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Sleep duration and all-cause mortality: a critical review of measurement and associations

Lianne M. Kurina PhD [a,*], Martha K. McClintock PhD [b], Jen-Hao Chen PhD [a], Linda J. Waite PhD [c], Ronald A. Thisted PhD [a], Diane S. Lauderdale PhD [a]

[a] Department of Health Studies, University of Chicago, Illinois
[b] Department of Psychology, University of Chicago, Illinois
[c] Department of Sociology, University of Chicago, Illinois

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ABSTRACT

Purpose: Variation in sleep duration has been linked with mortality risk. The purpose of this review is to provide an updated evaluation of the literature on sleep duration and mortality, including a critical examination of sleep duration measurement and an examination of correlates of self-reported sleep duration.
Methods: We conducted a systematic search of studies reporting associations between sleep duration and all-cause mortality and extracted the sleep duration measure and the measure(s) of association.
Results: We identified 42 prospective studies of sleep duration and mortality drawing on 35 distinct study populations worldwide. Unlike previous reviews, we find that the published literature does not support a consistent finding of an association between self-reported sleep duration and mortality. Most studies have employed survey measures of sleep duration, which are not highly correlated with estimates based on physiologic measures.
Conclusions: Despite a large body of literature, it is premature to conclude, as previous reviews have, that a robust, U-shaped association between sleep duration and mortality risk exists across populations. Careful attention must be paid to measurement, response bias, confounding, and reverse causation in the interpretation of associations between sleep duration and mortality.
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Introduction

Over the past decades, a growing body of literature has examined how habitual sleep duration is related to mortality [1–36]. Several recent reviews have summarized this literature and have concluded that a robust association exists between sleep duration and mortality risk; specifically, that mortality risk is higher among both short sleepers and long sleepers compared with normal length sleepers [37–40]. Upon re-examination, however, the literature is not as consistent as might be expected given these conclusions. A careful reconsideration of the sleep duration/mortality literature is warranted, given the increasing interest of epidemiologists in studying sleep [41] and the number of studies citing this literature to motivate research focused on physiologic mechanisms linking sleep and health outcomes.

Past reviews have not described the specific ways in which sleep duration was queried in each of the original studies or the possible implications of these measurement differences for study findings. Although all of the reviews acknowledge methodologic issues, insufficient attention has been paid to the several plausible alternative explanations to a causal link from sleep to mortality, including systematic measurement bias, unmeasured confounding, and reverse causation.

Therefore, in this review we 1) review how sleep duration has been measured in epidemiologic studies and discuss the challenges of using these different measurement approaches, 2) identify the correlates of short and/or long self-reported sleep duration in the interest of highlighting the threat of confounding by these factors, and 3) summarize the findings of prospective studies of sleep duration and mortality among adults, discussing possible differences in these relationships by gender and measurement type.

Methods

To find studies of sleep duration and all-cause mortality among adults, we searched all studies in PubMed up to October 5, 2012, using the search terms "sleep duration" and "mortality," which

* Corresponding author. Department of Health Studies, University of Chicago, 5841 S. Maryland Ave., MC 2007, Chicago, IL 60637.
E-mail address: lkurina@health.bsd.uchicago.edu (L.M. Kurina).

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yielded 281 articles. Eligible studies were those published in English as full-length articles that included sleep duration as the exposure and all-cause mortality as the outcome among adult populations (≥18 years of age). We additionally searched citation lists of earlier review articles on the topic.

Several research groups have published multiple papers from the same study population [2,5,15–21,26,42]. In these cases, all of the studies are described in Table 1, but only the report with the longest follow-up time and most detailed mortality analysis is included in our primary results table (Table 2). Effect estimates from the most fully adjusted models from each study were extracted from data tables. We considered results to be significant at the $P < .05$ level on the basis of reported P values or 95% confidence intervals. When available, we reported gender-stratified results in Table 2. Gender-specific findings from the same study were considered to be independent.

Results

Sleep duration measurement

There is no perfect way to measure sleep duration. Survey-based methods include both retrospective questions and prospective sleep logs. However, almost all epidemiologic studies examining sleep duration and mortality have used retrospective habitual sleep questions, and the actual questions have varied. Broadly, questions fall into three categories. A key question, not previously explored, is whether the type of question asked matters for associations with mortality.

Nighttime sleep

The most frequently used questions query sleep duration during a typical night. Wording varies, such as “About how many hours of sleep did you get on a typical night during the past 4 weeks” [4] versus “In the last 2 weeks, how many hours a night did you usually sleep?” [10]. Other variations include asking separately about weekdays and weekends, or asking about “average” rather than “typical” sleep.

24-Hour sleep

Other surveys ask about sleep over 24 hours: For example, “How many hours do you usually sleep per day (including both nighttime and daytime sleep)” [32], or simply specify sleep “per 24 hours” [1]. Naps may be explicitly mentioned, and a few surveys separately ask about nap frequency and duration [33].

Bedtimes and waking times

Some studies ask about usual bedtime and waking time, and then calculate duration [9,12,22,34]. In theory, there may be advantages to this approach over asking about total duration. Even though bedtime and waking time may also be difficult to report accurately, they do not require mental arithmetic. Also, although 8 hours may be considered a normative sleep duration for adults, it is not clear whether there is an equivalent normative answer for bedtime and waking time; therefore, responses may be less subject to biases such as social desirability bias.

