as the dependent variable. For each sleep parameter, relevant control variables, often including mean values of that sleep variable, were entered in Step 1 of the regression. The three independent variables of interest (age, sex, and race) were entered in Step 2. Finally, potential interactive effects between age, sex, and race were entered in Step 3. Nonsignificant control variables and interactions were removed from the final regression models.

A medium size effect ($f^2 = .15$ or 13% variance) was expected for total variance explained in iSD by all the predictors combined. Using a statistical power level of .80, probability level of 0.05, and the maximum number of 11 possible predictors (including four potential covariates, three independent variables, and four potential interactions), power analyses determined a minimum sample size of 122 was needed to detect a medium size effect for overall variance explained in the dependent variable. Furthermore, since age, sex, and race were the independent variables of interest, power analyses were also conducted for a hierarchical multiple regression analysis. Anticipating a small effect size ($f^2 = .02$ or 2% variance explained) for the addition of the set of demographic variables (age, sex, and race) in the second step of a hierarchical regression analysis requires a minimum sample size of 547.

RESULTS

Sample Characteristics

During the 3-year recruitment period, a total of 1,769 participants were recruited, with an adjusted response rate of 37.7% (Lichstein et al., 2004). The final sample of 772 participants ranged in age from 20 to 98 years (M = 53.8 years, SD =19.8) and was evenly distributed between males (49.4%) and females (50.6%). The sample was composed of primarily Whites (69.8%) and Blacks (28.9%). To obtain our subsample of normal sleepers, 137 individuals were excluded for having insomnia and 33 individuals for reporting another sleep disorder (e.g., sleep apnea, restless leg syndrome). In addition, 9 participants who identified themselves as belonging to a racial-ethnic group other than Blacks or Whites were excluded from analyses due to their limited numbers. Thus, data from 593 normal sleepers were identified.

Data were first examined for outliers and missing data. One participant's data yielded extreme values on all four sleep outcome variables (i.e., intra-individual standard deviations of zero for TST, NWAK, SOL, and WASO). Upon further inspection of the participant's original sleep diary responses, this individual's data were determined to be invalid and excluded from all analyses, resulting in a final sample of 592 participants. The amount of missing data was minimal and seemed at random, with the exception of household education level. The question about education was added to the questionnaire packets shortly after data collection began, so this data was not collected from 89 participants in the current study sample (15%). Regarding the sleep diary data, less than 1% of the possible 8288 nightly measurements (592 participants x 14 nights) were missing for each sleep parameter of interest.

The final sample of normal sleepers (*N* = 592) ranged in age from 20 to 96 years with a mean age of 52.3 years (*SD* = 19.5). The sample was relatively well-educated, reporting a household education level ranging from 2 to 20 years (*M* = 14.5, *SD* = 2.9), with over half of these participants reporting college coursework (Median = 14 years). The number of reported health problems ranged from 0 to 6 (*M* = .97, *SD* = 1.2), with chronic pain (23%) and hypertension (21%) as the most commonly endorsed medical conditions. Although we previously excluded individuals meeting criteria for insomnia or another sleep disorder, 17% of this normal sleeper sample reported sleep complaints. Overall mean score on the BDI-II (*M* = 7.0, *SD* = 6.3) indicated a minimal level of depressive symptoms in this sample. Regarding other health behaviors, almost 80% of the sample was self-reported non-smokers and 58% of the sample reported no alcoholic drinks per week. For descriptive purposes, three age categories were used; young: 20-35 years, middle-age: 36-64 years, older: 65-96 years. Table 1 presents the breakdown of the sample by demographic group (i.e., age, sex, and race) and provides sample characteristics for each group (i.e., highest household education level in years, average number of physical health problems endorsed, and BDI-II score).

Sources of Variability in Self-Reported Sleep

The first set of analyses examined the sources of variability in self-reported sleep for the full sample of normal sleepers. The total variance in sleep across the two weeks of diary data is composed of differences within a person in the fluctuation of each sleep value from one night to the next and differences between persons in their average values (i.e., mean level of sleep). Using four unconditional multilevel models, total variance in each of the four sleep outcomes (TST, NWAK, SOL, and WASO) was partitioned into variance due to within- and between-person sources. Table 2 presents the estimated variance components and the relative contribution of each component to the total variance for the entire sample of normal sleepers (e.g. percent of total variance due to within-person variability). All variance components were statistically significant ($p < .001$), indicating they differed from zero. Thus, there was significant variability among nightly measures of sleep within the same person, as well as significant variability in reported sleep between individuals.

Once statistical significance for each variance component was established, actual values guided further interpretation. The intraclass correlation coefficient (ICC) was calculated in the first step of multilevel analyses (Bryk & Raudenbush, 1992). An ICC measures the degree of relation among observations taken from a common class and is typically used to assess reliability or consistency of multi-item scales (e.g., Cronbach's alpha). In this case, the ICC reflects the average correlation among repeated measurements from the same person and can signify the stability of a person's sleep over multiple nights.

The ICC also reflects the proportion of between-person variance to total variance (i.e., between-person variance divided by the sum of within- and between-person variance). As such, it can be interpreted as the proportion of variance in nightly sleep that is attributable to the object of measurement, which in this case is the individual (McGraw & Wong, 1996). Therefore, a large ICC (closer to 1) indicates that individual differences in a sleep characteristic are considerable (large between-person variance) and that an individual's sleep is stable across nights (small within-person variance). A large ICC would also indicate that a single night of sleep is representative of an individual's overall sleep. In contrast, the lower the ICC (closer to zero), the more variable or unstable that sleep parameter is from night to night, due to relatively large within-subjects variance and comparatively small between-person variance.

It is important to note that since ICC's and related ratios are dependent on the total amount of variability in a particular population, they cannot be directly compared across samples with differing amounts of between-person variability (see van Dongen et al., 2005 Appendix for review). Similarly, there are no universal cut-off values for classifying "high" and "low" ICC's. Given this difficulty in interpreting the ICC in absolute terms, we reported values of both within- and between-persons variance components, as recommended by van Dongen and colleagues. By placing these estimates in a ratio, we were able to describe the magnitude of within-person variability relative to between-person variability. Nesselroade and Salthouse (2004) have proposed using this comparison as a measure of effect size for within-person variability since differences between-persons is a useful reference point.

