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Intraindividual Variability in Psychometrically Defined Mild Cognitive Impairment Status in Older African Americans

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Abstract

The current study examines day to day variability in psychometrically defined MCI status and potential predictors of changes in MCI status in an independent-living sample of urban dwelling older adults in Baltimore, Maryland. The participant sample consisted of 50 older adults ranging in age from 50 to 80 years. Participants completed health and cognitive measures (i.e. executive function, language, memory, and global cognition) over 8 occasions within a 2–3 week period. After each testing occasion, a post-hoc classification of MCI status was determined using psychometrically defined criteria based upon cognitive performance. Participants who classified as MCI after one assessment often did not meet MCI criteria at subsequent occasions. Daily fluctuations in sleep duration were associated with an increased risk for MCI classification. These results demonstrate that changes in sleep may explain changes in MCI status, particularly for African Americans.

Keywords

mild cognitive impairment; intraindividual variability; sleep; blood pressure

A diagnosis of mild cognitive impairment (MCI), the transitional period between normal cognitive functioning and impaired cognitive functioning, is often unstable and changes over the course of several years (Larrieu et al., 2002; Ritchie et al., 2001). The unstable MCI diagnosis can vary depending on the diagnostic criteria used (Ganguli, Chang, Snitz, Saxton, Vanderbilt, and Lee, 2010). Specifically, MCI status is partially determined by objective cognitive assessments (Petersen, 2004), which tend to demonstrate day to day variability. For example, within-person daily fluctuations have been previously observed on psychometric and neuropsychological assessments of memory, reasoning, perceptual speed, executive function, and language (Gamaldo, Allaire, Sims, & Whitfield, 2010; Gamaldo, Weatherbee, & Allaire, 2008; Weatherbee, Gamaldo, & Allaire, 2009). Thus, this paper sought expand upon the previous literature suggesting that MCI classification varies across a macro-level time course (i.e. yearly) by examining whether an MCI classification would vary across a micro-level time course (i.e. daily). In addition, the current study will examine whether short-term changes in MCI classification may be dependent upon short-term

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changes in potential factors (i.e. blood pressure and sleep disturbance) contributing to health disparities in African Americans..

Studies have found that variability in cognitive performance is significantly related to other domains such as blood pressure (Gamaldo et al., 2008), vision (Weatherbee et al., 2009), stress (Neupert, Almeida, Mroczek, & Sprio, 2006), emotion, and physical functioning (Strauss, MacDonald, Hunter, Moll, & Hultsch, 2002). For example, individuals with pre-hypertension appear to exhibit worse reasoning performance, especially when their systolic blood pressure (SBP) fluctuated above their mean SBP (Gamaldo et al., 2008). Given the covariation between the intraindividual variability of non-cognitive and cognitive domains, intraindividual variability of non-cognitive domains may also be associated with intraindividual variability in MCI status.

Complaints of sleep problems have shown to be associated with cognitive functioning in older adults (Gamaldo, Allaire, & Whitfield, 2008; Nebes, Buysse, Halligan, Houck, & Monk, 2009). Self-reported complaints of trouble falling asleep have shown to be associated with worse short-term and working memory, which is often used to determine MCI status (Gamaldo et al., 2008). Sleep disturbances have also been shown to be associated with MCI status (Gauthier & Touchon, 2005). MCI cases appear to have a higher frequency of disturbances in sleep than other symptoms (i.e. irritability and depression; Lyketsos, Lopez, Jones, Fitzpatrick, Breitner, & DeKosky, 2002). Thus, an older adult might have a bad night of sleep prior to a cognitive assessment and score poorly due to the lack of sleep, which, in turn, may cause that individual to be classified as MCI.

Within African Americans, elevated blood pressure and sleep disturbances appear to be common health issues (Durrence & Lichstein, 2006; Sundquist, Winkleby, & Pudaric, 2001), and both appear to be associated with worse cognition (Gamaldo et al., 2008; Whitfield, Allaire, Aiken-Morgan, Gamaldo, Sims, & Edwards, 2008). The current study is particularly interested in exploring whether these factors may explain fluctuations in MCI status.