Non-survey sleep measurement

There are two “objective” ways to estimate sleep duration based on physiologic monitoring: polysomnography and actigraphy. Polysomnography estimates sleep based on electrical brain activity and is considered by many to be the “gold standard” for defining sleep [43,44]. However, polysomnography is not well-suited to estimating usual sleep duration in a population-based study; the unfamiliarity of the procedure and its invasiveness often alter sleep. Although generally carried out in a clinical laboratory, polysomnography can be adapted for home monitoring [45]. Typically, polysomnography includes about 20 electrodes and monitors measuring brain activity, muscle activity, eye movements, heart activity, airflow, breathing, and blood oxygen levels, but fewer monitors could be used were the focus just on sleep duration. Two studies reviewed here estimate duration from polysomnography [27,36]; one included an acclimation night [27].

Actigraphy estimates sleep based on arm movement using multidirectional accelerometers that measure activity counts per epoch (e.g., 30 seconds); it is noninvasive, can be worn for many days, and is simple to use. Activity counts are used to categorize epochs as sleep or wake. Actigraphy is thought not to alter sleep because there is no “first-night effect” [46]. Hip actigraphs have been used to measure physical activity [47], but wrist models are used to estimate sleep. They can store many days’ data and yield estimates of total duration and some other sleep parameters, such as fragmentation, but not sleep stages or apnea.

Actigraphy has recently been incorporated into several epidemiologic studies [48–50]. Total sleep duration generally correlates highly between polysomnography and actigraphy—a comprehensive review summarized the correlation at around 90% [46], with higher estimated total sleep for actigraphy than polysomnography and worse agreement for those with worse quality sleep [51,52]. Only one of the mortality studies has used actigraphy [4].

Comparisons of survey sleep duration and actigraphy or polysomnography

Many small clinical studies have compared survey-measured sleep duration with an “objective” measure among individuals with sleep or health problems, but we have identified only four large studies of community-based adults with such comparisons. In these studies average physiologically estimated sleep is between 6 and 6.5 hours, with a standard deviation of around 1 hour. Very few individuals have estimated sleep durations longer than 9 hours, often the definition of “long sleep” in surveys.

In the Sleep Heart Health Study, a population-based study of older adults, one night of home polysomnography was compared with the next-morning survey estimate of the same night and to previously reported habitual sleep [53]. The average polysomnography sleep time was 6 hours, and the average survey estimate for the same night was 18 minutes longer, but the correlation was only 0.16. Habitual sleep reports averaged an hour longer than polysomnography and the correlation was 0.18. Greater divergence was found for those with less education.

The Rotterdam Study of older adults included several nights of actigraphy (average duration 6.5 hours), and subjects also reported estimated sleep each morning [54]. On average the morning estimates were 23 minutes longer than actigraph sleep, but about one third of the sample had more than an hour difference. On average, women reported a quarter hour less sleep than men, although their actigraph sleep was one quarter hour longer. Several covariates, including age and cognitive function, had opposite effects on sleep diary and actigraph sleep.

An ancillary study to the Women’s Health Initiative [4] oversampled women reporting short or long sleep in response to “About how many hours of sleep did you get on a typical night during the past 4 weeks?” The question was asked twice, a few months apart, with a correlation of 0.60. Participants wore an actigraph for 7 nights and wrote down nightly estimates. Self-reported typical sleep and averaged self-reported nightly estimates were very similar (correlation 0.84). Actigraph sleep averaged 6 hours, about 48 minutes shorter than either self-report measure. The correlation between actigraph sleep and self-reported sleep was 0.48. Examining time in

Table 1
Studies of sleep duration and all-cause mortality, arranged first by sleep measure and then alphabetically by cohort name

