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The economic cost of inadequate sleep FREE

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Abstract

Study Objectives

To estimate the economic cost (financial and nonfinancial) of inadequate sleep in Australia for the 2016–2017 financial year and relate this to likely costs in similar economies.

Methods

Analysis was undertaken using prevalence, financial, and nonfinancial cost data derived from national surveys and databases. Costs considered included the following: (1) financial costs associated with health care, informal care provided outside healthcare sector, productivity losses, nonmedical work and vehicle accident costs, deadweight loss through inefficiencies relating to lost taxation revenue and welfare payments; and (2) nonfinancial costs of loss of well-being. They were expressed in US dollars ($).

Results

The estimated overall cost of inadequate sleep in Australia in 2016–2017 (population: 24.8 million) was $45.21 billion. The financial cost component was $17.88 billion, comprised of as follows: direct health costs of $160 million for sleep disorders and $1.08 billion for associated conditions; productivity losses of $12.19 billion ($5.22 billion reduced employment, $0.61 billion premature death, $1.73 billion absenteeism, and $4.63 billion presenteeism); nonmedical accident costs of $2.48 billion; informal care costs of $0.41 billion; and deadweight loss of $1.56 billion. The nonfinancial cost of reduced well-being was $27.33 billion.

Conclusions

The financial and nonfinancial costs associated with inadequate sleep are substantial. The estimated total financial cost of $17.88 billion

substantial investment in preventive health measures to address the issue through education and regulation.

inadequate sleep, sleep disorders, sleep deprivation, medical economics, public health

Statement of Significance

Inadequate sleep is a substantial public health problem regularly affecting more than one in three adults. Although partly related to clinical sleep disorders and other health complaints, much appears to due to work or lifestyle-related sleep restriction. Health, well-being, productivity, and safety suffer. Besides their human cost, these consequences have an economic cost which the present study demonstrates is very substantial. The importance of such an analysis is that political and administrative decisions are largely based on economic data. As there is strong competition for health and preventive health funds, sleep health advocates must establish how inadequate sleep ranks alongside other health and social problems in terms of societal and financial cost and associated communal illness and injury burden.

Introduction

Sleep is under unprecedented challenge as technological advances increase the pressures on it and the temptations to truncate it in an effort to create more time for wakeful work, social, and family activities [1]. Developments in communication technologies within and across time zones, web-based information, and entertainment platforms and social media have each played a role in this. Furthermore, there is evidence of increasing prevalence of common sleep disorders such as insomnia and obstructive sleep apnea (OSA), in part due to the pressures, sedentariness, and other lifestyle changes that accompany these modern pursuits [2, 3].

Community sleep surveys suggest that the prevalence of inadequate sleep is

6]. Recent surveys suggest that this proportion is increasing with between 33 and 45 per cent of Australian adults now having this complaint, depending on the measure employed [7]. The growth of the problem over time appears to be shared by other nations with similar demographics [1, 2, 8].

Sleep is an active process that is essential for recuperation, memory consolidation, emotional modulation, performance, and learning [9, 10]. Sleep loss impairs cognition, psychomotor function, and mood [11]. These effects have been well described in the medical workforce where it is associated with as follows: lapses in attention and inability to stay focused; reduced motivation; compromised problem solving; confusion, irritability, and memory lapses; impaired communication; slowed or faulty information processing and judgment; diminished reaction times; and indifference and loss of empathy [12]. Furthermore, short sleep has an adverse effect on physical health with small but measurable increases in risk of heart attacks, stroke, hypertension, obesity, diabetes, depression, and mortality [13–19]. Experimentally, even brief periods of sleep restriction can impair intellectual performance, psychomotor vigilance, memory, and mood and increase insulin resistance and inflammatory markers [11, 20]. These physical and psychological changes adversely affect health, mood, safety, and productivity both in the workplace and beyond it with costs in terms of health and well-being.

