# Change in Sleep Duration and Cognitive Function: Findings from the Whitehall II Study 

Jane E. Ferrie, PhD ${ }^{1}$; Martin J. Shipley, MSc'; Tasnime N. Akbaraly, $\mathrm{PhD}^{1,2}$; Michael G. Marmot, MD¹; Mika Kivimäki, PhD ${ }^{1,3 ;}$; Archana Singh-Manoux, $\mathrm{PhD}^{11,4,5}$<br>${ }^{1}$ University College London, Department of Epidemiology and Public Health, London, UK; ${ }^{2}$ INSERM U888-University Montpellier 1, Montpellier, France; ${ }^{3}$ Finnish Institute of Occupational Health, Helsinki, Finland; ${ }^{4}$ INSERM, U1018, Centre for Research in Epidemiology \& Population Health, France; ${ }^{5}$ Centre de Gérontologie, Hôpital Ste Périne, AP-HP, Paris, France

Study Objectives: Evidence from cross-sectional studies shows that sleep is associated with cognitive function. This study examines change in sleep duration as a determinant of cognitive function.
Design: Prospective cohort.
Setting: The Whitehall II study.
Participants: 1459 women and 3972 men aged 45-69 at baseline.
Interventions: None.
Measurements and Results: Sleep duration ( $\leq 5,6,7,8, \geq 9 \mathrm{~h}$ on an average week night) was assessed once between 1997-1999, baseline for the present study, and once between 2002-2004, average follow-up 5.4 years. Cognitive function was measured (2002-2004) using 6 tests: verbal memory, inductive reasoning (Alice Heim 4-I), verbal meaning (Mill Hill), phonemic and semantic fluency, and the Mini Mental State Examination (MMSE). In analyses adjusted for age, sex, and education, and corrected for multiple testing, adverse changes in sleep between baseline and follow-up (decrease from 6,7 , or 8 h , increase from 7 or 8 h ) were associated with lower scores on most cognitive function tests. Exceptions were memory, and, for a decrease from 6-8 h only, phonemic fluency. Further adjustment for occupational position attenuated the associations slightly. However, firm evidence remained for an association between an increase from 7 or 8 h sleep and lower cognitive function for all tests, except memory, and between a decrease from 6-8 h sleep and poorer reasoning, vocabulary, and the MMSE. The magnitude of these effects was equivalent to a 4-7 year increase in age.
Conclusions: These results suggest that adverse changes in sleep duration are associated with poorer cognitive function in the middle-aged.
Keywords: Change in sleep duration, cognitive function, white-collar, cohort study
Citation: Ferrie JE; Shipley MJ; Akbaraly TN; Marmot MG; Kivimäki M; Singh-Manoux A. Change in sleep duration and cognitive function: findings from the Whitehall II study. SLEEP 2011;34(5):565-573.

## INTRODUCTION

Ageing appears to be accompanied by a decrease in duration of good quality nocturnal sleep and an increase in sleeplessness and sleep disturbances. ${ }^{1-3}$ Sleep deprivation is related to worse performance on many daily tasks, such as driving and operating machinery ${ }^{4}$ and, in laboratory settings, has been shown to have adverse consequences for contiguously measured cognitive performance. ${ }^{5}$ Cognitive aging is characterized by heterogeneity in that not everyone experiences decline at the same rate. ${ }^{6-8}$ It is also clear that many of the neuronal changes that accompany cognitive decline are evident in midlife. ${ }^{7}$ There are multiple determinants of cognitive decline, ${ }^{7-9}$ but the extent to which sleep plays a role remains unclear.

Short sleep, long sleep, and sleep problems have all been found to be associated with poorer cognitive function in crosssectional studies, ${ }^{10-19}$ and poor sleep is also a feature of dementia. ${ }^{20}$ However, the few studies that have examined prospective associations between sleep assessed once at baseline and cognitive function at follow-up or cognitive decline between baseline and follow-up are inconsistent. One small laboratory-based study in the elderly that measured cognitive function once at

[^0]follow-up demonstrated associations between poor sleep patterns and cognitive impairment 14 years later. ${ }^{21}$ Similarly, a population-based study of people aged 50 and over found those who reported "any" sleep problem to have greater cognitive decline over a 3-year follow-up than those who did not report sleep problems. ${ }^{22}$ However, in the Nurses Health Study there was no association between self-reported sleep problems and cognitive decline over a period of 2 years. ${ }^{23}$

Even less work has used data on sleep assessed on two occasions to examine associations between change in sleep over time and cognitive function. One exception is a large study of people aged $\geq 65$ that examined associations between insomnia, depression, and cognitive decline over a 3 -year period. In this study, chronic insomnia was associated with cognitive decline in men and, where conjoint with depression, in both sexes, but new onset insomnia between baseline and follow-up was associated with cognitive decline only in men with depression. ${ }^{24}$ However, despite evidence of cross-sectional associations and widely accepted evidence that sleep duration and cognitive performance decrease with age, ${ }^{1,9,25}$ only one small study appears to have examined change in sleep duration, as opposed to insomnia, as a determinant of cognitive function. ${ }^{26}$ In this paper, we examine whether sleep duration and changes in sleep duration are associated with subsequent cognitive function in a large study of middle-aged women and men.

## METHODS

## Study Population

The target population for the Whitehall II study was all London-based office staff aged 35-55 working in 20 civil ser-

Table 1-Change in sleep duration categories

| Phase 5 | Phase 7 Sleep Duration* |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Sleep Duration* | $\leq 5$ | 6 | 7 | 8 | $\geq 9$ |
| $\leq 5$ | 188 | A (165) | A (39) | A (6) | A (0) |
| 6 | C (170) | 995 | A (535) | A (70) | A (8) |
| 7 | C (48) | C (522) | 1387 | B (376) | B (20) |
| 8 | C (7) | C (53) | C (296) | 416 | B (55) |
| $\geq 9$ | D (4) | D (5) | D (7) | D (29) | 30 |

*Sleep duration refers to hours sleep on an average week night; A , increase from $\leq 5 \mathrm{~h}$ or 6 h per night; B , increase from 7 or 8 h per night; $C$, decrease from 6,7 , or 8 h per night; D , decrease from $\geq 9 \mathrm{~h}$ per night.
vice departments in 1985. Of these, 10,308 participants (3,413 women and $6,895 \mathrm{men}$ ) were enrolled, a response rate of $73 \%$. Although mostly white collar, participants covered a wide socioeconomic range with a 10 -fold difference in salary across the occupational hierarchy. ${ }^{27}$ Data collection at enrollment, Phase 1 (1985-1988) involved a clinical examination and selfadministered questionnaire containing sections on demographic characteristics, health, lifestyle factors, work characteristics, social support, and life events. The clinical examination included measures of blood pressure, anthropometry, biochemistry, neuroendocrine function, and subclinical markers of cardiovascular disease. Subsequent phases of data collection have alternated between postal questionnaire alone (all even-numbered phases), and postal questionnaire accompanied by clinical examination (all odd-numbered phases). The current study uses data for 5,431 participants ( 1459 women and 3972 men) from Phase 5 (1997-1999) and Phase 7 (2003-2004), baseline and follow-up for the present study.

## Study Design

This study examines associations between change in sleep duration (Phase 5 to Phase 7) and cognitive function at followup (Phase 7), in addition to presenting cross-sectional associations between sleep duration and cognitive function at Phase 7 separately by sex.