As seen in Table 2 (and illustrated in Figure 1), the proportion of total variation due to within-person differences was greater than variation due to between-person differences for TST, SOL, and WASO. This means that night-to-night differences within the same individual are greater than differences between individuals in TST, SOL, and WASO. For example, the ICC for TST is .38, which indicates that roughly 38% of the total variance in TST over the two weeks is due to individual differences in sleep time. Since the ICC is the proportion of total variance due to between-persons differences, subtracting the ICC from 1 yields the proportion due to within-persons (1 - .38 = .62). Therefore, 62% of the variance in subjective TST is due to night-to-night fluctuations within a person. Finally, a direct comparison of the variance components for TST yields a ratio of 1.66 (within-person variance of 5782 / between-person variance of 3479). Thus, the nightly fluctuation in TST within individuals was more than 1.5 times the size of the observed variation in TST between individuals. The ratios of within-person to between-person variance for SOL and WASO were slightly larger. The difference in within- and between-person variability was minimal for NWAK (52% compared to 48%, yielding a ratio of within-person to between-person variance of almost 1.0).

Sources of variability by demographic group. Next, we report results of unconditional multilevel models for each demographic group. Results are presented separately for each sleep outcome (Tables 3 through 6).

Table 3 presents estimates of within- and between-person variability for TST. Results show a pattern for age, where 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 only 28% of the variance in young adults' TST attributed to individual characteristics, ICC = .28). In contrast, the proportion of variance in TST for older adults was similar for within- and between-person sources, suggesting that night-to-night differences in TST for older adults is roughly the same as differences between older adults in amount of TST. 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 in average TST.

Ratios of within-person to between-person variance were lower for NWAK (Table 4). Between-person differences in NWAK were actually greater than variability within-persons for older adults and males, as noted by ratios less than one (.7 and .8). However, there was still significant within-person variability for all demographic categories, with at least 40% of the total variance attributed to night-to-night fluctuations in NWAK occurring within persons.

Tables 5 and 6 report the variability estimates for SOL and WASO. Overall, these findings suggest that night-to-night, within-person variability in self-reported SOL and WASO is higher than differences between persons in these sleep measures. Notably, for females, over 70% of the variance in WASO was attributable to nightly fluctuations within persons (with an ICC <

.30). Middle-aged adults also had approximately 70% of variance in WASO due to within-person variability as compared to between-persons.

Sleep Characteristics

Nightly sleep diary data were aggregated across the two weeks to provide summary measures of sleep for each individual. Specifically, intra-individual means and intra-individual standard deviations (iSD) of each sleep parameter were calculated across all available nights of data per individual. These individual means and standard deviations were used for the remainder of the study analyses. In this sample of 592 normal sleepers, an individual's mean TST across two weeks ranged from 2.3 hours to almost 12 hours. The variability in TST within an individual (measured by their iSD) ranged from 8 minutes to almost 4 hours, with a mean iSD for the sample of over 1 hour. See Table 7 for descriptive information regarding individual-level means and variability in all sleep parameters for the sample. Tables 8 and 9 display means and standard deviations of these sleep characteristics for each age, sex, and race group.

Given the study goal of examining the overall magnitude of within-person variability across two weeks, temporal dependency in the data or how one night affects the following night's sleep was not explored. Furthermore, these summary measures of the amount of within-person variability span a relatively short time-period of two weeks, so we did not expect a change in values due to the passage of time. In support of this, paired t-tests comparing an individual's week one mean TST with their mean TST from week two were not significant, suggesting no effect of time on subjective sleep in this sample. Paired t-tests of iSD in TST for weeks one and two also indicated no change in the amount of within-person variability from week one of the study to week two. Finally, to explore the possibility of curvilinear effects or other time trends in the data, we examined bivariate scatterplots of each sleep parameter/outcome (i.e., nightly TST, NWAK, SOL, WASO) by time (14 nights). Visual inspection of the plots did not reveal any systematic patterns in the data across the 14 nights, suggesting that it was not necessary to detrend the variability data in regard to time.

Prior to conducting correlational or regression analyses, data were examined to ensure the appropriate assumptions required for linear regression were met. Examination of the shape and distribution of the sleep variables revealed several violations of normality, and further examination of residuals and associations between variables revealed some heteroscedasticity and nonlinearity. Therefore, logarithmic transformations were conducted on the following variables: mean NWAK, iSD NWAK, mean SOL, iSD SOL, mean WASO, and iSD WASO, which greatly improved the shape of each variable's distribution (reducing skewness and kurtosis values into the normal range) and reduced heteroscedasticity and nonlinearity to an acceptable level (Tabachnick & Fidell, 2007).

Potential correlates of sleep variability. To test for potential covariates of sleep variability, we ran bivariate correlations 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). Regarding the independent variables of interest, 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). 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. Intercorrelations are presented in Table 10.

Examination of correlations among mean sleep and iSD sleep measures revealed no association between mean TST and variability in TST. However, as one would expect due to the nature of the measures, iSDs for each measure of sleep disturbance (NWAK, SOL, and WASO) were strongly correlated with mean levels of its corresponding sleep parameter. In addition, all four sleep variability measures were correlated with each other (ranging from r =.20 to r =.50, $p < .001$), indicating that variability in one sleep parameter was associated with greater variability in other sleep characteristics.

We also examined bivariate correlations among the primary independent variables (i.e., age, sex, and race) and sleep outcomes. Age was negatively correlated with iSDs for TST (r = -.35, $p < .001$) and NWAK (r = -.16, $p < .001$), indicating that nightly variability in TST and NWAK decreases with increasing age. Female sex was associated with greater variability in all three measures of sleep disturbance; SOL (r = .16), WASO (r =.15), NWAK (r =.16), all p < .001, as well as variability in TST (r = .11, p =.01). Race was correlated with iSDs in TST and SOL (both r = .16, $p < .001$), indicating that Blacks tend to have greater variability in both TST and SOL than Whites.