Cohort name	Country	Age range (yrs)	Study population	Year(s) sleep data collected	Follow-up (yrs)	Cohort size (n)	Reference
Survey sleep measure: nighttime sleep*							
American Cancer Society (ACS)	USA	30–90+	Individuals enrolled from 25 states in the U.S. via ACS volunteers	1959–60	2 6	1,064,004 823,065	Hammond 1964† [2] Kripke et al. 1979‡ [5]
Cancer Prevention Study II	USA	30–102	Friends and relatives of American Cancer Society volunteers	1982	6	1,116,936	Kripke et al. 2002 [3]
Dalarna County postal survey	Sweden	45–65	Random sample of adults living in the County of Dalarna	1983	12	1870	Mallon et al. 2002 [8]
Elderly cohort	USA	65–98	Representative sample of elderly residents in an urban community	1984–5	3.5	1855	Pollak et al. 1990 [10]
FINRISK Surveys	Finland	25–64	Representative population–based sample of North Karelia and Kuopio residents	1972, 1977	35	23,290	Kronholm et al. 2011 [11]
Japan Collaborative Cohort Study for Evaluation of Cancer	Japan	40–79	Attendees of screening programs in 45 areas	1988–90	Mean = 9.9 NR Median = 14.3	104,010 NR 98,634	Tamakoshi & Ohno 2004† [19] Suzuki et al. 2007† [20] Ikehara et al. 2009‡ [21]
Massachusetts Health Care Panel Study	USA	66–98	Probability sample of the noninstitutionalized elders in Massachusetts	1976	5	1235	Branch and Jette 1984 [24]
Miyagi Prefecture survey	Japan	≥40	Residents of a rural town in Miyagi prefecture	1988	4	4318	Tsubono et al. 1993 [25]
National Health and Nutrition Examination Survey I	USA	32–86	Probability sample of the civilian adult noninstitutionalized population	1982–4	10	7844	Qureshi et al. 1997† [42]
					8–10	9789	Gangwisch et al. 2008‡ [26]
Rancho Bernardo Study	USA	60–96	Community-dwelling residents from Rancho Bernardo, CA	1984–7	19	2001	Jung et al. 2012 [98]
Whitehall II Cohort	UK	35–55	White-collar British civil servants	1985–8	Mean = 17.1	10,308	Ferrie et al. 2007 [35]
Survey sleep measure: 24-hour sleep*							
Chinese Longitudinal Healthy Longevity Survey (CLHLS)	China	65–100+	Representative sample of elderly population in Mainland China	2005	3	12,671	Qiu et al. 2011 [97]
Finnish Twin Cohort	Finland	24–101	All Finnish twin pairs of the same sex born before 1958 with both co-twins alive in 1975	1975, 1981	21	21,268	Hublin et al. 2007 [1]
Health Interview Study of Barcelona (HISB)	Spain	≥65	Random sample of noninstitutionalized individuals in Barcelona	1986	5	1219	Ruigomez et al. 1995 [14]
National Health Interview Survey (NHIS)	USA	≥18	Nationally representative sample of adults in the USA	1990	16	38,891	Krueger et al. 2011 [115]
Nurses' Health Study	USA	40–65	Female health professionals	1986	14	82,969	Patel et al. 2004 [29]
Ohsaki Cohort Study	Japan	40–79	National Health Insurance beneficiaries	1994	Mean = 10.8	49,236	Kakizaki et al. 2012 [116]
Scottish working cohort	Scotland	<60 females; <65 males	Employees of a variety of workplaces in the west of Scotland	1970–3; 1977	25	6797	Heslop et al. 2002 [30]
Shizuoka Study	Japan	65–85	Population-based cohort study in the Shizuoka prefecture	1999	6	11,395	Suzuki et al. 2009 [31]
Spanish cohort	Spain	≥60	Probability sample of noninstitutionalized persons representative of Spanish population	2000–1	Mean = 6.8	3820	Mesas et al. 2010 [32]
Study of Osteoporotic Fractures	USA	≥69	Population-based cohort of ambulatory, community-dwelling women	1993–4	Mean = 6.9	8101	Stone et al. 2009 [33]
Survey sleep measure: bedtime and waking time*							
Bambui Health and Ageing Study	Brazil	≥60	Residents of Bambui city	1997	9	1512	Castro-Costa et al. 2011 [6]
Cross-Sectional and Longitudinal Aging Study	Israel	75–94	Random sample of older Jewish population in Israel	1989–92	20	1166	Cohen-Mansfield et al. 2012 [99]
Department of Health and Social Security Survey	UK	≥65	Random sample of older adults living in eight areas of Great Britain	1973–4	23	862	Gale and Martyn 1998 [9]
Gifu Prefecture cohort study	Japan	20–67	Residents of Shirakawa town who attended health examinations	1982–6	Mean = 11.9	5322	Kojima et al. 2000 [12]
Jichi Medical School Cohort Study	Japan	19–93	Population-based study in 12 rural areas	1992–5	Mean = 8.2	11,325	Amagai et al. 2004 [22]
Kiryat Yovel Community Health Study	Israel	≥50	Population-based study of residents of a West Jerusalem community	1985–7	9–11	1842	Burazeri et al. 2003 [23]
Survey of Health and Living Status of the Elderly in Taiwan	Taiwan	≥64	Probability sample of the elderly population of Taiwan	1993	10	3079	Lan et al. 2007 [34]

(*continued on next page*)

Table 1 (*continued*)

Cohort name	Country	Age range (yrs)	Study population	Year(s) sleep data collected	Follow-up (yrs)	Cohort size (n)	Reference
Survey sleep measure: not clearly specified*							
Chin-Shan Community Cardiovascular Cohort Study	Taiwan	≥35	Ethnic Chinese residents of Chin-Shan township	1990–1	Median = 15.9	3430	Chien et al. 2010 [7]
Health and Lifestyle Survey	UK	≥18	Representative sample of the British noninstitutionalized population	1984–5	7	6096	Huppert and Whittington 1995 [13]
Human Population Laboratory (Alameda County study)	USA	<45–75+	Probability sample of noninstitutionalized adult residents of Alameda County, California	1965	5.5	6928	Belloc 1973† [15]
		30–69		1965	9	4713	Wingard and Berkman 1983† [17]
		<45–75+		1965	9.5	6928	Breslow and Enstrom 1980† [16]
		38–94		1965	17	4174	Kaplan et al. 1987‡ [18]
Nottingham Longitudinal Study of Activity and Ageing	UK	>65	Randomly selected older community residents	1985	5	1042	Rumble and Morgan 1992 [28]
Polysomnography [27,36] and wrist actigraphy [4]*							
NIH-funded protocols	USA	≥50	Healthy elders who underwent polysomnography at University of Pittsburgh's sleep center	1981–1997	4.1–19.5	184	Dew et al. 2003 [27]
Penn State Cohort	USA	≥20	Probability sample of adults from central Pennsylvania	NR	14 (males); 10 (females)	1741	Vgontzas et al. 2010 [36]
Women's Health Initiative Observational Study	USA	50–81	Subsample from WHI San Diego site structured to over-represent women reporting sleep durations of ≤6 or ≥8 h	1995–9	Mean = 10.5	444	Kripke et al. 2011 [4]