Inadequate sleep also has an economic cost relating to its effect on health, safety, and productivity. This has been previously demonstrated for sleep disorders [21]. Estimates have also been made of the costs of lost productivity associated with short sleep duration and poor sleep patterns [22, 23]. A broad examination of the economic costs (health and safety aspects, as well as productivity implications) of inadequate sleep from all its sources is now warranted. The value in estimating these costs is to determine whether they are sufficient to justify current or increased levels of expenditure on the problem. Although human costs may be well appreciated, political and administrative decisions are largely based on economic data. As there is strong competition for available funds, it is important for sleep health advocates to establish how the problem of inadequate sleep might rank against other health and social problems in terms of societal and financial cost and associated communal illness and injury burden.

The purpose of this study was to undertake such an economic evaluation in Australia for the 2016–2017 financial year estimating the financial cost associated with inadequate sleep as well as its nonfinancial cost, which

A targeted literature search was conducted to establish the prevalence of inadequate sleep in its various forms and of the economic impacts associated with them for the 2016–2017 financial year. Australian sources were sought to provide total costs of the following economic impacts: (1) the financial (monetary) costs associated with health care of relevant sleep disorders or of other health conditions associated with inadequate sleep, productivity losses, informal care provided by family or others outside the formal care sector, nonmedical aspects of work and vehicle-related accidents, and the deadweight loss to the economy due to inefficiencies associated with welfare payments and forgone taxation revenue; and (2) the nonfinancial (nonmonetary) costs associated with loss of life quality.

The proportion of the total economic costs of other health and accident outcomes associated with inadequate sleep were determined from the respective prevalences of the sleep problem and the outcome and the odds ratio linking them, using the population attributable fraction (PAF) methodology (see Appendix) [24].

Prevalences of the various sources of inadequate sleep

The prevalences of symptoms associated with inadequate sleep, including those of sleep disorders and excessive daytime sleepiness (EDS), were largely obtained from a recent national sleep survey of the sleep health of Australian adults [7]. Other data sources were used to supplement this sleep survey [4–6, 25]. Inadequate sleep was defined as difficulties with sleep initiation, maintenance, or quality associated with the presence of impaired daytime alertness on several days a week or more. The survey enquired about the various potential sources of inadequate sleep, including sleep disorders [7]. Amongst the questions asked, characteristics of the following sleep disorders were sought: (1) OSA, which was judged to be present if previously diagnosed by overnight sleep study or if the respondent reported witnessed breathing pauses at least three times a week or witnessed breathing pauses a few times per month with loud snoring at least three times a week; (2) insomnia, the presence of which was judged using International Classification of Sleep Disorders (3rd edition) criteria of report of sleep initiation or maintenance problems, accompanied by daytime consequences (daytime sleepiness/fatigue or exhaustion/irritable or moody), at least three times a week despite adequate opportunity and circumstances for sleep; and (3) restless legs 3 nights a week or more [7]. The prevalence estimates from this survey were used in the present analysis, modified where specified using other data from sources with similar demographics.

inadequate sleep were partitioned into three mutually exclusive categories to facilitate analysis: (1) EDS associated with clinical sleep disorders (EDS-SD); (2) EDS from other sources apart from clinical sleep disorders (EDS-Other); and (3) regular (daily or near daily) subjective insufficient sleep where Epworth Sleepiness Score (ESS) is ≤10 (Insufficient Sleep).

The presence of EDS was determined from the ESS using a score of >10 to define its presence [7]. The ESS is the most commonly used measure of sleepiness in sleep research and clinical settings [26]. It has been widely used in analysis and decision making for sleep disorder interventions [27–29] and has been shown to be a suitable instrument for economic evaluation of the effects of daytime sleepiness [30].

The proportion of those with "EDS-SD" was estimated using the PAF methodology provided in the Appendix [24]. The odds ratio required for this estimation (the ratio of the proportion of those with EDS plus a sleep disorder vs. EDS but no sleep disorder [26 vs. 17 per cent, unadjusted odds ratio 1.7]) was derived from data provided by Adams from his study (personal communication) [7]. In estimating EDS-SD, it was recognised that the risk of EDS varies between sleep disorders and that other sleep disorders besides the major three are associated with EDS. Although having no effect on the overall proportion identified as having EDS, these factors have the potential to affect the partitioning of those with EDS into the EDS-SD or EDS-Other categories. Nonetheless, the low prevalence of these additional sleep problems limits their economic impact.