Other potential covariates of nightly sleep variability were examined in correlational analyses. BDI-II scores were positively associated with iSD TST (r = .13, p = .001) and iSD SOL (r = .12, p = .004). Variability in WASO was also associated with higher BDI-II scores (r = .19, $p < .001$), as well as greater number of health problems (r = .12, p = .003). Of the four measures of sleep variability, household education level was only correlated with iSD NWAK, with a greater number of years of education associated with greater variability in NWAK (r = .16, $p < .001$).

Multiple Regression Analyses Predicting Intra-individual Variability in Sleep

As stated previously, assumptions for regression analysis were met or data transformation performed when appropriate. Again, 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 for all analyses was white males. All continuous predictor variables, including age, were centered at their mean. The following product terms were created to explore potential interactions among the three demographic variables: age × sex, age × race, sex × race, and age × sex × race.

Relation with variability in TST. The first hierarchical regression was conducted using iSD TST as the outcome. Given previous research suggesting a relationship between depression and sleep variability (Bernert, 2009), BDI-II scores were entered as a covariate in Step 1 and explained almost 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 the variance explained by almost 14%, F (3,587) = 31.65, p < .001. Subsequent steps in the model examined potential interactive effects and revealed several interactions among the three demographic variables. Adding the interaction terms increased variance explained, ΔR^2 = .02, F (4,583) = 3.78, p = .005. Results of the final regression model testing the interactions between age, sex, and race as predictors of variability in TST were significant, F (8,583) = 15.55, p < .00. Table 11 presents fully partialed values for all variables in the final regression model.

As seen in Table 11, BDI-II remained a significant predictor in the final model, uniquely predicting over 1% of variance in iSD TST, sr^2 = .01, t(582) = -3.14, p = .002. Given the presence of significant higher-order interactions, main effects of the demographic variables are not discussed here, as they are not representative of the whole sample. Similarly, given the presence of the 3-way interaction, the 2-way interactions in this regression model are conditional effects linked to the referent group for this analysis (which is white males), and will be discussed in the context of the significant 3-way interaction.

The significant 3-way interaction indicates that the relationship between age and intra-individual variability in TST depends on both sex and race. (The 3-way interaction uniquely predicted 1% of variance, $sr^2 = .01$, $t(582) = -2.57$, p = .01.) 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 $p < .05$. Plotting the simple regression lines for each demographic group (see Figure 2) illustrates the slopes for age. Figure 2 also depicts the group differences in slopes. Slope difference tests 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 shown in Table 11 only applies to the mean age of the sample (*M* = 52 years). Figure 2 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. The next hierarchical regression analysis predicted variability in NWAK using log transformations of both iSD NWAK and mean NWAK. As noted previously, correlational analyses found that having more nighttime awakenings and a higher education level are related to greater variability in NWAK. Therefore, mean NWAK and education were both entered as covariates into Step 1 of the regression model. These two covariates accounted for 33% of the variance in iSD NWAK, F (2,500) = 122.56, p < .001. Next, age, sex, and race were entered in step two of the model. Together, these demographic variables provided a 9% increment in explained variance, F (3,497) = 25.76, p < .001. The full model accounted for 42% of the variance F(5,497) = 71.77, p < .001 (Table 12). There were no interactions among demographic variables.

The covariate, mean NWAK was the strongest predictor of nightly variability in NWAK, accounting for almost 40% of the variance explained by the full model. Household education level was positively associated with iSD NWAK, sr^2 = .01, with more education associated with greater variability in NWAK. Even after controlling for mean number of awakenings and education, both age and sex were significant predictors of iSD NWAK. Age uniquely accounted for a little over 7% of the variance, t(496) = -7.92, p < .001. With increasing age, the amount of intra-individual variability in NWAK decreased. Sex was also related to iSD NWAK, uniquely explaining 2% of the variance, sr^2 = .02, t(496) = 3.90, p = .001, with females reporting more nightly variability in NWAK than males. In the presence of other variables, race was not associated with variability in NWAK.

Relation with variability in SOL. As previously discussed, logarithmic transformations were used on both mean SOL and iSD SOL variables due to marked violations of skewness and kurtosis. Given the high correlation between an individual's mean SOL and the amount of nightly variability in SOL (r = .75), mean SOL was entered as a covariate in the model predicting iSD SOL. As expected, entering mean SOL in Step 1 of the model explained a significant amount of variance, R^2 =.56, F (1,590) = 742.0, p < .001. Adding the set of demographic variables in Step 2 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 13). There were no interactive effects among the demographic variables.

Mean SOL remained the strongest predictor in in the final model, accounting for 53% of the total variance, sr^2 = .53, *t*(586) = 27.0, p < .001. Each of the demographic variables contributed to the prediction of iSD SOL, but to a much lesser degree than mean SOL. Age and sex each accounted for approximately 1% of variance, with younger age (sr^2 =.01, *p* < .001) and female sex (sr^2 = .01, *p* = .002) associated with greater variability in SOL. Race accounted for less than 0.5% of variance (sr^2 = .003, *p* = .03). When controlling for mean SOL, age, and sex, 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 (Whites: *M* =11, *SD* = 11.0; and Blacks: *M* = 14, *SD* =13). Furthermore, a comparison of the regression coefficient for race (β = -.05) with the zero-order correlation of race and iSD SOL (*r* = .16) shows opposite signs. Given the significant association between Black race and the covariate, mean SOL (*r* = .26), and the high correlation between mean SOL and iSD SOL (*r* = .75), a suppression effect is likely.

Relation with variability in WASO. Logarithmic transformations were also used on mean WASO and iSD WASO. Bivariate correlational analyses with the transformed iSD variable suggested three potential covariates for variability in WASO; mean WASO, BDI, and number of health problems. Entering these three covariates in Step 1 of a multiple regression model accounted for 74% of the variance in iSD WASO, *F* (3,588) = 564.91, *p* < .001. Mean WASO, but not BDI or number of health problems, significantly predicted variability in WASO. Adding the set of three demographic variables in Step 2 increased the 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 two covariates were removed and a final model run with only mean WASO, age, sex, and race entered as predictors. There was no change in total variance explained from the first model (R^2 =.76) to the second model (R^2 =.76), suggesting that the elimination of BDI and health problems did not reduce the predictive utility of the model.