## Measures

## Sleep

Habitual sleep duration was measured at Phase 5 (baseline) and Phase 7 (follow-up) using a single question "How many hours of sleep do you have on an average week night?" Response categories were $\leq 5 \mathrm{~h}, 6,7,8$, and $\geq 9 \mathrm{~h} .{ }^{28}$

For the examination of changes in sleep duration between Phases 5 and 7, participants were divided into 4 categories based on whether they slept more, the same, or less hours at follow-up than at baseline. Changes in sleep duration were categorized using the following classification, as previously: ${ }^{28}$ For increased sleep durations we hypothesized that an increase from $\leq 5$ or 6 h at Phase 5 would have a beneficial effect on cognitive function, whereas an increase from 7 or 8 h would have a detrimental effect. We therefore created 2 categories; "increase from $\leq 5$ or 6 hours" (Table 1: A) at Phase 5, and "increase from 7 or 8 hours" at Phase 5 (Table 1: B). Reduced sleep duration for the catego-
ries 6,7 , and 8 h , hypothesized to have a detrimental effect on cognitive function, were pooled to form the category "decrease from 6, 7, or 8 hours" (Table 1: C). All participants who slept $\geq$ 9 h at Phase 5, but less at Phase 7 were categorized as "decrease from 9 hours or more" (Table 1: D). In each of the 4 sleep categories we compared those sleeping less hours or more hours with the reference group, which in each case was comprised of participants who slept the same number of hours at Phase 7 as at Phase 5. For example, for the category "increase from 5 or 6 h," the reference group was participants who slept either 5 or 6 h at both phases.

## Cognitive function

Cognitive function was assessed at Phase 7 using a battery of 6 standard tests: Memory-a 20-word free recall test measured short-term verbal memory. Participants were presented with a list of 20 one- or 2-syllable words at 2-sec intervals and were then asked to recall, in writing, as many of the words as possible in any order over a period of 2 min . Reasoning-the Alice Heim 4-I (AH4-I), consisting of 65 verbal and mathematical reasoning items of increasing difficulty with a $10-\mathrm{min}$ time limit for completion, measured inductive reasoning; the ability to identify patterns and infer principles and rules. ${ }^{29}$ Vo-cabulary-the Mill Hill Vocabulary test consists of a list of 33 stimulus words ordered by increasing difficulty, each presented with 6 multiple choice responses. ${ }^{30}$ Verbal fluency was measured using two tests; phonemic fluency and semantic fluency. In both cases fluency was assessed by the written recall of as many words as possible in one minute; phonemic fluency by the recall of words beginning with "S," and semantic fluency by the recall of animal names. ${ }^{31}$ Finally, the 30-item Mini-Mental-State-Examination (MMSE) was used to assess global cognitive status. ${ }^{32}$

## Covariates

The covariates age, sex, education, and occupational position were derived from the Phase 7 questionnaire. We adjusted for the effects of education and occupational position due to their known association with cognitive performance. ${ }^{33}$ Education was categorized by the highest qualification on leaving full-time education; Secondary (left school at or before age 16); Higher secondary (left school at age 18); or Tertiary (bachelor's degree, postgraduate degree). Occupational position, measured as last Civil Service employment grade, was categorized as low (clerical and administrative support staff), intermediate (professional and executive staff), or high (senior administrative staff and managers).

## Ethics Approval

Ethical approval for the Whitehall II study was granted by the University College London Medical School committee on the ethics of human research.

## Statistical Analysis

Of the 10,308 participants at baseline, 7830 (76\%) responded at Phase 5 and 6967 ( $68 \%$ ) responded at Phase 7. Removal of participants with missing data for variables included in the present study left 5431 participants ( 1459 women and 3972 men) in the analyses. Descriptive statistics for participant char-
acteristics at Phase 7 and sleep duration at Phase 5 by sleep duration at Phase 7 are presented and tested using $\chi^{2}$ tests for heterogeneity for categorical variables and analysis of variance for age. Cognitive test scores were standardized in women and men separately to a T-score, similar to a z-score, but with a mean of 50 and a standard deviation (SD) of 10 , in order to allow comparison between the measures. Multiple regressions with cognitive function as the dependent variable and sleep duration categories as the independent variables were fitted, and least squares means from these regressions used to estimate means adjusted for age. Tests of heterogeneity across the sleep duration categories and tests of the difference in cognitive function compared with the $\leq 5 \mathrm{~h}$ category were also obtained from these regressions.

Further multiple regression models with cognitive function as the dependent variable and the changes in sleep duration as the independent variables were fitted and used to estimate means adjusted for (a) age, sex, and education; and (b) age, sex, education, and occupational position. These regression models were parameterized so as to allow each change in sleep duration category to be compared to its appropriate no change in sleep duration reference category, as described above, in a single unified model. An advantage of this unified approach is that the adjustments for the covariates come from their relationships with the outcome in the whole sample and apply to all the change in sleep duration categories.

Tests of interaction between sex and change in sleep duration in the fully adjusted models confirmed that there was no evidence of any difference in the change in sleep duration effects in women and men (all P-values $>0.16$ ). The false discovery rate method ${ }^{34}$ was used to take account of the multiple testing arising from comparing each change in sleep duration category with its "no change" reference group for each of the 6 cognitive function outcomes, and this correction is reflected in these tests of difference. To apply the method, the P-values for the 18 sleep duration versus "no change" comparisons were ranked by increasing magnitude. If the ranks of the P -value are denoted r , then we compare each P -value with its critical significance level defined as $(\mathrm{r} / 18) * 0.05,(\mathrm{r} / 18) * 0.01,(\mathrm{r} / 18)^{*} 0.001$. To facilitate interpretation, the adverse effects of change in duration of sleep on cognitive function were also expressed as an equivalent effect of age using the observed cognitive data and age (range $50-74$ years) at Phase 7. This was estimated from the fitted regressions by dividing the coefficient for the change in sleep by the coefficient for age. All analyses were conducted using the SAS statistical program, version 9.1 (SAS Institute, Cary, NC, USA).

## RESULTS

Compared to the 4877 participants enrolled in the cohort but not contributing to the analyses in the present study, the 5431 individuals included in the analyses were more likely to be men ( $73.1 \%$ vs. $59.9 \%$ ), younger at baseline ( 44.0 vs. 44.9 ), have a tertiary education ( $36.8 \%$ vs. $31.5 \%$ ), and less likely to be of low occupational position ( $12.8 \%$ vs. $33.7 \%$ ). The percentage of short ( $\leq 5 \mathrm{~h} / \mathrm{night}$ ) and long ( $\geq 9 \mathrm{~h} / \mathrm{night}$ ) sleepers was higher at enrolment into the Whitehall II cohort among those not included in the analyses (Table 2). However at Phase 7, habitual sleep duration for the majority of participants was either 6 or $7 \mathrm{~h} /$ night
( $72 \%$ women, $75 \%$ men). Short sleep was reported by $10 \%$ of women and $7 \%$ of men. In both sexes $2 \%$ were long sleepers. Short and long sleep was less common in women with a university education or high occupational position. In men, education was not associated with sleep duration, but shorter sleep ( $\leq 5$ and 6 h ) durations were more prevalent among men in the lower occupational positions and longer sleep ( 7 and 8 h ) durations in the higher positions. Sleep duration between the Phase 5 baseline and follow-up remained unchanged for about half the participants, while change in duration $>1 \mathrm{~h}$ was observed in only $7 \%$ of the women and $4 \%$ of the men.