In people with EDS-SD, their EDS was assumed to be related to the disorder. Their inadequate sleep may also be associated with secondary health conditions such as depression and obesity. As these secondary health conditions may be related to lack of sleep, a proportion of their costs are included in the costs of inadequate sleep.

Having calculated the proportion of those with EDS-SD, the balance of participants with EDS was assigned to "EDS-Other." A substantial number of conditions are associated with EDS apart from clinical sleep disorders, including poor sleep behaviors, jet lag, environmental sleep disturbances, and a variety of neurological, psychiatric, and other organic diseases and various medications [31]. Where a person has EDS-Other, the presumption is that the EDS results from the secondary condition, rather than vice versa. That said, there are some secondary conditions that have been shown to be the result of EDS—mostly injuries, but also some depression and stroke. These are also included in the costs of inadequate sleep.

this report, subjective insufficient sleep that does not result in EDS appears to be mostly attributable to behavioral factors.

Although those with sleep disorders with subjective sleepiness but not EDS were included in the Insufficient Sleep category, those with sleep disorders but no EDS or subjective sleepiness were excluded from the analysis.

Estimating proportion of total costs of secondary outcomes attributable to inadequate sleep

Prevalence of secondary outcomes associated with the various sources of inadequate sleep and the odds ratios linking them was estimated from published sources. The proportion of the secondary outcome attributable to the inadequate sleep variant was then estimated from their respective prevalence and their linking odds ratios, using the PAF methodology specified in the Appendix. Table 1 provides these estimates along with the sources for their derivation. Note that although all the outcomes specified are linked to types of EDS-SD (OSA, insomnia, restless legs syndrome), a more limited array is linked to EDS-Other and a still more limited array to Insufficient Sleep, reflecting the absence of data to substantiate other associations. For example, apart from some motor vehicle accidents and workplace injuries (and its productivity impacts), insufficient sleep without EDS was assumed not to be associated with other comorbid health conditions. The PAFs specified in Table 1 were then used in combination with the respective total costs of the outcome to derive the fractional cost of the outcome that was attributable to inadequate sleep.

Table 1. Linkages between various categories of inadequate sleep and associated conditions

		EDS-SD			EDS-Other		Insufficier Sleep	
Condition	**Prevalence or Annual Rate (%)**	**Type of EDS-SD**	**Odds ratio**	**PAF (%)**	**Odds ratio**	**PAF (%)**	**Odds ratio**	**P/ (%**
Congestive heart failure	1.9 [70]	OSA	1.6 [71]	1.5	—		—	
Coronary artery disease	4.9 [70]	OSA	3.2 [72]	4.8	—		—	
Cerebrovascular	1.6 [73]	OSA	2.9	4.8	1.4	5.0	—	

Depression	6.2 [77]	OSA	2.6 [78]	3.6	1.87 [79]	9.4	—	
		Insomnia	2.1 [80]	2.4				
		RLS	1.9 [81]	0.5				
Workplace injury	1.4 [43]	OSA	1.5 [82]	1.3	2.2 [83]	13.7	1.4 [84]	5.
		Insomnia	2.4 [85]	3.3				
Motor vehicle accident	1.3 [43]	OSA	2.5 [86]	3.8	1.9 [87]	10.3	1.5 [88]	11

EDS = Excessive daytime sleepiness; SD = sleep disorders; PAF = population attributable fraction; OSA = obstructive sleep apnea; RLS = restless legs syndrome.

Data sources for prevalence and odds ratios are indicated in the table.

Financial costs of inadequate sleep and its secondary outcomes

The financial costs considered were partitioned into those pertaining to health care, informal care, nonmedical costs of workplace and motor vehicle accidents, productivity losses, and deadweight loss from inefficiencies associated with forgone taxation revenue and welfare payments.