Although the current study is not designed to assess whether variability in cognitive performance is a precursor to cognitive impairment, this study attempts to assess whether changes in MCI status, using an ad hoc approach to MCI classification, might be a proxy for fluctuations on cognitive variables.

The current study had three primary aims. First, determine whether there is variability or consistency in MCI classification across testing occasions. Second, examine whether blood pressure was a predictor of MCI status across the testing occasions. Third, examine whether sleep was a predictor of MCI status across the testing occasions.

Method

Participants

The current study was a supplemental project of the Baltimore Study of Black Aging: Patterns of Cognitive Aging (BSBA: PCA; NIA#24108), which was designed to examine cognition, health, and other critical factors in older African Americans (Whitfield, Baker-Thomas, Heyward, Gatto, & Williams, 1999). The current study recruited 50 community-dwelling African Americans 50 years of age or older. Participants were recruited from the senior housing facilities in Baltimore, Maryland.

Demographics and Health Measures

The current analyses included the demographic variables age, education, and gender. Participants were asked to report whether they had been diagnosed with any of a series of specified illnesses or diseases. A composite score, labeled cardiovascular risk factors (CVRFS), was estimated by summing the self-report of diabetes, cardiovascular disease, high blood pressure, stroke, heart attack, angina, and circulation problems. The CVRFS variable had scores that ranged from 0 (*no risk factors*) to 7 or more risk factors. A second composite score, labeled other comorbid health illnesses (Non-CVRFS), summed the report of health illnesses that included arthritis, broken hip, asthma, gout, gallbladder problems, stomach ulcers, thyroid trouble, tuberculosis, kidney trouble, and cancer. Non-CVRFS had scores that ranged from 0 (*no comorbid health illnesses*) to 10 (*high comorbid health illnesses*). Both the CVRFS and Non-CVRFS variables were included in the analyses as covariates.

The Elderly Life Stress Inventory (ELSI; Aldwin, 1990) was used to assess self-reported stress at baseline testing. This questionnaire asked participants to indicate on a scale of 0 (*did not occur*) to 5 (*extremely stressful*) the extent to which they have experienced a number of different stressful events (i.e. death of spouse, major personal injury, and retirement) during the past year.

The Center for Epidemiological Studies-Depression (CES-D) scale was used to measure depressive symptoms at the baseline testing session (Radloff, 1977). The CES-D is commonly used in detecting depressive symptoms in older adults across diverse populations (Foley, Reed, Mutran, & DeVellis, 2002). The total CES-D score was included in the analyses.

The Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1988) was used to assess participants' typical sleep habits within the last month at the baseline testing session. Questions were designed to assess seven components, including sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, sleep medications, and daytime dysfunction due to sleep habits. Global sleep quality scores can range from 0 (*good sleeper*) to 21 (*poor sleeper*). In addition to including the global sleep quality score in the analyses, the analyses included the item regarding the use of sleep medications.

At baseline and each follow-up testing session, participants were asked the number of hours slept the previous night at each testing session. Responses for this question were categorized as sleep duration.

Systolic and diastolic blood pressures were monitored at the end of each testing occasion using an oscillometric automated device (A & D model UA-767; Milpitas California). Following a five minute rest period, a trained research assistant placed a blood pressure cuff of appropriate size on participants' bare arms to record blood pressure while the participant was sitting. Three readings were taken to assure accuracy and consistency of the blood pressure measures. The average of these three readings was included in the current study's analyses.