## Sleep Duration

Table 3 shows the age-adjusted distribution of cognitive function T-scores by sleep duration at Phase 7. Ranges (observed) for the cognitive function test scores; Memory (0-18), Reasoning (12-65), Vocabulary (1-33), Phonemic fluency (3-47), Semantic fluency (2-34), and MMSE (18-30) were standardized to a mean of 50 and a standard deviation of 10 in women and men separately to allow comparison across cognitive tests. Overall associations between sleep duration and all cognitive function measures were U-shaped with poorer cognitive function scores at the short and long ends of the sleep distribution. More specifically, in women $7 \mathrm{~h} /$ night was associated with the highest score for every measure, followed closely by $6 \mathrm{~h} /$ night. Women who slept less or more had lower scores. In men, cognitive function T-scores were similar for men sleeping 6,7 , or 8 h ; and only short and long sleep appeared to be associated with low scores. The pattern of the cognitive function T-scores by sleep duration remained similar after further adjustment for education and occupational position. However, differences between the sleep duration categories were attenuated, particularly in men (see supplementary Table S1).

## Change in Sleep Duration

Sleep duration categories used in the analyses of change are shown in Table 4. The proportions of participants remaining in the same category at baseline and follow-up are similar in both sexes, although men are more likely to sleep 7 h at both time points. Since only 19 women and 26 men report a "decrease from 9 hours or more" and only 7 women and 23 men reported having 9 h sleep at both phases, we excluded these 75 participants from the analyses of change in sleep duration.

Table 5 shows the difference in cognitive function score at Phase 7 for each change in sleep duration category between Phases 5 and 7 relative to the appropriate reference group whose hours of sleep did not change between the 2 phases. Findings for women and men combined are shown in the upper section of the table (A) adjusted for age, sex, and education, and the lower section, (B), additionally adjusted for occupational position at Phase 7. We hypothesized that an "increase from $\leq 5$ or 6 hours" sleep per night would have a beneficial effect on cognitive function, but our findings provided no evidence of any effect, either beneficial or detrimental, Table 5A. However, an "increase from 7 or 8 hours" was associated with lower scores at follow-up on all the cognitive function tests, equivalent to a 5-8 year increase in age. After correction for multiple testing, firm evidence of an association remained for all the tests except memory. In similar analyses, a "decrease from 6, 7 , or

Table 2-Characteristics ${ }^{+}$at Phase 7 and sleep duration at Phase 5 by number of hours of sleep at Phase 7 and sleep duration at enrolment among those included and excluded from the study analyses

|  | $N$ | Hours of Sleep at Phase 7 |  |  |  |  | P-value* |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Women |  | $\leq 5 \mathrm{~h}$ | 6 h | 7 h | 8 h | $\geq 9 \mathrm{~h}$ |  |
| Number (\%) | 1459 | 148 (10.1) | 494 (33.9) | 550 (37.7) | 242 (16.6) | 25 (1.7) |  |
| Age, years | 1459 | 61.2 (0.5) | 60.9 (0.3) | 60.6 (0.3) | 62.3 (0.4) | 60.6 (1.0) | 0.004 |
| Education |  |  |  |  |  |  |  |
| Tertiary | 408 | 6.9 | 35.0 | 41.7 | 14.7 | 1.7 |  |
| Higher secondary | 326 | 12.2 | 30.7 | 37.4 | 16.0 | 3.7 | 0.004 |
| Secondary | 725 | 11.0 | 34.6 | 35.6 | 17.9 | 0.8 |  |
| Occupational position |  |  |  |  |  |  |  |
| High | 725 | 6.2 | 34.3 | 42.4 | 16.6 | 0.8 |  |
| Intermediate | 326 | 10.1 | 33.7 | 38.6 | 15.3 | 2.3 | 0.002 |
| Low | 408 | 14.5 | 33.6 | 30.7 | 19.7 | 1.5 |  |
| Sleep duration at Phase 5 |  |  |  |  |  |  |  |
| $\leq 5 \mathrm{~h}$ | 139 | 48.9 | 37.4 | 11.5 | 2.2 | 0.0 |  |
| 6 h | 470 | 11.7 | 51.7 | 32.1 | 4.3 | 0.2 |  |
| 7 h | 571 | 3.0 | 30.7 | 49.7 | 15.9 | 0.7 | $<0.001$ |
| 8 h | 253 | 2.0 | 8.3 | 37.9 | 46.6 | 5.1 |  |
| $\geq 9 \mathrm{~h}$ | 26 | 11.5 | 11.5 | 11.5 | 38.5 | 26.9 |  |
|  |  | Hours of Sleep at Enrolment to the Whitehall II Cohort |  |  |  |  |  |
|  |  | $\leq 5 \mathrm{~h}$ | 6 h | 7 h | 8 h | $\geq 9 \mathrm{~h}$ |  |
| Included in the study analyses, N (\%) | 1454 | 84 (5.8) | 389 (26.8) | 709 (48.8) | 260 (17.9) | 12 (0.8) |  |
| Excluded from the study analyses, N (\%) | 1954 | 134 (6.9) | 536 (27.5) | 877 (45.0) | 365 (18.8) | 35 (1.8) |  |
|  |  | Hours of Sleep at Phase 7 |  |  |  |  |  |
| Men |  | $\leq 5 \mathrm{~h}$ | 6 h | 7 h | 8 h | $\geq 9 \mathrm{~h}$ |  |
| Number (\%) | 3972 | 269 (6.8) | 1246 (31.4) | 1714 (43.2) | 655 (16.5) | 88 (2.2) |  |
| Age, years | 3972 | 60.1 (0.4) | 60.2 (0.2) | 61.0 (0.1) | 62.5 (0.2) | 63.1 (0.6) | $<0.001$ |
| Education |  |  |  |  |  |  |  |
| Tertiary | 1593 | 6.8 | 31.2 | 43.6 | 15.9 | 2.4 |  |
| Higher secondary | 1204 | 6.5 | 31.5 | 43.4 | 16.5 | 2.2 | 0.99 |
| Secondary | 1175 | 7.1 | 31.2 | 42.3 | 17.3 | 2.0 |  |
| Occupational position |  |  |  |  |  |  |  |
| High | 2238 | 5.3 | 30.7 | 44.2 | 17.7 | 2.2 |  |
| Intermediate | 1605 | 8.1 | 31.8 | 42.8 | 15.1 | 2.2 | $<0.001$ |
| Low | 129 | 15.5 | 38.0 | 30.2 | 14.0 | 2.3 |  |
| Sleep duration at Phase 5 |  |  |  |  |  |  |  |
| $\leq 5 \mathrm{~h}$ | 259 | 46.3 | 43.6 | 8.9 | 1.2 | 0.0 |  |
| 6 h | 1308 | 8.8 | 57.5 | 29.4 | 3.8 | 0.5 |  |
| 7 h | 1782 | 1.7 | 19.5 | 61.9 | 16.0 | 0.9 | $<0.001$ |
| 8 h | 574 | 0.4 | 5.6 | 34.8 | 51.9 | 7.3 |  |
| $\geq 9 \mathrm{~h}$ | 49 | 2.0 | 4.1 | 8.2 | 38.8 | 46.9 |  |
|  |  | Hours of Sleep at Enrolment to the Whitehall II Cohort |  |  |  |  |  |
|  |  | $\leq 5 \mathrm{~h}$ | 6 h | 7 h | 8 h | $\geq 9 \mathrm{~h}$ |  |
| Included in the study analyses, N (\%) | 3960 | 135 (3.4) | 1092 (27.6) | 2127 (53.7) | 578 (14.6) | 28 (0.7) |  |
| Excluded from the study analyses, N (\%) | 2903 | 137 (4.7) | 824 (28.3) | 1457 (50.2) | 459 (15.8) | 26 (0.9) |  |

+Figures are unadjusted means (standard errors) for age and percentages for education, occupational position and sleep duration; *P-value for heterogeneity.