This final model was significant, *F* (4,587) = 472.10, $p < .001$ (see Table 14), accounting for 76% of total variance in iSD WASO. Similar to the relationship between mean levels and nightly variability in SOL, mean WASO was strongly related to variability in WASO, explaining 74% of the variance. After controlling for mean WASO, age was the only significant predictor in the model. Age was negatively associated with variability in WASO, accounting for almost 3% of the variance (sr^2 = .03, $p < .001$). In the presence of the other predictors, neither sex nor race contributed to variability in WASO. There were no interactions among the demographic characteristics.

Table 1

Sample Characteristics by Demographic Group (N = 592)

Group		*n* (%)	# Health problems	BDI-II scores	Years of Education
			M (SD)	*M (SD)*	*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.
[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 for Overall Sample

	Within-person		Between-person		Ratio of
	Variance component	% within	Variance component	ICC (% between)	within/ between
TST	5782.30	62.4	3478.96	37.6	1.66
NWAK	.945	51.7	.883	48.3	1.07
SOL	324.37	67.6	155.82	32.4	2.08
WASO	636.92	64.9	343.80	35.1	1.85

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

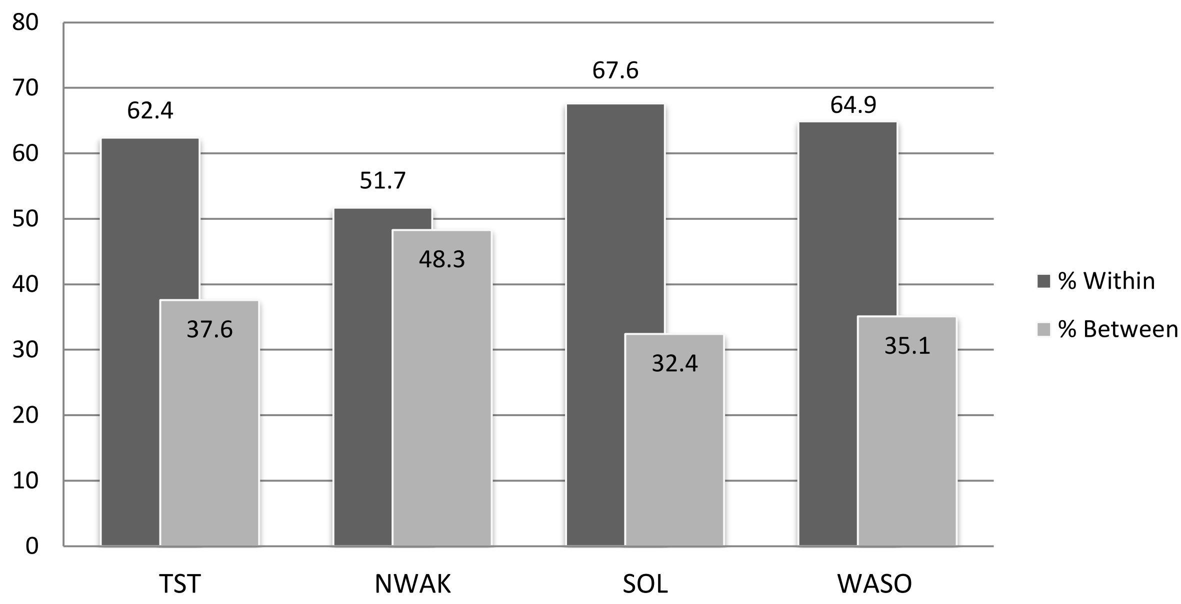

Figure 1. Sources of variability in sleep diary measures. Each columns represents the percentage of total variability in a sleep parameter that is due to either within-person or between-person sources. TST= total sleep time; NWAK= number of nighttime awakenings; SOL= sleep onset latency; WASO= wake-time after sleep onset.

Table 3

Estimates of Within- and Between-Person Variance in TST by Demographic Group

Group		Within-person		Between-person		Ratio of
		Variance component	% within	Variance component	ICC (% between	within/ between
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

Note. TST = total sleep time; ICC = intraclass correlation coefficient. Variance components estimated from null multilevel models.

Table 4

Estimates of Within- and Between-Person Variance in NWAK by Demographic Group

Group		Within-person		Between-person		Ratio of
		Variance component	% within	Variance component	ICC (% between)	within/ between
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

Note. NWAK = number of awakenings during the night; ICC = intraclass correlation coefficient. Variance components estimated from null multilevel models.

Table 5

Estimates of Within- and Between-Person Variance in SOL by Demographic Group

Group		Within-person		Between-person		Ratio of within/ between
		Variance component	% Within	Variance component	ICC (% Between)	
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

Note. SOL = sleep-onset latency; ICC = intraclass correlation coefficient. Variance components estimated from null multilevel models.

Table 6

Estimates of Within- and Between-Person Variance in WASO by Demographic Group

Group		Within-person		Between-person		Ratio of
		Variance component	% Within	Variance component	ICC (% Between)	within/ between
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. WASO = wake-time after sleep onset; ICC = intraclass correlation coefficient. Variance components estimated from null multilevel models.

Table 7

Means and Standard Deviations of Sleep Characteristics (N = 592)

Sleep Measure	*M (SD)*	Range
Mean TST	426.4 (62.4)	138 – 703
iSD TST	68.1 (33.9)	8 – 231
Mean NWAK	1.4 (.98)	0 – 5
iSD NWAK	.84 (.49)	0 – 3.2
Mean SOL	18.6 (13.1)	2 – 96
iSD SOL	12.0 (11.7)	0 – 89
Mean WASO	18.4 (19.9)	0 – 155
iSD WASO	18.0 (18.1)	0 – 122

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.