Cognitive Measurements

A large cognitive battery was administered to assess a broad range of cognitive abilities. Executive function was assessed using The Stroop Task (Trenerry et al., 1989) and the Clock Drawing Test (CDT), which measures a participant's ability to draw a clock to a specified time (i.e. 10 after 11, 3:25, 10 after 9, 6:55, 10 after 6, 1:45, 5 after 4, and 9:40). Clocks were scored based on a 10-point scoring system (Manos & Wu, 1994; Shulman et

al., 1986). Decalarative memory was assessed using the Rey Auditory Verbal Learning Task (AVLT; Rey, 1941). Perceptual speed was assessed using the Number Comparison test (Ekstrom et al., 1976). Inductive reasoning was assessed using the Letter Series test (Thurstone, 1962), a measure of a participant's ability to identify novel relationships in over learned material. Constructional praxis or visual-motor integration was assessed by asking participants to copy two constructions (i.e. circle, cube, diamond, two interlocking rectangles, triangle, circle touching a diamond, sideways diamond, and/or interlocking large and small squares (Beery, Buktenica, & Beery, 1997). Language was assessed using the Boston Naming Task (BNT; Goodglass & Kaplan, 1983). Finally, Verbal Fluency (Goodglass & Kaplan, 1983) was also used to assess language as well as semantic memory and executive function.

Procedure

Participants met with a research assistant for eight testing sessions over a 2–3 week period. At baseline testing, participants were randomly assigned a testing booklet associated with specific color, which consisted of the assessments as described above. At follow-up assessments (i.e. the daily sessions), participants were administered a battery of measures similar to the baseline assessment. To reduce practice effects, alternate versions were created for a majority of the measures. Testing booklets included eight alternate versions of the AVLT, Number Comparison, Letter Series, and CDT as well as four alternate versions of BNT, Letter Fluency, and Semantic Fluency. The order of each measure's alternate versions varied across the participants and occasions. The color of the testing booklet assigned at baseline testing for each participant assisted in identifying the specific order that the alternate versions for each measure were administered across the entire testing sessions. Alternate versions of the Stroop task were not included in the testing booklets. Given preliminary analyses revealed some significant differences in performance across the alternate measure versions, each measure's version was standardized to reduce the fluctuation from occasion to occasion. Initially, a mean and standard deviation was calculated for each of the measurement versions across occasions and participants. Using the version's mean and standard deviation, each version was then standardized to a mean of 50 and standard deviation of 10. Furthermore, the testing booklet color assigned at baseline was included as a covariate in the analyses.

Initial testing session lasted approximately 2 – 2 ½ hours, but subsequent testing sessions lasted roughly 1 ½ – 2 hours due to the administration of a shorter assessment battery. Participants were compensated a total of $120 for the completion of all 8 sessions within the two-week time period.

MCI status was psychometrically determined using a post-hoc approach in which a computer algorithm was conducted to identify mildly impaired individuals based upon their collected cognitive data at each testing assessment. This procedure has been used in several previous studies including non-clinical, community-based samples (Gamaldo et al., 2010; Manly, Tang, Schupf, Stern, Vonsattel, & Mayeux, 2008; Larrieu, Letenneur, Orgogozo, Fabrigoule, Amieva, Carret et al., 2002; Wadley, Crowe, Marsiske, Cook, Unverzagt, Rosenberg, & Rexroth, 2007). Our computer algorithm defined MCI status based upon a modified version of the age-associated cognitive decline criteria (Ritchie, Artero, & Touchon, 2001), which classifies individuals if they indicate impairment on at least one cognitive ability (i.e. language, memory, reasoning, executive functioning, constructional praxis, and perceptual speed). Unlike the original criteria, the modified version does not include a subjective memory complaint. As mentioned previously, all of the cognitive tests were standardized to a mean of 50 and standard deviation of 10. The influence of age and education was residualized from each standardized cognitive score which were standardized ($M = 50$, $SD = 10$) again. Individuals were divided into two groups: "normal" and "MCI".

For the "normal" group, individuals had to score at or above 1.5 *SD* below the sample mean on all the cognitive measures. For the "MCI" group, individuals had to score 1.5 *SD* (i.e. the bottom 6.68% of the sample distribution) below the sample mean on any of the cognitive measures (Ritchie et al., 2001).