NR = not reported.
* Sleep measure types are described in detail in the "Sleep measurement" component of the Results section.
† Study included for completeness, but not included in the results table (Table 2) given multiple publications on the same study population.
‡ Study relied upon in results table (Table 2) given multiple publications on same study population.

bed from the actigraphy—rather than total minutes coded as actual sleep—did not increase the correlation.

An ancillary study to CARDIA compared 3 nights of actigraph sleep duration (average 6 hours) with self-reported measures in a middle-aged population [55]. The correlation between the average actigraph and self-reported sleep was 0.47, with self-reported sleep averaging 48 minutes longer, similar to the Women's Health Initiative [4]. Persons with mortality risk factors (fair/poor self-rated health, obese, or more depressive symptoms) systematically reported shorter sleep at the same level of measured sleep, implying that reporting bias could generate associations between shorter reported sleep and mortality even were there no association for actigraph-estimated sleep.

These studies consistently find that sleep estimated from polysomnography or actigraphy is shorter than self-reported sleep. This does not just represent different calibration because the correlation is only low to moderate. As with any imperfect measure, a correlation depressed by random noise is less concerning than systematic bias. Studies examining whether demographic or health factors alter associations between measured and self-reported sleep find that they do, suggesting there may be systemic biases.

Correlates of self-reported sleep duration

Systematic and strong associations between sociodemographic and/or health-related factors and reported sleep duration could theoretically explain some of the reported associations between sleep duration and mortality. Therefore, in the next section we identify correlates of self-reported sleep and consider the implications of these correlations for our understanding of the relationship between sleep and mortality.

Demographic correlates

Men typically report longer sleep than do women [56]. Older individuals are more likely to report either short or long sleep compared with younger individuals [57]. Compared with Whites, Hispanics are more likely to report short sleep [58] and Blacks are more likely to report both short and long sleep [57–59]. Reporting short or long sleep is also associated with low socioeconomic status [57,60,61], and with working long hours [57,62].

Social correlates

Sleep is often shared between partners and is likely shaped by household and partnership characteristics. Unmarried individuals are more likely to report shorter sleep [63] or shorter and longer sleep [57,64]. Co-sleeping is associated with shorter self-reported sleep duration [65]. Differences in objective sleep duration based on marital status have not been reported, although there are indications of differences in sleep quality and continuity [66]. Finally, living in the inner city and perceived neighborhood disorder also influence individuals' self-reported sleep properties [58,67,68]. These household- and neighborhood-level characteristics are also linked to health outcomes, including mortality risk (e.g., [69–73]).

Health correlates

Longer self-reported sleep has been associated with increased total cholesterol and a higher total/high-density lipoprotein cholesterol ratio among the elderly [74], greater carotid intimal medial thickness [75], recent treatment for cancer [62], having had a heart attack or angina [62], poorer cognitive function [76], having a history of depression [60], and using antidepressants [60]. Shorter self-reported sleep has been reported as associated with obesity [77–81], the metabolic syndrome [82,83], diabetes [81], hypertension [84], cortisol secretion [85], poor general health [63], and having more medical conditions [86,87]. Shorter self-reported sleep

Table 2
Results of studies of sleep duration and all-cause mortality, arranged first by sleep measure and then alphabetically by cohort name