Table 8

Means and Standard Deviations of Sleep Characteristics by Age Group

	Age groups		
	Young[a]	Middle-age[b]	Older[c]
Sleep Measure	*M (SD)*	*M (SD)*	*M (SD)*
Mean TST	425.8 (60.7)	415.0 (58.5)	441.3 (66.1)
iSD TST	82.1 (37.1)	67.7 (30.7)	54.2 (28.2)
Mean NWAK	1.1 (.90)	1.3 (.94)	1.7 (1.0)
iSD NWAK	.93 (.48)	.86 (.55)	.73 (.40)
Mean SOL	18.5 (12.1)	18.2 (14.2)	19.1 (12.7)
iSD SOL	12.4 (10.1)	11.9 (12.4)	11.8 (12.5)
Mean WASO	15.6 (19.2)	16.8 (18.4)	23.2 (21.6)
iSD WASO	18.0 (17.4)	17.7 (18.2)	18.5 (18.6)

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.

Table 9

Means and Standard Deviations of Sleep Characteristics by Demographic Group

	Sex		Race	
	Males[a]	Females[b]	Whites[c]	Blacks[d]
Sleep Measure	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Mean TST	425.5 (64.0)	427.3 (60.9)	427.2 (55.2)	424.7 (76.9)
iSD TST	64.5 (32.4)	71.7 (35.1)	64.6 (29.6)	76.4 (41.3)
Mean NWAK	1.3 (1.0)	1.4 (.95)	1.4 (.96)	1.2 (1.0)
iSD NWAK	.76 (.43)	. 92 (.54)	.86 (.48)	.79 (.51)
Mean SOL	17.1 (11.8)	20.0 (14.2)	16.4 (11.3)	23.7 (15.5)
iSD SOL	10.1 (9.5)	13.9 (13.3)	11.1 (11.0)	14.2 (13.0)
Mean WASO	16.4 (19.5)	20.3 (20.2)	17.5 (18.2)	20.6 (23.4)
iSD WASO	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* = 294. [b]*n* = 298. [c]*n* = 415. [d]*n* = 177.

Table 10

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 11

Final Multiple Regression Analysis Predicting Intra-individual Standard Deviations in TST

Predictor	B	*SE* B	β	*t*	*p*	sr^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

Note. Values for individual predictors reflect fully partialed values from final regression model. TST = Total sleep time; *sr* =semi-partial correlation coefficient; BDI-II = Beck Depression Inventory-II; Sex is coded as 0=male, 1=female; Race coded as 0=White, 1=Black. All continuous predictor variables are centered at the mean. Total R^2 = .176.

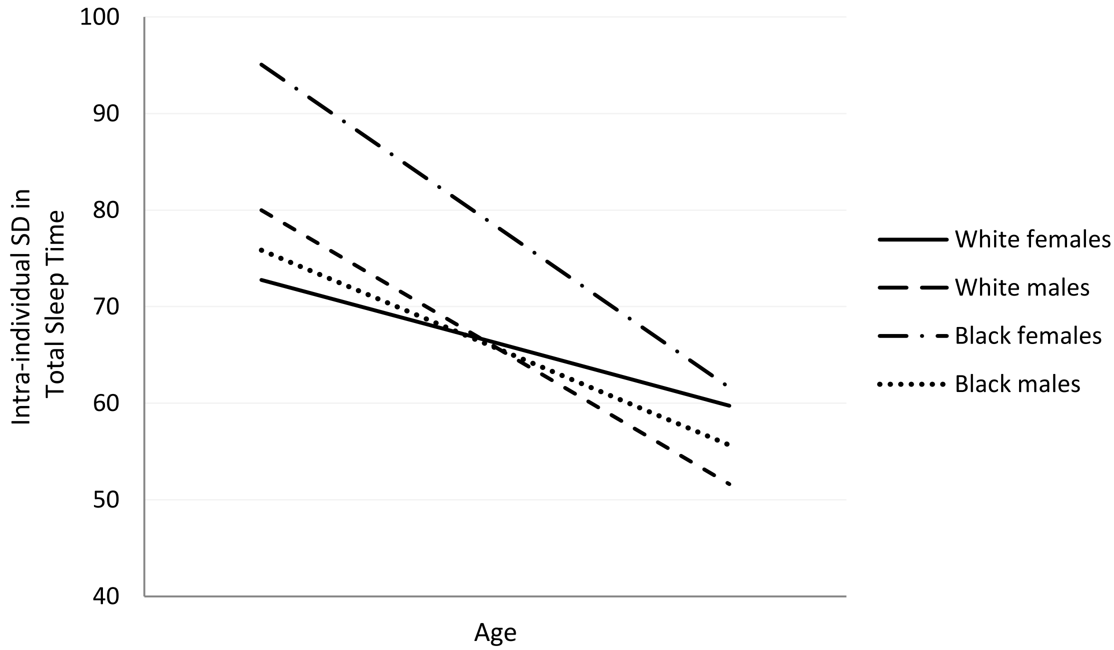

Figure 2. Three-way interaction of age × sex × race on variability in TST. Simple regression lines for intra-individual standard deviation (iSD) in TST are plotted at one standard deviation above and below the sample's mean age. TST = total sleep time.

Table 12

Final Multiple Regression Analysis Predicting Intra-individual Standard Deviations in NWAK[a]

Predictor	B	*SE* B	β	*t*	*p*	sr^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		

Note. Values for individual predictors reflect fully partialed values from final regression model. NWAK = Number of awakenings; *sr* =semi-partial correlation coefficient. Sex is coded as 0=male, 1=female; Race coded as 0=White, 1=Black. All continuous predictor variables are centered at the mean. Total R^2 = .419.

[a]LG10(X+1) transformation used on iSD NWAK and mean NWAK.

Table 13

Final Multiple Regression Analysis Predicting Intra-individual Standard Deviations in SOL[a]

Predictor	B	*SE* B	β	*t*	*p*	sr^2
Mean SOL[b]	.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

Note. Values for individual predictors reflect fully partialed values from final regression model. SOL = Sleep onset latency; *sr* =semi-partial correlation coefficient. Sex is coded as 0=male, 1=female; Race coded as 0=White, 1=Black. All continuous predictor variables are centered at the mean. Total R^2 = .577.

[a]LG10(X+1) transformation used on iSD SOL. [b]LG10(X) transformation used on mean SOL.