Health system costs

The health system costs considered were both those directly associated with sleep disorders and those associated with conditions attributable to inadequate sleep including the following: workplace injuries and motor vehicle accidents (for all forms of inadequate sleep [EDS-SD, EDS-Other, and Insufficient Sleep]); stroke and depression (for EDS-SD and EDS-Other); and heart disease and diabetes (for EDS-SD alone). The proportions of these related conditions and their associated costs that were attributable to an underlying sleep problem were calculated using the PAF methodology referred to in Appendix. The estimates were limited by availability of data that adequately substantiates the linkages. For example, although there are adequate data to attribute a fraction of coronary artery disease to the OSA

The health costs accounted for included all expenditure in the Australian health system for the care of sleep disorders and for the care of other inadequate sleep-associated health problems, including costs of hospital care, health practitioners, pharmaceuticals, diagnostic tests, health aids and appliances, aged care, research, community and public health, and capital and administration. These data were derived from the latest available Australian Institute of Health and Welfare data adjusted where appropriate to 2016–2017 values using the health price index [32–41].

Informal care costs

Costs were estimated for time spent by carers in providing assistance and support to people with inadequate sleep-related health problems outside the formal healthcare sector. This time could be used for work activities or as leisure time. Thus, although the time is given free of charge, it has associated opportunity costs due to a loss of economic resources.

The cost calculation assumed there would be no care requirements due to inadequate sleep itself, only to conditions attributed to inadequate sleep that increased personal, household, and other care needs. The distribution of these attributed conditions relative to the various forms of inadequate sleep is illustrated in Table 1. Costs were based on the following care requirements: (1) for motor vehicle accidents, the average care requirement was estimated to be 4.5 hr per week; (2) for workplace injuries, the average care requirement was estimated to be 3.7 hr per week, (3) for cardiovascular disease (cerebrovascular disease, coronary artery disease, and congestive heart failure), the average care requirement was estimated to be 1.1 hr per week; (4) for type 2 diabetes, the average care requirement was estimated to be 0.1 hr per week [42, 43]. Lack of adequate data precluded calculation of informal care costs for depression.

The hourly cost of informal care was based on Australian Bureau of Statistics average weekly earnings estimates by age and gender [44], which was adjusted to the 2016–2017 financial year using growth in average weekly earnings [45].

Nonmedical cost of accidents

The PAFs for motor vehicle accidents and for workplace accidents were used to derive the nonmedical costs of each from their respective total costs. These costs included those related to legal expenses, costs of investigation, services. The unit costs were derived from an earlier investigation by our group inflated to 2016–2017 dollars using the consumer price index [43].

Productivity losses

Four potential productivity losses were considered: (1) reduced employment through early retirement or other workforce withdrawal; (2) temporary absenteeism though time off work; (3) presenteeism, whereby the worker is at work but is less productive; and (4) premature mortality.

Potential double counting through estimation of the impacts of inadequate sleep itself and the conditions attributable to inadequate sleep (Table 1) was addressed by assuming that where an attributed condition existed the productivity impact was not compounded by inadequate sleep so that no additional productivity losses were assigned beyond those pertaining to the attributed conditions.

Reduced employment for EDS-SD, EDS-Other, and Insufficient Sleep was estimated using the employment rate reductions for each of the conditions attributable to the sleep problem (Table 1). These employment rate reductions were derived from a previous examination of the economic cost of sleep disorders in Australia undertaken by our group [43] and were as follows: coronary artery disease 19.0 per cent, congestive cardiac failure 20.7 per cent, stroke 24.8 per cent, depression 12.7 per cent, and type 2 diabetes 3.1 per cent. The same source provided an estimated productivity impact of workplace injury (over multiple years) of 1.22 × average annual earnings of the general population [43]. For motor vehicle accidents, the productivity impact was determined by the proportion of accidents that result in injury sufficient to prevent a return to work, estimated to be 0.73 per cent [43]. Although it is suggested that inadequate sleep itself can undermine motivation, performance, and employment opportunities, it is not clear to what extent this occurs and so no separate estimation was made for this potential influence [46].