Cohort name (country)	Age range (yrs)	Follow-up (yrs)	Cohort size (n)	Percent male	Findings for specific sleep categories	Significant elevation in mortality risk reported*			
						Short sleep effect only	Long sleep effect only	Short and long sleep effect (U-shaped)	No sleep effect
Survey sleep measure: nighttime sleep									
American Cancer Society (USA) [5]	30–≥95	6	823,065	44%	<4, 4, 5, 6, 7,† 8, 9, ≥10			Males‡ Females‡	
Cancer Prevention Study II (USA) [3]	30–102	6	1,116,936	43%	3^{f}, 4^{mf}, 5^{mf}, 6^{mf}, 7,† 8^{mf}, 9^{mf}, $\geq 10^{mf}$			Males Females	
Dalarna County postal survey (Sweden) [8]	45–65	12	1870	48%	<6, 6–8,† $>8^{m}$		Males		Females
Elderly cohort (USA) [10]	65–98	3.5	1855	34%	<5, 5, 6, 7, 8, ≥9				Males Females
FINRISK Surveys (Finland) [11]	25–64	35	23,290	49%	$\leq 5^{mf}$, 6^{f}, 7–8,† 9^{f}, $\geq 10^{mf}$			Males Females	
Japan Collaborative Cohort Study for Evaluation of Cancer (Japan) [21]	40–79	Median = 14.3	98,634	42%	$\leq 4^{mf}$, 5, 6, 7,† 8^{f}, 9^{mf}, $\geq 10^{mf}$			Males Females	
Massachusetts Health Care Panel Study (USA) [24]	66–98	5	1235	38%	1–6 or ≥9h vs. 7–8†				Males Females
Miyagi Prefecture survey (Japan) [25]	≥40	4	4318	40%	7–8 vs. ≤6† or ≥9†				Combined genders
National Health and Nutrition Examination Survey I (USA) [26]	32–86	8–10	9789	37%	≤5, 6, 7,† 8*, ≥9*		Combined genders		
Rancho Bernardo Study (USA) [98]	60–96	19	2001	44%	<6, 6, 7, 8, $\geq 9^{f}$		Females		Males
Whitehall II Cohort (UK) [35]	35–55	Mean = 17.1	10,308	67%	≤5, 6, 7,† 8, ≥9				Combined genders
Survey sleep measure: 24-hour sleep									
Chinese Longitudinal Healthy Longevity Survey (CLHLS) (China) [97]	65–≥100	3	12,671	43%	$\leq 5^{m}$, 6, 7, 8,† 9, $\geq 10^{m}$			Males	Females
Finnish Twin Cohort (Finland) [1]	24–101	21	21,268	48%	$<7^{mf}$, 7–8,† $>8^{mf}$			Males Females	
Health Interview Study of Barcelona (HISB) (Spain) [14]	≥65	5	1219	38%	<7, 7–9,† >9				Males Females
National Health Interview Survey (NHIS) (USA) [115]	≥18	16	38,891		≤6, 7–8, ≥9			Combined genders	
Nurses' Health Study (USA) [29]	40–65	14	82,969	0%	≤5, 6, 7,† 8^{f}, $\geq 9^{f}$		Females		
Ohsaki Cohort Study (Japan) [116]	40–79	Mean = 10.8	49,256	48%	≤6, 7,† 8*, 9*, ≥10*		Combined genders		
Scottish working cohort (Scotland) [30]	<60 females; <65 for males	25	6797	86%	<7, 7–8,† >8				Males Females
Shizuoka Study (Japan) [31]	65–85	6	11,395	51%	≤5, 6, 7,† 8^{m}, 9^{m}, $\geq 10^{mf}$		Males Females		
Spanish cohort (Spain) [32]	≥60	Mean = 6.8	3820	44%	$\leq 6^{f}$, 7,† 8^{m}, 9^{m}, $\geq 10^{mf}$		Males	Females	
Study of Osteoporotic Fractures (USA) [33]	≥69	Mean = 6.9	8101	0%	<6, 6–7, 8,† 9^{f}, $\geq 10^{f}$		Females		
Survey sleep measure: bedtime and waking time									
Bambui Health and Ageing Study (Brazil) [6]	≥60	23	1512	39%	<6, 6, 7,† 8, ≥9*		Combined genders		
Cross-Sectional and Longitudinal Aging Study (Israel) [99]	75–94	20	1166	55%	<7, 7–9,† >9*		Combined genders		
Department of Health and Social Security Survey (UK) [9]	≥65	10	862	51%§	≤7, 8, 9,† 10, 11, ≥12*		Combined genders		
Gifu Prefecture cohort study (Japan) [12]	20–67	Mean = 11.9	5322	46%	$<7^{m}$, 7–8,† 9, ≥10	Males			Females
Jichi Medical School Cohort Study (Japan) [22]	19–93	Mean = 8.2	11,325	39%	$<6^{m}$; 6; 7†; 8†; ≥9	Males			Females
Kiryat Yovel Community Health Study (Israel) [23]	≥50	9–11	1842	46%	<6,† 6–8, >8				Males‖ Females‖
Survey of Health and Living Status of the Elderly in Taiwan (Taiwan) [34]	≥64	10	3079	57%	<7, 7,† 8^{f}, 9^{f}, $\geq 10^{mf}$		Males Females		
Survey sleep measure: not clearly specified									
Chin-Shan Community Cardiovascular Cohort Study (Taiwan) [7]	≥35	Median = 15.9	3430	56%	≤5; 6, 7,† 8, ≥9*		Combined genders		
Health and Lifestyle Survey (UK) [13]	≥18	7	6096	44%	<6, 6–8,† ≥9		Males‡		Females
Human Population Laboratory (Alameda County study) (USA) [18]	38–94	17	1454	NR	<7 or >8 vs. 7–8†				Combined genders¶

(*continued on next page*)

Table 2 (*continued*)

Cohort name (country)	Age range (yrs)	Follow-up (yrs)	Cohort size (n)	Percent male	Findings for specific sleep categories	Significant elevation in mortality risk reported*			
						Short sleep effect only	Long sleep effect only	Short and long sleep effect (U-shaped)	No sleep effect
Nottingham Longitudinal Study of Activity and Ageing (UK) [28]	≥65	5	1042	NR	<4, 4–9,† ≥10				Combined genders
Polysomnography [36] and wrist actigraphy [4]									
NIH-funded protocols (USA) [27]	58.7–91.4	Mean = 12.8	184	46%	<6, ≥6†				Combined genders
Penn State Cohort Study (USA) [36]	≥20	14 (men); 10 (women)	1741	42%	<6, ≥6†				Males Females
Women's Health Initiative Observational Study (USA) [4]	50–81	Mean = 10.5	444	0%	<5f, 5–6.5,† >6.5f			Females	