Table 14

Final Multiple Regression Analysis Predicting Intra-individual Standard Deviations in WASO[a]

Predictor	B	*SE* B	β	*t*	*p*	sr^2
Mean WASO[a]	.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		

Note. Values for individual predictors reflect fully partialed values from final regression model. WASO = Wake time after sleep onset; *sr* =semi-partial correlation coefficient. Sex is coded as 0=male, 1=female; Race coded as 0=White, 1=Black. All continuous predictor variables are centered at the mean. Total R^2 = .763.

[a]LG10(X+1) transformation used on iSD WASO and mean WASO.

DISCUSSION

There was considerable intra-individual variability in subjective sleep across the two week period. For the overall sample of normal sleepers, the variance in sleep attributed to within-person sources was the same as or larger than the variance attributed to individual differences for all four sleep parameters (TST, NWAK, SOL, and WASO). With a greater proportion of the total variability in TST attributed to within-person sources, this means that their TST for any given night was more likely to resemble the TST of another person's sleep than their own on another night. SOL and WASO also showed greater variability within-individuals. The amount of variation in NWAK between two different individuals was approximately the same as fluctuation from one night to the next within the same individual.

There was a similar pattern of findings across each demographic group (i.e., young, middle-age, older, males, females, Whites, Blacks) examined in this study. 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 more similar in size for NWAK. These results are consistent with previous research using objective measures of sleep (Knutson et al., 2007; Mezick et al., 2009; Tworoger et al., 2005; van Hilten et al., 1993), as well as studies documenting variability in adult's subjective sleep (Buysse et al., 2010; Dautovich et al., 2012).

Partitioning the within- and between-person variation in different demographic groups revealed a pattern for age in TST and NWAK. For TST, younger adults had the lowest ICC's, (indicating more variability) followed by middle-aged adults, and then older adults. In young adults, 27% of the total unexplained variance in TST was due to between-person differences, leaving 73% of the variance attributed to within-person fluctuations. This finding indicates that young adults' TST differs more from night to night within the same individual than it does between one young adult and the next. In other words, TST for any given night from a young adult is more likely to resemble the TST of another young adult than their own sleep on another night. In contrast, the variance in TST for older adults was approximately the same for within- and between-person sources, suggesting that for older adults, the TST for one night is just as likely to represent the TST of a complete stranger as it is their own sleep on another night. This trend for older adults to have less within-person variability in their sleep (as indicated by higher ICC's) was also apparent for number of nighttime awakenings and was statistically significant in multiple regression analyses predicting iSD's in TST and NWAK.

This association between age and variability in subjective sleep is a new contribution to the field, as previous research (i.e., Mezick et al, 2009., van Hilten et al., 1993) failed to find age differences in their samples of older adults. However, as the previous authors noted, the lack of age effects could be due to the limited age range in their samples, as their youngest participants were age 46 (Mezick et al., 2009) and age 50 (van Hilten et al., 1993). In contrast, the sample used in the current study ranged from age 20 to 98 years. For subjective TST, we also found that the amount of variability associated with age depends on the individual's 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 amount of variability in TST with increasing age when compared to White females.

There are several possible reasons that intra-individual variability 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 a longer and more solid sleep on a subsequent night due to the accumulation of sleep debt and resultant increased level of sleepiness. Therefore, the 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 time as a mechanism of regulating one's sleep need. Regarding nighttime awakenings, greater night-to-night variability in younger adults could reflect a stronger sleep recovery mechanism that allows younger adults to sleep more solidly and have fewer awakenings on some nights (in response to a greater sleep debt) than on other nights. In contrast, the lower variability observed in older adults may suggest that the sleep recovery mechanism is less responsive with increasing age. A second possibility is that older adults have a more regular sleep pattern due to greater lifestyle regularity. Alternatively, this would suggest that younger and middle-aged adults have more variable sleep patterns due to more irregular timing of their sleep schedules.

Although age was significant in models predicting variability in SOL and WASO, correlational analyses revealed no direct relation between iSD WASO and age, and only a weak correlation between age and iSD SOL**.** Therefore, the contribution of age in each of these regression models was likely due to statistical suppression effects and associations of age with mean SOL and mean WASO. Likewise, ICC's for SOL and WASO were similar across all age groups, indicating there was significant within-person variation (ICC's all < .4) in these variables across the entire age range observed in this study.

Regarding sources of variance for each sex, females appeared to have greater within-person variability relative to between-person variation for all four sleep outcomes. In particular, ratios comparing these two sources of variation for SOL and WASO indicate that the amount of nightly fluctuation within an individual female was over twice the amount of fluctuation observed between two different females. This finding could indicate females' sleep is more vulnerable to external and environmental influences from one night to the next. Additionally, as Tworoger and colleagues (2005) pointed out after examining sleep variability in a female sample, short-term variability in sleep of females could be due to hormonal fluctuations.

When statistically controlling for mean levels of each sleep parameter, female sex contributed to variability in NWAK and SOL, but not to variability in WASO. In addition, as previously discussed, there were interactive effects for sex differences in TST variability. For instance, at average age of the sample, White females and White males do not differ in amount of variability in TST. However, at this same age, Black females have greater intra-individual variability in TST than Black males. Although effect sizes were small, the finding that females generally tend to have greater intra-individual variability in sleep than males is consistent with previous research documenting IIV in objective measures of adult sleep (Knutson et al., 2007; Mezick et al., 2009; van Hilten et al, 1993).

Variability in sleep for each race revealed a more complicated pattern. Looking only at iSD values for TST, SOL, and WASO suggest that Blacks have greater intra-individual variability than Whites. Similarly, the raw variance components derived from multilevel models show large amounts of both within- and between- person variation in these three measures for Blacks. However, when taking both sources of variance into account; within-person fluctuation in SOL and WASO for Whites is twice as large as the variation between White adults. Furthermore, in the presence of mean levels of sleep, age, and sex as other predictors, race did not make a significant contribution toward aggregate values of intra-individual variability in NWAK or WASO. Although race contributed to the prediction of variability in SOL, the effect was small. Furthermore, the direction of this effect indicated a statistical suppression effect, suggesting that race may be associated with intra-individual variability in SOL due to its stronger association with mean SOL. The high between-subjects variability for Blacks in this study supports previous research suggesting that Blacks are more likely to report sleep durations at both extremes (e.g., Hale & Do, 2007; Nunes et al., 2008). Moreover, this propensity for greater variability in sleep between Blacks highlights additional methodological issues in the study of sleep (see van Dongen et al., 2005 Appendix for review).