Brief Description of Logistic Multilevel Modeling

Logistic multi-level models (MLM) were run to examine the association between blood pressure/sleep duration and MCI. These models predicted the dichotomous dependent variable of MCI status. Two models were conducted. In the first model, the "coupling parameters" (level 1 predictor), between-person parameters (or level 2), linear time, quadratic time, and those covariates (i.e. days between first and final testing, gender, education, CES-D total, Non-CVRFS CVRFS, and stress) were included in the model to assess potential main effects. All covariates that did not have meaningful zero were grand-mean centered by the sample's average score, so the intercept in the model could be interpreted. The coupling parameters (Occasion SBP_{ij} – Mean SBP_i or Occasion Sleep $Duration_{ij}$ – Mean Sleep $Duration_i$; i range from 1 to 50; j range from 1 to 8) were group-mean centered by each individual's average score across all 8 testing occasions. The quadratic effect of occasion SBP and sleep duration were included in the model by squaring the within-person variables.

The between-person parameters (i.e. covariates and level 2 predictors of interest) were grand-mean centered by the sample's average score. For example, the models reflected the relationship between cognition and an individual's mean SBP (see Appendix A) or mean sleep duration (see Appendix B) across the 8 occasions (γ_{01}). The quadratic effect of mean SBP and sleep duration were also calculated and included in the model by squaring these between-person sleep variables. Additionally, the models included a level 2 predictor that reflected the relationship between cognition and individual's average stress levels (γ_{02}). Finally, the model with sleep duration included a level 2 predictor that reflected the relationship between cognition and average PSQI scores (γ_{03}). The model with sleep duration also included a covariate of sleep medication use. Several interactions (i.e. a between-person interaction, two cross-level interactions, and a three-way cross-level interaction) were added to the initial model in a second model to assess potential moderating relationships.

Results

The current study enrolled 50 (39 women and 11 men) older African American adults ranging in age from 50 to 80 years (M = 65.40, SD = 8.53). Participants' average monthly income was $950 ($SD$ = $500; range = < $100 – >$2300) and the average years of education was 11.62 years (range = 6–18, SD = 2.38 years). Although 50 participants were tested at the baseline assessment, 3 participants withdrew (1 male; 2 females) before completing all 8 daily assessments. Participants' average PSQI score was approximately 7 (SD = 4; Table 1) and on average, they reported approximately 6 hours of sleep (SD = 1.99). Based on a PSQI global score of 5 or more (Buysee, Reynolds, Monk, Berman, Kupfer, 1989), 52% of the sample would be considered poor sleepers. Participants, on average, typically report taking none or few sleep medications in the past month. On average, approximately two CVRFS (SD = 1.33) as well as two Non-CVRFS (SD = 1.03) were reported. Average systolic blood pressure was approximately 135.21 (SD = 26.95), which is considered pre-hypertensive (Chobanian et al., 2003). Mean CES-D scores were 11 (SD = 8.87), suggesting that the sample on average did not have high depressive symptoms. Mean stress scores were approximately 14 (SD = 12.25), which suggest that the sample on average did not report extremely high stress, and the scale distribution was positively skewed. A median split was

performed on this scale to create two levels of stress: low stress (8 or less) and stressed (9 or more).