NR = not reported.
Results from the most fully adjusted models from each study are presented.
"Combined genders" denotes results from studies adjusting for gender.
"Males" and "Females" indicate gender-specific results.
m and f indicate a statistically significant elevation in mortality risk associated with a particular sleep category among males and females, respectively, in gender-specific analyses.
* Results were considered statistically significant on the basis of either stated P values ($P < .05$) or 95% confidence intervals.
† Reference category.
‡ Significance tests not reported for specific sleep categories; overall sleep effect inferred from text.
§ Personal communication, C. Gale, University of Southampton, 2012.
‖ Burazeri et al. [23] used the short sleeping category as the reference category and reported a significant difference for males between the longest sleepers (>8 h) and the shortest sleepers (<6 h). However, the confidence intervals for the effect estimates for the long and short sleepers relative to the average sleepers (6–8 h) all overlapped substantially, strongly suggesting that if the middle group had been the reference, no significant effect of either long or short sleep would have been found.
¶ Kaplan et al. [18] did observe a significant elevation in mortality risk for 50- to 59-year-olds, but no significant increases in risk for those 38–49, 60–69, or ≥70 years of age.

has also been associated with reduced cognitive function [56], unhappiness, symptoms of depression [56,88], and more suicidal ideation and attempts [89].

Other studies have documented an increased odds of reporting either shorter sleep or longer sleep in association with obesity [57], diabetes [57,90], hypertension [57], cardiovascular disease [57,90,91], metabolic syndrome [92], physical illness [61], activity limitations [57], poorer self-rated health [93], poorer objective and subjective cognitive functioning [94], depression [57], other psychiatric conditions [61,86], and with deleterious health behaviors including smoking, alcohol consumption, and low levels of physical activity [57].

Implications of correlates with self-reported sleep duration

Nearly all of the demographic, social, and health-related factors identified as being correlated with self-reported sleep are also known to be associated with mortality risk (e.g., [69,70,95,96]), suggesting that associations observed between self-reported sleep duration and mortality risk need to be interpreted with care. Demographic and social factors logically lie upstream of sleep duration, whereas health factors may lie upstream or downstream from self-reported sleep duration. Ambiguities about where in the causal pathway the health conditions lie make it impossible, given the present state of knowledge, to distinguish confounders and mediators.

Differences in sleep length by sociodemographic factors or by health conditions could reflect true differences, differential reporting, or a combination of the two. Regardless, failure to adjust fully for these factors when testing for effects of short or long sleep on mortality (unless they are mediators) would result in residual confounding and an incorrect inference with regard to the independent effect of sleep on mortality risk.

Review of studies of sleep duration and mortality

We identified 42 prospective studies of sleep duration and mortality drawing on 35 distinct study populations across the globe (Table 1). Sample sizes ranged from 184 [27] to over 1 million individuals [2,3]; the interquartile range was from 1512 to 12,671. Follow-up times ranged from 3 years in the Chinese Longitudinal Healthy Longevity Survey [97] to 35 years in a Finnish population-based study [11]. Three studies employed polysomnography or actigraphy [4,27,36]; the remainder relied on self-reported sleep duration. A number of studies reported gender-specific results and thus the number of findings in Table 2 (n = 55) exceeds the number of distinct study populations (n = 35).

With the exception of individual reports of decreased mortality risk in association with long sleep in Scottish men [30] and with short sleep in older Chinese women [97], there are four types of findings that have been reported in these studies: (1) That only short sleep is associated with increased mortality, (2) that only long sleep is associated with increased mortality, (3) that both long *and* short sleep duration are associated with increased mortality (the "U-shaped effect"), and (4) that sleep duration is not associated with increased mortality. Findings have not been consistent (Table 2). Among 55 findings, two support an association of increased mortality risk with short sleep only (both in populations of young to middle-aged Japanese men) [12,22], 16 support an association with long sleep only, 14 support a U-shaped effect, and 23 support no association.

Even among studies reporting significant associations, effect measures have been modest. Higher values, such as the hazard ratio of 2.4 reported by Amagai et al. [22] for males sleeping fewer than 6 hours, were rare. The largest study—the Cancer Prevention Study II [3]—reported significant effect sizes ranging from a hazard ratio of 1.07 for women who reported sleeping 5 hours per night to a maximum hazard ratio of 1.41 for women who reported sleeping 10 or more hours per night. This study controlled for many demographic, behavioral, and medical risk factors and the authors suggest that most of the mortality risk observed in association with short sleep could be explained by comorbidities [3].

The variability among study findings is striking given that recent reviews have concluded that both short and long sleep are consistently associated with increased mortality risk [37–40]. Below we explore some possible explanations for heterogeneity among study findings.