Most of the research linking sleep with health outcomes has made an assumption that the sleep of an individual is relatively stable from one night to the next and that one night is an adequate representation of the individual's true sleep. If this is true, the variation between persons should be comparatively larger than variation within a person upon repeated measurements. However, the findings of this study are opposite, indicating that nightly, within-person fluctuations in self-reported sleep of normal sleeping adults are greater than the between-person differences. Given the large amount of intra-individual variability in sleep for all demographic groups, characterization of an individual's sleep by a single night's score or an average level may not be appropriate. In addition, this large night-to-night variability indicates that other factors which vary from day-to-day within a person (e.g., mood states, daily demands, environmental factors such as outside noise or bed partners) have an influence on sleep and should be explored in future studies.

Finally, the degree of nightly fluctuation in sleep may have clinical and theoretical importance in its own right. The differentiation between inter-individual and intra-individual variability has received attention in recent years across several fields of study (e.g., blood pressure: Muntner et al., 2011; cognitive functioning: Nesselroade & Salthouse, 2004; personality and affect: Mroczek, Spiro, & Almeida, 2003). For example, Muntner et al (2011) found that variability in an individual's systolic blood pressure across office visits increased risk of mortality, independent of mean blood pressure. Regarding sleep, Dautovich et al. (2012) found that the day-to-day variability in naptime of older adults, but not average duration of naptime, was uniquely linked with number of physical health problems. Likewise, in an adolescent sample, intra-individual variability was associated with psychological well-being independent of mean levels of sleep (Fuligni & Hardaway, 2006). The current study began exploring this possibility by examining unique associations of demographic variables with the amount of intra-individual variability in sleep.

In addition to the findings regarding age, sex, and race differences in sleep variability, potential covariates were examined. Of note, BDI scores made a unique contribution to intra-individual variability in TST. Although the effect size was small in this sample, this association is consistent with previous research suggesting depression is related to variability in sleep duration in suicidal college students (Bernert, 2009) and in individuals with bipolar disorder (Gruber et al., 2011). Household education was also uniquely linked with intra-individual variability in NWAK, such that higher education was associated with higher variability in NWAK.

There were some limitations of this study worth noting. Despite the stratified sampling procedure, the number of Blacks was still somewhat small (n =177) compared to the number of Whites (n = 415) in this sample of normal sleepers. Blacks also had greater amounts of variability in each sleep diary measure, both within the same individual and between individuals. As a result, the findings for Blacks are less reliable and should be interpreted with caution until replicated with other samples. Other limitations are that this normal sleeping sample was relatively healthy with low levels of depression. Thus, the restricted range on these variables could have made it more difficult to detect true associations with the sleep outcomes. Additionally, though household education level was assessed for the majority of participants, there are other indicators of socioeconomic status that could confound the relationships between nightly variability in sleep and demographic variables such as age, sex, and race. Other potential confounds that were not assessed in this study include income level, employment and marital status, and caregiving or parenting responsibilities.

Finally, the current study did not control for day of week effects in the multilevel analyses, which might influence the amount of intra-individual variability in sleep. Previous research using objective measures of sleep provides mixed results, with two studies finding no effects for day of the week in variability of sleep in middle-age to older adults (Mezick et al., 2009; van Hilten et al., 1993), and another study suggesting that sleep is more variable on weekends in middle-aged females (Tworoger et al., 2005). The potential influence that day of the week may have on sleep variability relates to the issue regarding variability in daily routines and sleep schedules. For example, nightly variability in the sleep parameters measured in this study (particularly for SOL and TST) could be dictated by variability in the timing of sleep from one night to the next. Given the differences in typical bedtimes and arising times across the age span (Thomas, Lichstein, Taylor, Riedel, & Bush, in press); future studies should examine how variability in bedtimes and rise times affects variability in other sleep diary parameters.

As mentioned, this study addresses a largely neglected, but potentially very important topic in the literature: nightly variability in normal sleep. The majority of the research on intra-individual variability in sleep has focused on sleep disturbance, documenting that people with insomnia exhibit greater intra-individual variability in sleep than people without sleep complaints (e.g., Buysse et al., 2010; Wohlgemuth et al., 1999). However, gaining a better understanding of the mechanisms regulating sleep patterns in normal sleepers is important, as it could shed light on how sleep disturbances develop and/or resolve.

Variations in normal sleep could also help explain the link between sleep and health. For instance, greater night-to-night variability in sleep could indicate (or contribute to) a dysregulated circadian pattern that has adverse effects on physiological processes (e.g., such as metabolic function). Preliminary support comes from Mezick et al's (2009) finding that individuals with high nightly variability in objective TST and sleep fragmentation had elevated nocturnal norepinephrine levels. More recently, Okun and colleagues (2011) associated greater variability in sleep-wake behaviors (i.e., bedtimes, rise times, and time in bed) with increased levels of inflammatory markers in community dwelling older adults (including good sleepers and people with insomnia). Research has also explored the impact of sociodemographic factors on 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). In light of our finding that variability in total sleep time differs by age, sex, and race, it would be interesting to examine whether intra-individual variability also plays a role in such health disparities.

Given documented differences in objective and subjective measures of sleep, another strength of this study is the use of self-reported data, which captured variability in sleep occurring in an individual's natural sleep environment. Furthermore, the current study was able to examine the variability in subjective sleep in two different ways, by separating the overall variance in each measure of sleep into within- and between-person sources, as well as exploring associations among intra-individual variability in sleep and demographic variables. Additionally, when examining unique associations with intra-individual variability, we accounted for relations between the mean level of each sleep parameter and the variability in that measure by including average levels of sleep as covariates in regression analyses.