8 hours" was associated with lower scores at follow-up for all cognitive tests equivalent to a 3-5 year increase in age. Firm evidence of an association remained after correction for multiple testing for reasoning, vocabulary, semantic fluency, and the MMSE. Further adjustment for occupational position, Table

5B, resulted in a slight attenuation of these associations, suggesting they are partially explained by this socioeconomic measure. However, after correction for multiple testing and, as in the education-only adjusted analyses, firm evidence remained for the association between an increase from 7 or 8 h sleep and

Table 3-Age-adjusted cross-sectional associations between sleep duration and cognitive function at Phase 7

|  |  | Hours of sleep at Phase 7 |  |  |  |  | P-value** |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Women | N | $\leq 5 \mathrm{~h}$ | 6 h | 7 h | 8 h | $\geq 9 \mathrm{~h}$ |  |
| Number | 1459 | 148 | 494 | 550 | 242 | 25 |  |
| Cognitive function T-scores ${ }^{\dagger}$ |  |  |  |  |  |  |  |
| Memory | 1455 | 48.7 (0.8) | 50.0 (0.4) | 50.3 (0.4) | 50.1 (0.6) | 49.0 (1.9) | 0.49 |
| AH4-I (reasoning) | 1456 | 47.4 (0.8) | 50.1* (0.4) | $51.2^{*}(0.4)$ | 48.8 (0.6) | 48.8 (1.9) | $<0.001$ |
| Mill Hill (vocabulary) | 1452 | 46.9 (0.8) | 50.2* (0.4) | 51.3* (0.4) | 48.7 (0.6) | 48.4 (2.0) | < 0.001 |
| Phonemic fluency | 1445 | 48.2 (0.8) | 50.0* (0.4) | 50.8* (0.4) | 49.7 (0.6) | 47.4 (1.9) | 0.03 |
| Semantic fluency | 1450 | 48.4 (0.8) | 50.0 (0.4) | 50.9* (0.4) | 48.9 (0.6) | 49.5 (1.9) | 0.01 |
| MMSE | 1434 | 47.2 (0.8) | 50.7* (0.4) | $50.7^{*}(0.4)$ | 49.1 (0.6) | 46.1 (2.0) | < 0.001 |
| Men |  |  |  |  |  |  |  |
| Number | 3972 | 269 | 1246 | 1714 | 655 | 88 |  |
| Cognitive function T-scores ${ }^{\dagger}$ |  |  |  |  |  |  |  |
| Memory | 3965 | 49.3 (0.6) | 49.7 (0.3) | 50.5 (0.2) | 49.6 (0.4) | 48.6 (1.0) | 0.03 |
| AH4-I (reasoning) | 3969 | 47.4 (0.6) | 49.8* (0.3) | 50.6* (0.2) | $50.1{ }^{*}(0.4)$ | 49.3 (1.0) | < 0.001 |
| Mill Hill (vocabulary) | 3967 | 48.4 (0.6) | 49.6 (0.3) | $50.5^{*}(0.2)$ | $50.2^{*}(0.4)$ | 49.0 (1.1) | 0.006 |
| Phonemic fluency | 3957 | 48.5 (0.6) | 50.1* (0.3) | $50.2^{*}(0.2)$ | $50.1 *$ (0.4) | 48.5 (1.1) | 0.05 |
| Semantic fluency | 3965 | 48.0 (0.6) | 49.9* (0.3) | 50.4* (0.2) | $50.1{ }^{*}(0.4)$ | 47.8 (1.0) | < 0.001 |
| MMSE | 3857 | 48.6 (0.6) | 49.9 (0.3) | 50.5* (0.2) | 49.8 (0.4) | 48.2 (1.1) | 0.01 |

${ }^{\dagger}$ Figures are means using T-scores (standard errors); *P $<0.05$ for difference relative to $\leq 5 \mathrm{~h}$ (arbitrary reference category); **P-value for heterogeneity.
poorer cognitive function for all the tests except memory. In the case of a decrease from 6, 7 or 8 h sleep, firm evidence of an association with poorer cognitive function remained for reasoning, vocabulary, and the MMSE. The magnitude of these effects was equivalent to a 4-7 year increase in age.

## DISCUSSION

## Synopsis of Findings

This study suggests that moves from a regular pattern of 6-8 hours per night to the short and long ends of the sleep distribution are associated with poorer cognitive function relative to those whose sleep duration remains unchanged. In analyses adjusted for age, sex, and education and corrected for multiple testing, a move to the long end of the sleep distribution appeared the most detrimental. An increase in sleep from 7 or 8 hours per night is associated with poorer cognitive function scores for all tests (reasoning, vocabulary, phonemic, and semantic fluency, and the mini mental state examination), except memory-equivalent to an increase in age of 5-8 years. A move to the short end of the sleep distribution, a decrease from 6, 7, or 8 h sleep per night, was also associated with poorer scores for all tests except memory and phonemic fluency-equivalent to a $3-5$ year increase in age. Although these associations were partially explained by occupational position, evidence of associations between changes in sleep duration and cognitive function remained firm with the exception of that between a decrease from 6,7 , or 8 h sleep and semantic fluency.

## Shape of the Associations

Most existing studies have examined cross-sectional associations between sleep problems and cognitive function. ${ }^{11-13,15-19}$ Of those that have examined sleep duration, ${ }^{10,14,1,2,2,35}$ only two

Table 4-Sleep duration category at Phase 7 defined by change in number of hours sleep between Phase 5 and Phase 7

| Sleep duration category | Women $(N=1459)$ | $\begin{gathered} \text { Men } \\ (\mathrm{N}=3972) \end{gathered}$ |
| :---: | :---: | :---: |
| No change in sleep duration | \% (N) | \% (N) |
| $\leq 5 \mathrm{~h}$ at both phases | 4.7 (68) | 3.0 (120) |
| 6 h at both phases | 16.7 (243) | 18.9 (752) |
| 7 h at both phases | 19.5 (284) | 27.8 (1103) |
| 8 h at both phases | 8.1 (118) | 7.5 (298) |
| $\geq 9 \mathrm{~h}$ at both phases | 0.5 (7) | 0.6 (23) |
| Total - no change in sleep duration | 49.5 (720) | 57.8 (2327) |
| Decrease from 9 hours (9 h sleep at Phase 5 and $<9 \mathrm{~h}$ at Phase 7) | 1.3 (19) | 0.7 (26) |
| Increase from $\leq 5$ or 6 hours ( $\leq 5$ or 6 h sleep at Phase 5 and $>5$ or 6 h , respectively, at Phase 7) | 16.7 (243) | 14.6 (580) |
| Decrease from 6, 7 or 8 hours ( 6,7 , or 8 h sleep at Phase 5 and $<6$, 7 , or 8 h , respectively at Phase 7) | 25.3 (369) | 18.3 (727) |
| Increase from 7 or 8 hours ( 7 or 8 h sleep at Phase 5 and $>7$ or 8 h, respectively, at Phase 7) | 7.4 (108) | 8.6 (343) |

appear to present data separately for men as well as women. ${ }^{10,14}$ The present study enabled us to compare the shape of associations between sleep duration and a range of cognitive function measures separately by sex. Overall associations between sleep duration and all cognitive function measures were $U$-shaped, with the lowest scores consistently associated with short and long sleep. These findings are similar to those from a population