Variability or Consistency in MCI Classification Across Testing Occasions

As illustrated in Table 2, 14 individuals (28%) met MCI criteria at baseline testing. The frequency of these cases remaining MCI tended to fluctuate over the occasions. At occasion 1, 9 out of the 14 baseline MCI cases (64%) were still considered MCI. As indicated in the parentheses, 2 out of the 14 baseline MCI cases (14%) were considered between MCI and normal. The remaining 3 out of the 14 (22%) baseline MCI cases were considered normal at the subsequent testing occasion. Six new cases of MCI were observed at occasion 1 (new cases of MCI at each occasion are illustrated in Table 2 in the rows following the baseline assessment), and, subsequently, 5 (83%) remain MCI at occasion 2. After the initial classification of MCI, 3 individuals consistently met MCI criteria at subsequent occasions. Two of these individuals were first identified as MCI at baseline, and one individual was first identified as MCI at occasion 1. One of these participants had eventually withdrawn from the study after occasion 5. In addition, 3 MCI cases at baseline and 1 new MCI case at occasion 1 often met the MCI criteria at subsequent occasions, but on 1–2 occasions performed between MCI and normal.

Dynamic Relationship Between Blood Pressure/Sleep Duration and MCI Status

Occasion SBP and mean SBP were not significant predictors of MCI status, but occasion sleep duration was a significant predictor of MCI status across the testing occasions. Specifically, the quadratic effect of occasion sleep was a significant predictor of MCI status (see Table 3). On those occasions where an individual reported fewer hours of sleep than on average, he/she was more likely to meet criteria for MCI. Although the risk for being classified as MCI tended to decline on those occasions where an individual reported sleeping their average hours of sleep across the occasions, the risk for meeting MCI criteria appeared to slightly increase on those occasions where an individual reported sleeping considerably more than on average. Linear occasion sleep duration, linear mean sleep duration, and the quadratic effects of mean sleep duration were not significant predictors of MCI status. Males were significantly at greater risk for being classified as MCI across the occasions. Finally, a high number of cardiovascular risk factors were a significant risk for MCI classification. No significant interactions were observed in the second model.

Discussion

Participants who were classified as MCI after one assessment often did not meet MCI criteria at subsequent occasions, which has been previously reported (Larrieu et al., 2002; Ritchie et al., 2001). At subsequent testing occasions, many of these MCI cases were considered to be performing between the MCI and normal cognition cutoffs or performing normally. Daily blood pressure, one of the predictors of interest, was not significantly associated with MCI status across the occasions. The current study, however, observed that on those occasions where individuals slept less or substantially more hours the previous night than on average, they were at greater risk for meeting classification criteria for MCI. Cases of MCI associated with sleep difficulties may represent a miscellaneous MCI sub-type, which can be successfully treated (Gauthier & Touchon, 2005). Studies, however, have suggested that sleep disturbances may not only be observed in this miscellaneous MCI sub-type (Lyketsos et al., 2002; Muangpaisan, Intalapaporn, & Assantachai, 2008). In fact, sleep difficulties have shown to be more common in amnestic MCI participants than normal participants (Muangpaisan et al., 2008). More research is needed to explore whether poor sleep quantity can differentiate MCI from normal cognitive function as well as differentiate the MCI sub-types.

The relationship between sleep duration and MCI status may also reflect diagnostic issues with the MCI classification criteria. Since poor performance on one cognitive measure could result in MCI classification, a lack of sleep the prior night could result in poor cognitive performance the following day and, consequently, a MCI classification. Indeed, several studies have consistently reported that tasks of memory (Schmutte, Harris, Levin, Zweig, Katz, & Lipton, 2007; Ferrie, Shipley, Akbaraly, Marmot, Kivimäki, & Singh-Manoux, 2011; Xu et al., 2011), attention-concentration (Blackwell et al., 2011; Ohayon & Vecchierini, 2002), and executive function (Ferrie et al., 2011; Blackwell et al., 2011) are vulnerable to poor sleep duration. Thus, impaired performance on these abilities may be incorrectly classified as MCI, when performance is possibly related to disturbed sleep.

It is also possible that the instability in cognitive performance, which may have influence the instability in MCI classification, may indeed represent an early indication of cognitive impairment. In fact, previous literature has suggested that fluctuations in cognitive performance are a predictor of future cognitive decline and dementia (Bielak, Hultsch, Strauss, MacDonald, & Hunter, 2010). Given our study is observing a potential within-person coupling relationship between MCI status and sleep duration, it might be beneficial to further explore wither fluctuation in sleep duration may also be a predictor of future cognitive decline and dementia.