Absenteeism for medical conditions associated with inadequate sleep was estimated to be 11.5 days of sick leave per year, compared with 6 sick days per year for those without a chronic disease [32]. For motor vehicle accidents, it was estimated that sufferers would be away from work for an average of 9.3 days [43]. For workplace injuries, no separate estimate of costs of absenteeism was made as these were captured in calculation of the effects of them on reduced employment. In addition to the cost impacts of the effects of attributable conditions, there is an absenteeism cost of an estimated 3.1

quartile ESS relative to the lowest which applied to the average absenteeism days in Australia of 9.5 days per year equate to an additional 1.2 days off per year [47, 48]; (2) Adams et al. who note that 17 per cent of their survey participants reported taking an extra 1 to 2 days off per month because of a sleep-related problem, with 3.5 per cent reporting more than 3 days per month, suggesting additional days off could be as high as 5.2 days per person per year [7]; and (3) Hafner et al. who, in contrast, report no absenteeism impacts due to reduced sleep hours [49].

Apart from EDS, the estimated absenteeism impact of Insufficient Sleep was derived from the work of the following: (1) Lallukka et al. where a weighted average of absenteeism days for those who slept less than 8 hr per night suggested that an additional 0.8 days per year would be taken off work by those with insufficient sleep [47]; and (2) Hafner et al. who found no discernible impact of insufficient sleep on absenteeism days [49]. Given the latter finding, the estimate based on Lallukka's work was discounted by one half to 0.4 additional days off work per year.

Presenteeism cost estimates varied depending on whether there was EDS (either EDS-SD or EDS-Other) or Insufficient Sleep (without EDS) and whether or not there was an attributable condition associated with these. Where there was an attributable condition, presenteeism impacts were conservatively assumed to have been captured within absenteeism or reduced employment estimates with people suffering such conditions either taking time off work and returning when they had recovered or exiting the workforce if there were persistent problems. Where there was no attributable condition, the presenteeism impact of EDS was estimated to be 3.4 per cent based on an average of the impacts estimated by Mulgrew et al. of 3.7 per cent, Hafner et al. (2016) of 2.4 per cent for short sleep, Hafner et al. of 4.4 per cent for EDS, and Rosekind et al. of 3 per cent for poor vs. good sleep [22, 23, 49, 50]. For Insufficient Sleep, the presenteeism impact was estimated to be a 1.6 per cent reduction in productivity based on an average of estimates based on the work of Hafner et al. of 1.4 per cent, Hafner et al. of 1.2 per cent for people who sleep 6–7 hr a night vs. 7–8 hr a night, and Rosekind et al. for "at risk" vs good sleep of 2.1 per cent [22, 23, 49].

Premature mortality estimates were derived from deaths associated with the attributed conditions summarized in Table 1. The mortality rates for each of these conditions were based on age- and gender-related estimates from a previous analysis of the economic cost of sleep disorders in Australia undertaken by our group [43]. In the absence of attributed conditions, it was assumed that inadequate sleep had no discernible impact on mortality.

Deadweight loss captures the cost of the substantial inefficiencies associated with transfer payments including disability support pension, pension supplement and rent assistance, and reduced income and consumption taxation revenue, as well as reduced company tax revenue due to lost earnings. The deadweight loss calculations assume that there is no change to overall government spending due to reduced taxation. The lost taxation revenue was estimated by applying average tax rates to the total productivity impacts (including informal care costs). The inefficiency losses associated with these various expenses ranged from 24 per cent for individual income to 30 per cent for welfare payments to 45 per cent for state health expenditure to 50 per cent for reduced income for employers [43].

Nonfinancial costs of inadequate sleep and its various sources

The nonfinancial costs of inadequate sleep derive from the less tangible costs of loss of life quality through pain and suffering, and premature death measured in terms of disability adjusted life years. A monetary value can be assigned to this burden of disease estimate using the "value of a statistical life year" to calculate the value of years of healthy life lost due to disability or premature death. The value of a statistical life year is based on willingness to pay measures for Australia [51, 52].