A particular strength of this study is the wide age range of the sample. Instead of comparing discrete age groups, we were able to examine the association between sleep variability and age across adulthood. Additionally, this study adds to the literature on general sex and ethnic differences in self-reported sleep. Although previous studies using polysomnography and actigraphy indicate that females have greater intra-individual variability in sleep than males, this difference has not been documented in self-reported sleep until now. In contrast, findings regarding race differences in sleep variability are still not clear. However, this study was able to highlight potential methodological issues to consider in research design. For example, if Blacks truly have greater intra-individual variability in sleep, it may be necessary to collect more nights of data to provide an accurate representation of their typical sleep. However, given the high amounts of between-person variability found for Blacks in this study, it is also imperative to have an adequate sample size of Blacks, especially if race differences are being explored.

Overall, these results provide support for further research into inter-individual and intra-individual differences in sleep. Our findings corroborate previous research suggesting variation in mean levels of sleep that needs to be accounted for by individual-level characteristics, which has long been an area of study (van Dongen et al., 2005) that should continue to be explored. Importantly, this study also documented significant within-person variation in sleep that needs to be accounted for. Future research should explore other daily variables that may covary or relate to nightly sleep (e.g., if days with greater pain were related to nights with shorter TST or poorer sleep quality ratings). A handful of studies have begun to explore this possibility, examining within-person associations with sleep and other daily variables (e.g., mood: McCrae et al., 2006).

Our results indicate there is high intra-individual variability in subjective sleep across the adult age span. To truly assess and understand individual differences in sleep, future research needs to take into account this night-to-night variability (including what makes sleep vary from one night to the next), in addition to average levels of sleep. Furthermore, investigation into potential associations between sleep variability and other aspects of health is necessary, particularly in regard to understanding the role sleep may play in health disparities.

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Appendix 1

HEALTH SURVEY

Please **PRINT** and Supply **ALL** Information

ID# ____________________ Height _________ Weight __________

Race __________________

1. Do you have a sleep problem? yes or no
   If yes, describe (e.g., trouble falling asleep, long or frequent awakenings, sleep apnea):

   ____

   If yes, on average, how many nights per week do you have this problem? ________________

   How long have you had this sleep problem? ________years ________months

2. Please indicate whether you or your bed partner have noticed any of the following:

   Are you a heavy snorer? yes no

   Do you have difficulty breathing or gasp for breath during sleep? yes no

   Do your legs jerk frequently during sleep or do they feel restless before sleep onset? yes no

   Do you have sleep attacks during the day or paralysis at sleep onset? yes no

If yes to any of the questions under #2, please explain and indicate how often symptoms occur:

____

____

3. Indicate with a check mark if you have the following health problems, and put the number of years you've had each problem:

Yes Years

___ ________Heart disease
___ ________ Cancer
___ ________ AIDS
___ ________ High blood pressure
___ ________ Neurological disease (ex: seizures, Parkinson's)
___ ________ Breathing Problems (ex: asthma, emphysema)
___ ________ Urinary problems (ex: kidney disease, prostate problems)
___ ________ Diabetes
___ ________ Chronic Pain (ex: arthritis, back pain, migraines)
___ ________ Gastrointestinal (ex: stomach, irritable bowels, ulcers)

4. Please list any mental health disorders you have and the number of years you've had the disorder(s)

____

____

5. List any other health problems you have (and the number of years you've had the problem).

____

6. Medical and mental health disorders may disrupt sleep. Medication may also disturb sleep. Please list any disorder or medication that affects your sleep and describe how it affects sleep.

____

____

7. List ALL **medications** taken within the past month, the frequency with which they are taken (e.g., daily, 3 times a day, weekly), time of day, and the purpose of the medication.

<u>Medicine</u> <u>Frequency</u> <u>Time of Day</u> <u>Purpose</u>

a. ____

b. ____

c. ____

d. ____

e. ____

f. ____

g. ____

8. List ALL **vitamins** taken within the past month, the frequency with which they are taken (e.g., daily, 3 times a day, weekly), time of day, and the purpose of the medication

<u>Vitamin</u> <u>Frequency</u> <u>Time of Day</u> <u>Purpose</u>

a. ____

b. ____

c. ____

d. ____

9. On average, how many alcoholic drinks do you drink per week? ____________

10. On average, how many cigarettes do you smoke per day? _______________

11. On average, how many caffeinated drinks do you have per day? __________

12. What is your highest level of education? ____________

13. If you have a spouse, what is his or her highest level of education? _________

Appendix 2

Sleep diary from Lichstein et al., 2004

SLEEP QUESTIONNAIRE
Department of Psychology, University of Memphis

ID# ____________________

Please answer the following questionnaire **WHEN YOU AWAKE IN THE MORNING.** Enter yesterday's day and date and provide the information to describe your sleep the night before. Definitions explaining each line of the questionnaire are given below.

yesterday's day ⇒ yesterday's date ⇒	**EXAMPLE** TUES 10/14/97	day 1	day 2	day 3	day 4	day 5	day 6	day 7
1. NAP (yesterday)	70							
2. BEDTIME (last night)	10:55							
3. TIME TO FALL ASLEEP	65							
4. # AWAKENINGS	4							
5. WAKE TIME (middle of night)	110							
6. FINAL WAKE-UP	6:05							
7. OUT OF BED	7:10							
8. QUALITY RATING	2							
9. BEDTIME MEDICATION (include amount & time)	Halcion 0.25 mg 10:40 pm							

ITEM DEFINITIONS

1. If you napped yesterday, enter total time napping in minutes.
2. What time did you enter bed for the purpose of going to sleep (not for reading or other activities)?
3. Counting from the time you wished to fall asleep, how many minutes did it take you to fall asleep?
4. How many times did you awaken during the night?
5. What is the total minutes you were awake during the middle of the night? This does not include time to fall asleep at the beginning of the night or awake time in bed before the final morning arising.
6. What time did you wake up for the last time this morning?
7. What time did you actually get out of bed this morning?
8. Pick one number below to indicate your overall QUALITY RATING or satisfaction with your sleep.
   1. very poor, **2.** poor, **3.** fair, **4.** good, **5.** excellent
9. List any sleep medication or alcohol taken at or near bedtime, and give the amount and time taken.