Study Limitations

There were several limitations to this study that should be noted. First, the study was the small sample size, which reduces the statistical power to detect significance, particularly for the between-person relationships. Second, the sample is homogeneous as evidenced by the sample's high average blood pressure. With there being less variance of blood pressure, the current study was less likely to detect a relationship between blood pressure and cognition. The current sample is also homogeneous as evidenced by the high percentage of participants that would be considered poor sleepers. Thus, the lack of variance in sleep quality may potentially explain the non-significant relationship between sleep quality and cognition. Previous studies have suggested that African Americans, particularly in urban settings, tend to report poor sleep quality and quantity (Bidulescu et al., 2010; Pigeon, Heffner, Duberstein, Fiscella, Moynihan, & Chapman, 2011). For example, in a large community sample of African Americans living in Atlanta, 50% of the sample had global PSQI scores suggestive of poor sleep (Bidulescu et al., 2010). Several factors such as social disadvantages, stress, weight, diabetes, and/or vascular disease may explain the high percentage of sleep disturbances in the sample (Bidulescu et al., 2010; Pigeon et al., 2011; Williams, 1998), but further research is needed to disentangle the mechanisms behind sleep disturbances in African Americans. Third, the impairment cutoff scores for MCI were established using the current study's sample distribution, which may not have been representative of other African American samples. MCI was not evaluated using a clinical criterion standard, which may have led to some misclassification of participants. A limited number of measures were also used to assess impairment on each of the cognitive domains used for MCI classification, which may not be an accurate representation of performance in a particular domain. Several studies, however, have used a post-hoc approach for MCI classification, particularly in community samples (Allaire, Gamaldo, Ayotte et al., 2009; Manly et al., 2008). Fourth, our measurements of stress and depressive symptomatology did not capture the participants' daily stress and/or mood levels, which limited our analyses from examining whether changes in stress and/or mood might explain the dynamic within-person coupling relationship between sleep duration and cognitive performance.

Conclusions

The current study suggests that intraindividual variability in MCI status, particularly for African Americans, may be due to common health issues (i.e. sleep difficulties) observed within this population. It reveals a promising direction for future research to explore how variability on objective cognitive assessments might be a useful in identifying an individual's cognitive competency as well as detecting the earliest sign of cognitive impairment.

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Appendix A. Blood Pressure MLM Model Equation

$$\text{Level 1:Cognition}_{ij}=\beta_{0ij}+\beta_1(\text{Occasion SBP}_{ij}-\text{Mean SBP}_i)+r_{ij}$$

$$\text{Level 2:}\beta_{0i}=\gamma_{00}+\gamma_{01}\,(\text{Mean SBP}_i-\text{Sample Mean SBP})+\gamma_{02}\,(\text{Mean Stress}_i-\text{Sample Mean Stress})+\gamma_{03}\,(\text{Mean SBP}_i-\text{Sample Mean SBP}\times\text{Mean Stress}_i-\text{Sample Mean Stress})+u_{0i}$$

$$\beta_{1i}=\gamma_{10}+\gamma_{11}\,(\text{Mean SBP}_i-\text{Sample Mean SBP})+\gamma_{12}\,(\text{Mean Stress}_i-\text{Sample Mean Stress})+\gamma_{13}\,(\text{Mean SBP}_i-\text{Sample Mean SBP}\times\text{Mean Stress}_i-\text{Sample Mean Stress})+u_{1i}$$