Gender effects

Interestingly, a number of studies report divergent effects for males and females (Table 2) [8,12,13,22,32,97,98]; however, the distribution across study finding types is very similar for the two genders. There seems to be no consistent difference between males and females with regard to the pattern of sleep duration effects on mortality.

Measurement effects

Given the potential problems with survey sleep measures, it is relevant to first examine the results of the studies employing physiologically estimated sleep duration measures. A study employing actigraphy among women 50 to 81 years of age (n = 444) concluded that the relationship between sleep duration and mortality was U-shaped [4]. Although the study population was specifically sampled to over-represent short and long sleepers, the longest average actigraphic sleep time was 8.37 hours. Although mortality was greater for both the short sleepers and long sleepers when sleep categories were collapsed into three groups (<5, 5–6.5 [referent], and >6.5 hours), death rates by more detailed sleep categories do not show a dose response for either side of the duration distribution. The top and bottom categories (<4.5 or >7.5 hours) have relatively low mortality, albeit with small numbers, and the highest mortality risk was observed in women sleeping either 4.5–5 hours or—interestingly—between 7 and 7.5 hours.

Neither of the two studies employing polysomnography reported significant associations between sleep duration and mortality [27,36]. In both studies, sleep duration was dichotomized at fewer than 6 and 6 or more hours, precluding the possibility of finding a U-shaped effect. As in the study employing actigraphy, Dew et al. [27] observed that no subjects had recorded sleep times greater than 8.3 hours.

One interesting pattern among studies using survey sleep measures is that all of the studies reporting U-shaped associations measured sleep duration with questions about typical nighttime sleep or 24-hour sleep (Table 2). None of the studies that asked about usual bedtimes and waking times reported a U-shaped association; rather, they reported either no association [12,22,23] or only a long sleep association [6,9,34,99], or, in the case of two studies of young to middle-aged Japanese men, only a short sleep association [12,22]. That the U-shaped associations are exclusively found in studies asking about usual sleep duration may be informative and suggests the possibility of systematic response biases, with people in generally good health more likely to give a “normative” response (i.e., 7 or 8 hours) and those in worse health more likely to give a “non-normative” (shorter or longer duration) response.

In three studies [1,30,35], sleep duration data were collected twice, several years apart. In one of these studies, there was a significant U-shaped sleep duration effect when using the more recent sleep data, but no significant sleep duration effect with longer follow-up [35]. In two studies, moving to either shorter or longer sleep (from average sleep) was associated with increased mortality [1,35]; however, no such effect was observed in the third [30]. Change in reported sleep may also reflect an underlying health process.

Table 2 shows how sleep duration was categorized, including the reference category (where specified). The number of analytic sleep categories varied from two to eight. The rationale for any particular categorization scheme was rarely stated, and almost no studies report sensitivity analyses with alternate cut-points. Short sleep was typically defined as less than 6 or less than 7 hours per night, although lower values were also represented. Long sleep was variously defined as more than 8, 9, or 10 hours. The reference category was most often 7 hours, but was sometimes 7 to 8 and occasionally 6 to 8 or 7 to 9 hours. In two instances, short and long sleepers were combined and compared with the reference group with a single statistical test [18,24]. As noted, in the two polysomnography studies, short sleepers (<6 hours) were compared with all others [27,36]. In the remaining studies, however, separate statistical tests were carried out for each sleep category relative to the reference category. Plausibly, these coding and analytic differences could help to explain the diverse results. For example, two studies published 2 years apart from the same cohort yielded different findings: Increased mortality for long sleep only when using three categories [20] and increased mortality for both long and short sleep when using seven categories [21].

One possibility is that those studies with null findings were underpowered, given the modest effect sizes expected. However, the study populations of studies reporting null effects were not anomalously small, the duration of follow-up was similar to those studies reporting significant effects, and the effect sizes that they reported were not consistently above 1. Thus, it is unlikely that the null findings were uniformly owing to lack of power.

Adjustment effects

Studies varied in the number of sociodemographic and health-related factors that they adjusted for. Some study investigators suggest (e.g., [29]) that including health conditions like diabetes and hypertension—which themselves may be on the causal pathway between sleep duration and mortality risk—would result in overadjustment. The judgment about whether some of these health conditions lie upstream or downstream from sleep duration (or are simply confounders) will influence the interpretation of these adjusted models. It is certainly the case, however, that divergent results among studies could be in part owing to the inclusion of different sets of control variables.

Discussion

Sleep is complex. Different ways of measuring it yield different results and elucidating the role it plays in our health is similarly challenging. One of the classic criteria for inferring causality from a body of observational studies is consistency [100], and, as shown here, findings are not consistent for the association between sleep duration and mortality.

Although a substantial fraction of the findings support the possibility that at least long self-reported sleep duration may be associated with increased mortality, we do not know whether long sleep duration is itself a causal factor for mortality, a marker of illness [26,101], or a product of response bias driven by other mortality risk factors. Studies with objective sleep measurement have found that there are very few individuals with measured sleep longer than 8.5 hours [4,27,48], emphasizing an essential difference between sleep as estimated by physiologic measures and sleep duration as reported with survey questions. It is possible that the two types of measures capture different aspects of the sleep experience.