Table 5-Cognitive function at Phase 7 by change in number of hours sleep between Phase 5 and Phase 7 in women and men combined

|  | Change in hours of sleep between Phase 5 and Phase 7 |  |  |  |
| :--- | :---: | :---: | :---: | :---: |
| Cognitive Function Test ${ }^{\#}$ | Increase from | Participants with no | Decrease from | Increase from |
| Number | 5 or $6 \mathrm{ha}^{\mathrm{a}}$ | change in sleep duration | 6,7, or $8 \mathrm{~h}^{\mathrm{b}}$ | 7 or $8 \mathrm{~h}^{\mathrm{c}}$ |
|  | 823 | 3047 | 1096 | 451 |


| A Adjusted for age, sex and education |  |
| :--- | ---: |
| Memory | $0.30(-0.54,1.14)$ |
| AH4-I (reasoning) | $0.06(-0.73,0.86)$ |
| Mill Hill (vocabulary) | $0.26(-0.55,1.06)$ |
| Phonemic fluency | $-0.21(-1.05,0.62)$ |
| Semantic fluency | $0.11(-0.71,0.93)$ |
| MMSE | $-0.19(-1.06,0.68)$ |


| Ref | $-0.27(-0.96,0.42)$ | $-1.09(-2.07,-0.10)$ |
| :--- | ---: | ---: |
| Ref | $-1.44^{* * *}(-2.09,-0.79)$ | $-1.36^{*}(-2.29,-0.43)$ |
| Ref | $-1.05^{* *}(-1.71,-0.39)$ | $-1.62^{* *}(-2.56,-0.68)$ |
| Ref | $-0.59(-1.27,0.09)$ | $-1.35^{*}(-2.33,-0.38)$ |
| Ref | $-0.90^{*}(-1.57,-0.23)$ | $-1.66^{* *}(-2.62,-0.70)$ |
| Ref | $-1.34^{* *}(-2.05,-0.63)$ | $-1.85^{*}(-2.87,-0.83)$ |
|  |  |  |
| Ref | $-0.12(-0.80,0.57)$ | $-0.98(-1.96,-0.01)$ |
| Ref | $-1.08^{* *}(-1.69,-0.47)$ | $-1.11^{*}(-1.98,-0.25)$ |
| Ref | $-0.72^{*}(-1.34,-0.10)$ | $-1.39^{* *}(-2.28,-0.50)$ |
| Ref | $-0.33(-0.99,0.33)$ | $-1.19^{*}(-2.14,-0.25)$ |
| Ref | $-0.62(-1.27,0.02)$ | $-1.47^{* *}(-2.39,-0.55)$ |
| Ref | $-1.19^{*}(-1.90,-0.49)$ | $-1.73^{* *}(-2.74,-0.72)$ |

\#Mean difference in score (95\% confidence interval)
${ }^{a} \leq 5$ or 6 h sleep at Phase 5 \& more than 5 or 6 hours respectively at Phase 7 , reference group is either $\leq 5$ or 6 h at both phases ( $\mathrm{n}=1183[68+243+120+752$

- see Table 4])
${ }^{\text {b }} 6,7$ or 8 h sleep at Phase 5 and $<6,7$, or 8 h, respectively, at Phase 7 , reference group is either 6,7 , or 8 hat both phases ( $n=2798[243+284+118+752+1103+298$
- see Table 4])
${ }^{\circ} 7$ or 8 h sleep at Phase 5 and $>7$ or 8 h respectively at Phase 7 , reference group is either 7 or 8 h at both phases ( $\mathrm{n}=1803[284+118+1103+298-$ see
Table 4])
${ }^{*} P<0.05$, **P < 0.01, and ***P < 0.001 for difference from no change group
The critical values determining the significance of each test have been adjusted to allow for the multiple comparisons in this table (see methods section).
sample of adults aged 60 and over in Spain which demonstrated U-shaped associations between sleep duration and a Spanish version of the Mini-Mental state examination in both women and men, although in this sample associations were much stronger for very long sleep durations than for short sleep. ${ }^{10}$

Differences between the scores for memory across the sleep duration distribution were small in both sexes. However, for other measures of cognitive function; reasoning, vocabulary, fluency, and the Mini-Mental state examination, there was good evidence that short sleep and sleep durations of 8 or more hours were associated with poorer cognitive function in women, although in men such associations were observed only for short and long sleep. While differences in the cognitive scores between the sleep duration categories seem relatively small, it is now increasingly recognized that cognitive trajectories over the life course are important for late life cognitive outcomes such as dementia. ${ }^{8,9}$ Previous work from the Whitehall II study indicates that they may be clinically relevant. Differences between sleep durations of 5 hours or less and 7 hours per night are equal to between $50 \%$ and $100 \%$ of the coronary heart disease-no coronary heart (CHD - No-CHD) disease differences in cognitive function scores observed previously in this cohort (see supplementary Table S2). ${ }^{36}$

Our findings for men exactly replicate findings for women aged 70 and over from the Nurses Health Study, ${ }^{23}$ but are slightly different from those from the two other studies that have reported on the association with sleep duration in men. ${ }^{10,14}$

Compared with 7 hours sleep per night, 6 hours or less was associated with poorer cognitive function in men aged 60+, and there were no associations between sleep durations of 8 hours or more and cognitive function. However, this smaller study had only one self-reported cognitive function measure that combined a measure of memory and general cognitive complaints. ${ }^{14}$ Associations observed in the present study between longer sleep and poorer cognitive function, both in the crosssectional and prospective analyses, highlight the importance of long sleep, which has tended to be overshadowed as a risk factor by insomnia and short sleep. ${ }^{37}$

## Nature of the Association

Although education is associated with both cognitive function and sleep in these data, moves from a regular pattern of 6-8 hours per night to the short and long ends of the sleep distribution were associated with poorer cognitive function in analyses adjusted for education. Further adjustment for employment grade, a comprehensive marker of socioeconomic position in this cohort, slightly attenuated the associations observed. Thus it seems that associations between change in sleep duration and cognitive function are partially accounted for by markers of socioeconomic position. However, this attenuation falls far short of abolishing the observed associations, indicating either a direct association between change in sleep and cognitive function, or an association mediated or confounded by factors other than education and occupational position.