β_{0ij} = Intercept; Cognition for person i on day j

γ_{00} = Grand mean/point estimate of cognition

γ_{01} = Between-person relationship between mean SBP and cognition

γ_{02} = Between-person relationship between mean stress and cognition

γ_{03} = Interaction between mean SBP and mean stress

γ_{10} = Within-person relationship between occasion SBP and cognition

γ_{11} = Cross-level interaction between occasion SBP and mean SBP

γ_{12} = Cross-level interaction between occasion SBP and mean stress

γ_{13} = Cross-level interaction among occasion SBP, mean SBP, and mean stress

r_{ij} = Within-person variability/random error

u_{0j} = Between-person variability/random error

u_{1i} = Variability around the slope between SBP and cognition

Appendix B. Sleep Duration MLM Model Equation

$$\text{Level 1:Cognition}_{ij}=\beta_{0ij}+\beta_1\,(\text{Occasion Sleep Duration}_{ij}-\text{Mean Sleep Duration}_i)+r_{ij}$$

$$\text{Level 2:}\beta_{0i}=\gamma_{00}+\gamma_{01}\,(\text{Mean Sleep Duration}_i-\text{Sample Mean Sleep Duration})+$$
$$\gamma_{02}\,(\text{Mean Stress}_i-\text{Sample Mean Stress})+$$
$$\gamma_{03}\,(\text{Mean PSQI}_i-\text{Sample Mean PSQI})+$$
$$\gamma_{04}\,(\text{Mean Sleep Duration}_i-\text{Sample Mean Sleep Duration}\times\text{Mean Stress}_i-\text{Sample Mean Stress})+\gamma_{05}\,(\text{Mean Sleep Duration}_i-\text{Sample Mean Sleep Duration}\times\text{Mean PSQI}_i-\text{Sample Mean PSQI})$$
$$\gamma_{06}\,(\text{Mean Stress}_i-\text{Sample Mean Stress}\times\text{Mean PSQI}_i-\text{Sample Mean PSQI})+u_{0i}$$
$$\beta_{1i}=\gamma_{10}+\gamma_{11}\,(\text{Mean Sleep Duration}_i-\text{Sample Mean Sleep Duration})+$$
$$\gamma_{12}\,(\text{Mean Stress}_i-\text{Sample Mean Stress})+$$
$$\gamma_{13}\,(\text{Mean PSQI}_i-\text{Sample Mean PSQI})$$
$$\gamma_{14}\,(\text{Mean Sleep Duration}_i-\text{Sample Mean Sleep Duration}\times\text{Mean Stress}_i-\text{Sample Mean Stress})+\gamma_{15}\,(\text{Mean Sleep Duration}_i-\text{Sample Mean Sleep Duration}\times\text{Mean PSQI}_i-\text{Sample Mean PSQI})$$
$$\gamma_{16}\,(\text{Mean Stress}_i-\text{Sample Mean Stress}\times\text{Mean PSQI}_i-\text{Sample Mean PSQI})+u_{1i}$$

β_{0ij} = Intercept; Cognition for person i on day j

γ_{00} = Grand mean/point estimate of cognition

γ_{01} = Between-person relationship between mean sleep duration and cognition

γ_{02} = Between-person relationship between mean stress and cognition

γ_{03} = Between-person relationship between PSQI and cognition

γ_{04} = Interaction between mean sleep duration and mean stress

γ_{05} = Interaction between mean sleep duration and PSQI

γ_{06} = Interaction between mean stress and PSQI

γ_{10} = Within-person relationship between occasion sleep duration and cognition

$\gamma_{11} - \gamma_{16}$ = Cross-level interactions between occasion sleep duration and Level 2 predictors

r_{ij} = Within-person variability/random error

u_{0j} = Between-person variability/random error

u_{1i} = Variability around the slope between sleep duration and cognition

Table 1

PSQI Global and Component Score Mean, Standard Deviation and Range

Variable	Mean	SD	range
PSQI global score	6.50	4.14	0–18
PSQI components			
1. Subjective sleep quality	0.79	0.87	0–3
2. Sleep latency	1.08	1.01	0–3
3. Sleep duration	1.24	1.05	0–3
4. Sleep efficiency	0.54	1.10	0–3
5. Sleep disturbance	1.34	0.63	0–3
6. Use of sleep medication	0.86	1.23	0–3
7. Daytime dysfunction	0.76	0.82	0–2