To date, the literature has focused on perceived sleep but perceived sleep is likely influenced by a complex combination of true sleep duration, some of the psychosocial and health-related factors identified earlier, and, very possibly, other, yet-to-be identified factors. Although actigraphy may be the most suitable measurement modality for sleep duration at present, it may be prohibitively expensive for use on a large scale. If survey measures must be used, we suspect that less biased data might result from querying usual bedtime and waking time before asking about duration, to help walk respondents through the steps of calculating an answer, or using prospective sleep log data collection, which was not employed in any of these studies.

Additional sleep phenotypes of importance include sleep quality and timing and the presence or absence of sleep apnea; these are often not considered in studies focused on sleep duration. Indeed, the diverse results across studies of sleep duration and mortality may point to a very complicated relationship between the two, one that may be modified by demographic, social, and health-related factors, as well, possibly, as by these other key sleep phenotypes. It is also essential to consider that using a single measurement over the life course, as is typically done, is clearly suboptimal for describing this complex, and likely dynamic, exposure.

Prior reviews of this topic have outlined possible mechanisms linking sleep duration with increased mortality risk. Typically, short sleep duration is thought to increase mortality risk through adverse endocrinologic, immunologic, or metabolic effects [102–105], through the induction of chronic, low-grade inflammation [106–109] (but see [110]), or via increases in cortisol secretion or altered growth hormone metabolism [85,111]. However, although the pathway outlined from the metabolic changes or pro-inflammatory changes observed in the experimental setting to mortality risk is via increased cardiovascular disease risk, a recent meta-analysis reported no significant increase in cardiovascular-related mortality [40].

Biologic mechanisms proposed for the association between long sleep and mortality risk include increased sleep fragmentation, fatigue, changes in immune function, photoperiodic abnormalities, lack of physiologic challenge, depression, or underlying disease processes [37]. As suggested by others [101], it is critical to distinguish between those mechanisms that may mediate the relationship between sleep duration and mortality and those that would confound the relationship as the two alternative explanations have very different implications.

Reverse causation—that is, that individuals with health conditions putting them at increased risk of mortality have either lengthened or shortened sleep—is an additional compelling alternative explanation for observed associations between sleep duration and mortality [101]. Past reviews have discounted this possibility given that a number of studies controlled for participants' health conditions. However, a complete accounting of health status—particularly the determination of underlying but as yet undetected disease—would be virtually impossible.

Our conclusions differ from those of two recent meta-analyses that report consistent increases in mortality risk among short and long sleepers, with an approximately 10% increase in mortality risk among short sleepers and a 20% to 30% increase in mortality risk among long sleepers [39,40]. Our review includes a substantially larger number of studies than either of those meta-analyses and includes the studies employing objective sleep duration measures, two of which were published in the intervening years. Although a summary estimate of the relationship between sleep duration and mortality risk is compelling, meta-analysis of these studies is challenging because of the substantial variability across the original studies with regard to the actual sleep duration question(s) used, which reference sleep category was employed, how long and short sleep were categorized, the level of confounder adjustment, the age range of study subjects, and the length of follow-up.

Integrating across studies employing different definitions of long and short sleep seems particularly problematic with regard to interpreting the final results. In one meta-analysis [39], short sleep definitions from the studies included were 4 or fewer, 5 or fewer, 6 or fewer, and fewer than 7 hours per night and long sleep definitions were more than 8, 9 or more, 10 or more, and 12 or more hours. The reference category was variously defined as 7 , 7 to 8 , 7 to 9 , 6 to 8, or 9 hours. Although in some of the original studies there was only one short or long sleep category, in others results for multiple categories above and/or below the reference category were presented and no decision rule was stated for which category would be chosen for the meta-analysis. In these cases, it seems that most of the time, the shortest of the "short sleep" categories and the longest of the "long sleep" categories were used in the meta-analysis [9,21,22,26,29,33–35]. However, in some cases a different category was employed (i.e., the middle of the short/long sleep categories or the shortest of the long sleep categories) [3,12,22]. In the other meta-analysis [40], results from multiple short or long sleep categories were pooled to comprise a single short or long sleep group, although how that pooling was undertaken was not specified. Reference groups were also somewhat diverse (i.e., 7–7.9, 7–8, 6–8, 6–7.9, 7–8.9, 9–9.9) in this meta-analysis [40]. In neither meta-analysis was the type of sleep question used explored as a source of heterogeneity.

An additional issue to be considered with meta-analysis is the statistical method used to integrate the original estimates. One of the meta-analyses detected significant heterogeneity between the studies [39] whereas the other did not [40]. Both meta-analyses employed the DerSimonian and Laird random-effect model [112,113]; this method, however, has been shown to underestimate heterogeneity across studies, which in turn can lead to overall effect estimates biased away from the null [114].

In conclusion, the substantial number of negative findings in the literature and our observation that only one quarter of the findings reported a significant U-shaped association between sleep duration and mortality risk would make us question the conclusions of recent reviews that sleep duration is consistently associated with mortality in a U-shaped fashion [37–40]. We would instead suggest that there is not a clear consensus on this association and that careful attention must be paid to measurement bias, confounding, and reverse causation in the interpretation of associations between sleep duration and mortality. Because sleep research is of great interest to the public, researchers should be careful not to overstate the support for these associations because they are so simply—and often—translated into advice.

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