Adequate, good quality sleep is fundamental to human functioning and well-being. Sleep deprivation and sleepiness have such adverse effects on performance, response times, errors of commission, and attention or concentration, ${ }^{38,39}$ that most countries have strict legislation regulating the number of hours people can work without adequate time for rest. While a direct association between sleeping for longer and adverse outcomes initially seems less plausible, a review by Grandner and Drummond ${ }^{40}$ has suggested seven possible mechanisms underlying the association between long sleep and early death. Of these; sleep fragmentation, which can result in poor quality sleep; depression; and underlying disease processes, such as CHD, appear to be relevant to the association between long sleep and cognitive function. While poor quality sleep, analogous to sleep deprivation, could indicate a direct association; the remaining explanations suggest associations mediated or confounded by depression or disease. Depression has been shown to be associated with poor sleep, including long-sleeping, ${ }^{41}$ and with cognitive function in this cohort. ${ }^{42}$ CHD similarly has been shown to be associated with poor sleep, ${ }^{43}$ and with poorer cognitive function. ${ }^{36}$

Reverse causality, the possibility that cognitive function determines sleep duration, cannot be ruled out in our analyses. However, the longitudinal nature of the data which permits the examination of change in sleep duration makes this explanation unlikely. Further support for this position comes from previous work that has provided no firm evidence that cognitive decline predicts sleep duration. ${ }^{35}$

## Comparison with Other Findings

While few studies of sleep and cognitive function have used longitudinal data, our findings support those that have demonstrated prospective associations between poor sleep patterns and cognitive impairment and cognitive decline. ${ }^{21,22}$ Our findings are also in agreement with the only previous study of change in sleep duration. In this small, population-based study a move from 7-8 hours sleep per night to $\geq 9$ hours over a period of 8.5 years was associated with a doubling of the prevalence of cognitive impairment. ${ }^{26}$

Sleep duration has been found to be associated with a wide range of quality of life measures, such as social functioning, ${ }^{44,45}$ health outcomes, such as poor mental health, obesity, type 2 diabetes, cardiovascular disease; and early death. ${ }^{28,46-51}$ In common with cognitive function in the present study, this association is typically U-shaped with poorer outcomes concentrated at the short and long ends of the sleep distribution. The only work that appears to have examined change in sleep as a determinant of health is three studies on associations with mortality. While an early study found no association, ${ }^{52}$ two subsequent studies have provided good evidence that moves to the short and long ends of the sleep distribution are associated with an excess risk of all-cause and cardiovascular mortality. ${ }^{28,53}$

## Methodological Considerations

This study appears to be the first large study to report on the association between change in sleep duration and cognitive function and among the first to report in detail on the shape of the association between sleep duration and cognitive function in men. In addition to large numbers, the study benefits from a clinic-based measure of cognitive function comprising six tests.

This gives it an advantage over the majority of other studies which either have cognitive function measured in the laboratory on small numbers or rely on self-reported measures of cognitive function. Although the cognitive function tests used did not allow us to explore specific cognitive functions with precision, the six tests provide a comprehensive evaluation of cognitive function for this population of older white-collar workers. Our findings probably represent conservative, but more realistic, estimates of the effects associated with changes in sleep duration since the reference group for each change category is participants from the same category at baseline who do not change rather than those who consistently have 7 or 8 hours sleep. This was a deliberate choice based on the understanding that habitual short or long sleep is not detrimental in all individuals.

This study has at least two main limitations. First, our measure of sleep duration is a single-item, self-reported measure that used hourly categories as responses and did not explicitly ask participants to differentiate time asleep from time in bed. Self-reports and actigraph-measured sleep duration appear to be moderately correlated in younger and older adults, with selfreports, on average, providing an overestimation of sleep duration. ${ }^{54,55}$ Concordance between self-reported sleep duration and polysomnography, the gold standard, in older adults is low to moderate. ${ }^{56}$ Obtaining repeat data using objective measures of sleep duration from large cohorts is expensive and time consuming, although actigraphy, the less expensive of the objective measures, is increasingly being introduced on a larger scale. ${ }^{55}$ Nonetheless, most large cohorts with repeat data on sleep duration are still reliant on self-reports, and it is important to recognize that self-reported sleep duration is strongly associated with health outcomes. ${ }^{28,46-51}$ Furthermore, assessments of sleep durations in the primary health care setting rely on self-reported data from patients and so our findings are likely to be ecologically valid. The other main limitation is generalizability. Findings from an occupational cohort aged 45-69 years of age at baseline and almost exclusively white-collar may not apply to wider populations.

## CONCLUSIONS

The "life-long" view of dementia emphasizes the importance of risk factors across the life course from early to mid and late adulthood. ${ }^{9,57,58}$ In the present study, we adopt this approach and apply it to sleep as a risk factor for poor cognitive function. The study describes the effects of changes in sleep over a five-year period starting in late middle age on cognitive function in later life. Our findings show that women and men who move toward the short and long ends of the sleep distribution appear to be subject to accelerated cognitive aging equivalent to a 3-8 year increase in age. Further research is needed to corroborate these findings in the general population, preferably in studies sufficient in size to examine the detriment associated with each hour of change in sleep duration. In addition, further work is needed to elucidate the mechanisms that underlie these associations.

## ACKNOWLEDGMENTS

This work was performed at Department of Epidemiology and Public Health, University College London Medical School.

The Whitehall II study has been supported by grants from the British Medical Research Council (MRC); the British Heart

Foundation; the British Health and Safety Executive; the British Department of Health; the National Heart, Lung, and Blood Institute (grant R01HL036310); the National Institute on Aging (R01AG013196; R01AG034454); the Agency for Health Care Policy and Research (grant HS06516); and the John D. and Catherine T. MacArthur Foundation Research Networks on Successful Midlife Development and Socioeconomic Status and Health. Dr. Ferrie is supported by the National Institute on Aging and Professor Kivimäki and Dr. Akbaraly by the Academy of Finland (project 124322). Professor Kivimäki is also supported by the BUPA Foundation. Dr. Singh-Manoux is supported by a 'EURYI' award from the European Science Foundation, Professor Marmot by an MRC Research Professorship, and Mr. Shipley by a grant from the British Heart Foundation.

## DISCLOSURE STATEMENT

This was not an industry supported study. The authors have indicated no financial conflicts of interest.