Note.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

PSQI, Pittsburgh Sleep Quality Index

Table 2

Frequency of MCI Participants (and Participants Between MCI and Normal cutoffs) at Each Occasion

	Occasions							
MCI Status	**Baseline**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Baseline	14	9 (2)	9 (4)	5 (5)	8 (4)	8 (5)	8 (4)	5 (5)
1	-	6	5 (0)	3 (1)	2 (2)	4 (0)	3 (2)	4 (0)
2	-	-	5	1 (1)	1 (4)	1 (2)	3 (1)	3 (1)
3	-	-	-	2	0 (2)	0 (2)	0 (1)	0 (2)
4	-	-	-	-	3	0 (1)	0 (1)	1 (0)
5	-	-	-	-	-	2	0 (1)	1 (0)
6	-	-	-	-	-	-	2	1 (0)
7	-	-	-	-	-	-	-	1

Note: The number in the first cell of each row represents the frequency of new MCI cases at each session. Numbers in the subsequent cells within the same row represent the frequency of those MCI cases who continue to meet MCI criteria. The numbers in the parentheses represent those MCI cases that went above the −1.5 *SD* cutoff, but below the normal cutoff of −1 *SD* at a particular occasion.

Table 3

Dynamic Relationship Between Sleep Duration and MCI Status

	Step 1		Step 2	
	Coefficients	**Odds Ratio**	**Coefficients**	**Odds Ratio**
Within-person				
Occ Sleep Duration	0.05 (0.10)	1.05	0.21 (0.21)	1.23
Quadratic Occ Sleep Duration	0.10 * (0.04)	1.10	0.09 ⁄ (0.05)	1.10
Time of Day	0.00 (0.01)	1.00	−0.00 (0.01)	1.00
Between-person				
Mean Sleep Duration	−0.22 (0.24)	0.80	0.27 (0.51)	1.31
Quadratic Mean Sleep Duration	−0.14 (0.11)	0.87	−0.11 (0.15)	0.90
PSQI	0.34 (0.84)	1.40	0.81 (1.29)	2.24
Sleep Medication Use	0.22 (0.34)	0.51	0.24 (0.37)	1.27
Days Between First & Last Test	−0.14 (0.10)	0.87	−0.11 (0.12)	0.90
Gender	−2.14 * (1.02)	0.12	−2.61 * (1.24)	0.07
Education	−0.23 (0.15)	0.80	−0.18 (0.17)	0.83
CVRFS	0.76 ** (0.28)	2.13	0.76 * (0.32)	2.13
Non-CVRFS	−0.20 (0.34)	0.82	−0.38 (0.41)	0.68
CES-D	0.01 (0.04)	1.01	−0.01 (0.05)	0.99
Stress	0.12 (0.78)	1.13	0.95 (1.30)	2.59
Interactions				
Mean Sleep Duration x PSQI			−0.16 (0.58)	0.85
Mean Sleep Duration x Stress			−0.79 (0.62)	0.46
PSQI x Stress			−0.98 (1.75)	0.37
Occ Sleep x Mean Duration Sleep			−0.05 (0.11)	0.95
Occ Sleep Duration x PSQI			−0.39 (0.34)	0.68
Occ Sleep Duration x Stress			−0.03 (0.36)	0.97
Occ Sleep Duration x Mean Sleep Duration x PSQI			−0.22 (0.20)	0.81
Occ Sleep Duration x Mean Sleep Duration x Stress			0.18 (0.19)	1.20
Occ Sleep Duration x PSQI x Stress			0.08 (0.52)	1.08

Note:

⁄ $p = .05$;

* $p < .05$;

** $p < .01$.

Occ = Occasion. CVRFS = Cardiovascular risk factors.