## REFERENCES

1. Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. Sleep 2004; 27:1255-73.
2. Basner M, Fomberstein KM, Razavi FM, Banks S, William JH, Rosa RR et al. American time use survey: sleep time and its relationship to waking activities. Sleep 2007; 30:1085-95.
3. Kumari M, Green R, Nazroo J. Financial circumstances, health and wellbeing of the older population in England: The 2008 English Longitudinal Study of Ageing (Wave 4). In: Banks J, Lessof C, Nazroo J, Rogers N, Stafford M, Steptoe A, eds. London: Institute for Fiscal Studies; 2010: 178-226.
4. Czeisler CA. Sleep deficit: the performance killer. A conversation with Harvard Medical School Professor Charles A. Czeisler. Harv Bus Rev 2006; 84:53-9, 148.
5. Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. Semin Neurol 2005; 25:117-29.
6. Finch CE. Middle age: an evolving frontier in gerontology. Neurobiol Aging 1991;12:1-2.
7. Rowe JW, Kahn RL. Successful aging. New York: Random House; 1998.
8. Salthouse TA. When does age-related cognitive decline begin? Neurobiol Aging 2009;30:507-14.
9. Brayne C. The elephant in the room - healthy brains in later life, epidemiology and public health. Nat Rev Neurosci 2007;8:233-9.
10. Faubel R, Lopez-Garcia E, Guallar-Castillon P, Graciani A, Banegas JR, Rodriguez-Artalejo F. Usual sleep duration and cognitive function in older adults in Spain. J Sleep Res 2009;18:427-35.
11. Nebes RD, Buysse DJ, Halligan EM, Houck PR, Monk TH. Self-reported sleep quality predicts poor cognitive performance in healthy older adults. J Gerontol B Psychol Sci Soc Sci 2009;64:180-7.
12. Schmutte T, Harris S, Levin R, Zweig R, Katz M, Lipton R. The relation between cognitive functioning and self-reported sleep complaints in nondemented older adults: results from the Bronx aging study. Behav Sleep Med 2007;5:39-56.
13. Blackwell T, Yaffe K, Ancoli-Israel S, et al. Poor sleep is associated with impaired cognitive function in older women: the study of osteoporotic fractures. J Gerontol A Biol Sci Med Sci 2006; 61:405-10.
14. Ohayon MM, Vecchierini MF. Normative sleep data, cognitive function and daily living activities in older adults in the community. Sleep 2005;28:981-9.
15. Bastien CH, Fortier-Brochu E, Rioux I, LeBlanc M, Daley M, Morin CM. Cognitive performance and sleep quality in the elderly suffering from chronic insomnia. Relationship between objective and subjective measures. J Psychosom Res 2003;54:39-49.
16. Ohayon MM, Vecchierini MF. Daytime sleepiness and cognitive impairment in the elderly population. Arch Intern Med 2002;162:201-8.
17. Crenshaw MC, Edinger JD. Slow-wave sleep and waking cognitive performance among older adults with and without insomnia complaints. Physiol Behav 1999; 66:485-92.
18. Jennum P, Sjol A. Self-assessed cognitive function in snorers and sleep apneics. An epidemiological study of 1,504 females and males aged 30-60 years: the Dan-MONICA II Study. Eur Neurol 1994;34:204-8.
19. Kronholm E, Sallinen M, Suutama T, Sulkava R, Era P, Partonen T. Selfreported sleep duration and cognitive functioning in the general population. J Sleep Res 2009;18:436-46.
20. Bliwise DL. Sleep in normal aging and dementia. Sleep 1993;16:40-81.
21. Spiegel R, Herzog A, Koberle S. Polygraphic sleep criteria as predictors of successful aging: an exploratory longitudinal study. Biol Psychiatry 1999;45:435-42.
22. Jelicic M, Bosma H, Ponds RW, Van Boxtel MP, Houx PJ, Jolles J. Subjective sleep problems in later life as predictors of cognitive decline. Report from the Maastricht Ageing Study (MAAS). Int J Geriatr Psychiatry 2002;17:73-77.
23. Tworoger SS, Lee S, Schernhammer ES, Grodstein F. The association of self-reported sleep duration, difficulty sleeping, and snoring with cognitive function in older women. Alzheimer Dis Assoc Disord 2006;20:41-8.
24. Cricco M, Simonsick EM, Foley DJ. The impact of insomnia on cognitive functioning in older adults. J Am Geriatr Soc 2001;49:1185-9.
25. Ancoli-Israel S, Ayalon L, Salzman C. Sleep in the elderly: normal variations and common sleep disorders. Harv Rev Psychiatry 2008;16:279-86.
26. Loerbroks A, Debling D, Amelang M, Sturmer T. Nocturnal sleep duration and cognitive impairment in a population-based study of older adults. Int J Geriatr Psychiatry 2010; 25:100-9.
27. Marmot MG, Davey Smith G, Stansfeld S, et al. Health inequalities among British civil servants: the Whitehall II study. Lancet 1991;337:1387-93.
28. Ferrie JE, Shipley MJ, Cappuccio FP, et al. A prospective study of change in sleep duration: associations with mortality in the Whitehall II cohort. Sleep 2007;30:1659-66.
29. Heim AW. AH 4 group test of general intelligence. Windsor, UK: NFERNelson Publishing Company Ltd.; 1970.
30. Raven JC. Guide to using the Mill Hill vocabulary test with progressive matrices. London, UK: HK Lewis; 1965.
31. Borkowski JG, Benton AL, Spreen O. Word fluency and brain damage. Neuropsychologica 1967;5:135-40.
32. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189-98.
33. Karlamangla AS, Miller-Martinez D, Aneshensel CS, Seeman TE, Wight RG, Chodosh J. Trajectories of cognitive function in late life in the United States: demographic and socioeconomic predictors. Am J Epidemiol 2009;170:331-42.
34. Curran-Everett D. Multiple comparisons: philosophies and illustrations. Am J Physiol Regul Integr Comp Physiol 2000; 279:R1-R8.
35. Yaffe K, Blackwell T, Barnes DE, Ancoli-Israel S, Stone KL. Preclinical cognitive decline and subsequent sleep disturbance in older women. Neurology 2007;69:237-42.
36. Singh-Manoux A, Sabia S, Lajnef M, et al. History of coronary heart disease and cognitive performance in midlife: the Whitehall II study. Eur Heart J 2008;29:2100-7.
37. Kripke DF. Do we sleep too much? Sleep 2004;27:13-4.
38. Dorrian J, Dinges DF. Sleep deprivation and Its Effects on Cognitive performance. In: Lee-Chiong T, ed. Sleep: a comprehensive handbook. Hoboken, NJ: Wiley-Liss; 2006:137-44.
39. Rosa RR. Sleep loss, sleepiness, performance, and safety. In: Lee-Chiong T, ed. Sleep: a comprehensive handbook. Hoboken, NJ: Wiley-Liss; 2006: 203-7.
40. Grandner MA, Drummond SP. Who are the long sleepers? Towards an understanding of the mortality relationship. Sleep Med Rev 2007;11:341-60.
41. Tsuno N, Besset A, Ritchie K. Sleep and depression. J Clin Psychiatry 2005;66:1254-69.
42. Singh-Manoux A, Akbaraly TN, Marmot M, et al. Persistent depressive symptoms and cognitive function in late midlife: the Whitehall II study. J Clin Psychiatry 2010;71:1379-85.
43. Mezick EJ, Hall M, Matthews KA. Are sleep and depression independent or overlapping risk factors for cardiometabolic disease? Sleep Med Rev 2011;15:51-63.
44. Baldwin CM, Griffith KA, Nieto FJ, O’Connor GT, Walsleben JA, Redline S . The association of sleep-disordered breathing and sleep symptoms with quality of life in the Sleep Heart Health Study. Sleep 2001;24:96-105.
45. Groeger JA, Zijlstra FR, Dijk DJ. Sleep quantity, sleep difficulties and their perceived consequences in a representative sample of some 2000 British adults. J Sleep Res 2004;13:359-71.
46. John U, Meyer C, Rumpf HJ, Hapke U. Relationships of psychiatric disorders with sleep duration in an adult general population sample. J Psychiatr Res 2005;39:577-83.
47. Gangwisch JE, Malaspina D, Boden-Albala B, Heymsfield SB. Inadequate sleep as a risk factor for obesity: analyses of the NHANES I. Sleep 2005;28:1289-96.
48. Knutson KL, Ryden AM, Mander BA, Van CE. Role of sleep duration and quality in the risk and severity of type 2 diabetes mellitus. Arch Intern Med 2006;166:1768-74.
49. Qureshi AI, Giles WH, Croft JB, Bliwise DL. Habitual sleep patterns and risk for stroke and coronary heart disease: a 10-year follow-up from NHANES I. Neurology 1997;48:904-11.
50. Ayas NT, White DP, Manson JE, et al. A prospective study of sleep duration and coronary heart disease in women. Arch Intern Med 2003;163:205-9.
51. Chandola T, Ferrie JE, Perski A, Akbaraly T, Marmot MG. The effect of short sleep duration on coronary heart disease risk is greatest among those with sleep disturbance: a prospective study from the Whitehall II Cohort. Sleep 2010;33:739-44.
52. Heslop P, Smith GD, Metcalfe C, Macleod J, Hart C. Sleep duration and mortality: The effect of short or long sleep duration on cardiovascular and all-cause mortality in working men and women. Sleep Med 2002;3:305-14.
53. Hublin C, Partinen M, Koskenvuo M, Kaprio J. Sleep and mortality: a population-based 22-year follow-up study. Sleep 2007;30:1245-53.
54. Lauderdale DS, Knutson KL, Yan LL, Liu K, Rathouz PJ. Self-reported and measured sleep duration: how similar are they? Epidemiology 2008;19:838-45.
55. van den Berg JF, Van Rooij FJ, Vos H, et al. Disagreement between subjective and actigraphic measures of sleep duration in a population-based study of elderly persons. J Sleep Res 2008;17:295-302.
56. Unruh ML, Redline S, An MW, et al. Subjective and objective sleep quality and aging in the sleep heart health study. J Am Geriatr Soc 2008;56:1218-27.
57. Launer LJ. The epidemiologic study of dementia: a life-long quest? Neurobiol Aging 2005;26:335-40.
58. Singh-Manoux A, Kivimaki M. The importance of cognitive ageing for understanding dementia. Age (Dordr). 2010;32:509-12.

Table S1-Age, education and occupational position adjusted cross-sectional associations between sleep duration and cognitive function at Phase 7

|  | N | Hours of sleep at Phase 7 |  |  |  |  | P -value** |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Women |  | $\leq 5 \mathrm{~h}$ | 6 h | 7 h | 8 h | $\geq 9 \mathrm{~h}$ |  |
| Number | 1459 | 148 | 494 | 550 | 242 | 25 |  |
| Cognitive function test scores ${ }^{\dagger}$ |  |  |  |  |  |  |  |
| Memory | 1455 | 49.5 (0.8) | 50.0 (0.4) | 50.1 (0.4) | 50.2 (0.6) | 49.0 (1.9) | 0.92 |
| AH4-I (reasoning) | 1456 | 48.8 (0.6) | 50.1 (0.3) | 50.8* (0.3) | 48.9 (0.5) | 48.4 (1.5) | 0.005 |
| Mill Hill (vocabulary) | 1452 | 48.3 (0.7) | 50.2* (0.4) | 50.8* (0.3) | 48.9 (0.5) | 48.0 (1.6) | 0.001 |
| Phonemic fluency | 1445 | 49.2 (0.7) | 50.0 (0.4) | 50.5 (0.4) | 49.8 (0.6) | 47.0 (1.7) | 0.22 |
| Semantic fluency | 1450 | 49.5 (0.7) | 50.0 (0.4) | 50.6 (0.4) | 49.1 (0.5) | 49.3 (1.7) | 0.18 |
| MMSE | 1434 | 47.8 (0.8) | 50.6 (0.4) | 50.5 (0.4) | 49.2 (0.6) | 46.1 (2.0) | 0.002 |
| Men |  |  |  |  |  |  |  |
| Number | 3972 | 269 | 1246 | 1714 | 655 | 88 |  |
| Cognitive function test scores ${ }^{\dagger}$ |  |  |  |  |  |  |  |
| Memory | 3965 | 49.9 (0.6) | 49.8 (0.3) | 50.4 (0.2) | 49.5 (0.4) | 48.6 (1.0) | 0.08 |
| AH4-I (reasoning) | 3969 | 48.8 (0.5) | 49.9 (0.2) | 50.3* (0.2) | 49.9 (0.3) | 49.2 (0.9) | 0.09 |
| Mill Hill (vocabulary) | 3967 | 49.6 (0.5) | 49.8 (0.2) | 50.3 (0.2) | 50.0 (0.3) | 48.8 (0.9) | 0.27 |
| Phonemic fluency | 3957 | 49.5 (0.6) | 50.2 (0.3) | 50.1 (0.2) | 50.0 (0.4) | 48.5 (1.0) | 0.51 |
| Semantic fluency | 3965 | 49.1 (0.6) | 50.0 (0.3) | 50.3* (0.2) | 49.9 (0.4) | 47.8 (1.0) | 0.05 |
| MMSE | 3857 | 49.1 (0.6) | 49.9 (0.3) | 50.4* (0.2) | 49.7 (0.4) | 48.2 (1.0) | 0.07 |

${ }^{\dagger}$ Figures are means (standard errors). ${ }^{*} \mathrm{P}<0.05$ for difference relative to $\leq 5 \mathrm{~h}$ (arbitrary reference category). ${ }^{* *} \mathrm{P}$-value for heterogeneity.

Table S2-Comparison of the cross-sectional association at Phase 7 between sleep duration and cognitive function with cognitive function differences between CHD and No-CHD*

| Women | N | Hours of sleep at Phase 7 |  | Standardized difference |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\leq 5 \mathrm{~h}$ | 7 h | $5 \mathrm{~h}-7 \mathrm{~h}$ | CHD-No CHD |
| Number | 1459 | 148 | 550 |  |  |
| Cognitive function T-scores ${ }^{\dagger}$ |  |  |  |  |  |
| Memory | 1455 | 48.7 (0.8) | 50.3 (0.4) | -0.16 | -0.35 |
| AH4-I (reasoning) | 1456 | 47.4 (0.8) | 51.2* (0.4) | -0.38 | -0.58 |
| Mill Hill (vocabulary) | 1452 | 46.9 (0.8) | 51.3* (0.4) | -0.44 | -0.46 |
| Phonemic fluency | 1445 | 48.2 (0.8) | 50.8* (0.4) | -0.26 | -0.47 |
| Semantic fluency | 1450 | 48.4 (0.8) | 50.9* (0.4) | -0.25 | -0.40 |
| MMSE | 1434 | 47.2 (0.8) | $50.7^{*}(0.4)$ | -0.35 | -0.31 |
| Men |  |  |  |  |  |
| Number | 3972 | 269 | 1714 |  |  |
| Cognitive function T-scores ${ }^{\dagger}$ |  |  |  |  |  |
| Memory | 3965 | 49.3 (0.6) | 50.5 (0.2) | -0.12 | -0.22 |
| AH4-I (reasoning) | 3969 | 47.4 (0.6) | 50.6* (0.2) | -0.32 | -0.25 |
| Mill Hill (vocabulary) | 3967 | 48.4 (0.6) | 50.5* (0.2) | -0.21 | -0.25 |
| Phonemic fluency | 3957 | 48.5 (0.6) | $50.2^{*}(0.2)$ | -0.17 | -0.13 |
| Semantic fluency | 3965 | 48.0 (0.6) | 50.4* (0.2) | -0.24 | -0.14 |
| MMSE | 3857 | 48.6 (0.6) | 50.5* (0.2) | -0.19 | -0.25 |

${ }^{\dagger}$ Figures are means (standard errors). *Standardized differences between CHD and No-CHD have been calculated from reference. ${ }^{34}$


[^0]:    Submitted for publication July, 2010
    Submitted in final revised form December, 2010
    Accepted for publication December, 2010
    Address correspondence to: Jane Ferrie, Senior Research Fellow, Department of Epidemiology and Public Health, University College London Medical School, 1-19 Torrington Place, London WC1E 6BT, U.K.; Tel: (+44 207) 679 5643; Fax: (+44 207) 813 0288; E-mail: j.ferrie@ucl.ac.uk