The years of healthy life lost due to disability (YLDs) for EDS-SD were based on the disability weights for OSA, insomnia, and restless legs syndrome and to their attributable conditions, using a simple multiplicative model to combine the impacts of the sleep disorder and the comorbidity where both existed. For EDS-Other or Insufficient Sleep, the disability weight was simply that of the attributed condition. These disability weights were as follows: OSA 0.105 [43], insomnia 0.1 [43], restless legs 0.12 [43], congestive heart failure 0.066 [53], coronary artery disease 0.079 [53], stroke 0.146 [53], type 2 diabetes 0.07 [54], depression 0.178 [53], workplace injuries 0.08 [55], and motor vehicle accidents 0.049 [53]. YLDs were then calculated by multiplying the prevalence of the individual and comorbid conditions by their disability weights.

The years of life lost due to premature death (YLLs) were calculated as the product of the number of deaths related to inadequate sleep and the standard life expectancy at the age when death occurred [56]. These estimates were based on premature death through health conditions attributable to inadequate sleep (Table 1), as there is insufficient evidence to link premature estimated using the “value of a statistical life year” of $132210, which is the national 2014 estimate updated for inflation [51, 52]. This was applied directly to YLDs. Regarding YLLs, a compounded discount rate of 3 per cent was applied to future years of life lost (determined from standard life expectancy at age of death) to reflect the greater value society places on a year of healthy life gained in the immediate future relative to subsequent years [57].

Sensitivity analysis

One-way sensitivity analyses were conducted on prevalence, the value of a statistical life year, the discount rate for YLLs, and estimated productivity losses. The choice of parameter values was either consistent with the literature that has been cited earlier, or within the 95% confidence interval of estimated base case values. For the lower-case sensitivity analyses, the parameters were set so that prevalence was 36.7 per cent, the value of a statistical life year was $113637, the discount rate for YLLs was 0 per cent, and productivity losses from presenteeism for Insufficient Sleep and EDS were 1 and 2 per cent, respectively. Upper-case sensitivities were set so that prevalence was 42.9 per cent, the value of a statistical life year was $151517, the discount rate for YLLs was 7 per cent, and productivity losses from Insufficient Sleep and EDS were 2 and 5 per cent, respectively. The upper and lower bounds for the value of a statistical life year were derived from previously described limits [51].

Currency standardization

All costs were expressed in US dollars ($), using the 2016 Organization for Economic Cooperation and Development purchasing power parity of 1.466 Australian dollars per US dollar [58].

Results

Prevalence of the various sources of inadequate sleep and attributable conditions

Sleep disorders

Insomnia. The estimates of insomnia prevalence vary widely depending, in

Obstructive sleep apnea

The estimated prevalence of OSA used in this report was 8.3 per cent, based on self-report using the criteria outlined in the Methods section [7]. This is consistent with current US estimates of clinically significant OSA of 9.5 per cent [3].

Restless legs syndrome

A high proportion of participants (17.6%) reported restless legs syndrome symptoms in the recent study of Adams et al. [7]. This is close to the midpoint of the range described by a meta-analysis of North American and European studies [62]. However, the problem has a wide spectrum of severity [63]. A prevalence estimate for clinically significant restless legs syndrome of 2.8 per cent was used for this study, which is well below the estimate of Adams et al., but consistent with the derivations of prevalence of clinically significant restless legs syndrome in other reports which suggest that this lies in the 2%–3% range [64, 65].

Prevalence of the various sources of inadequate sleep (EDS-SD, EDS-Other, and Insufficient Sleep)

EDS was present in 19.1 per cent of the participants in the study of Adams et al., with 26 per cent of those participants who also had a sleep disorder having EDS, whereas the proportion with EDS in those with no coexistent sleep disorder was 17 per cent (Table 2) [7]. This gives an estimated unadjusted odds ratio of 1.7 for those who have sleep disorders to also have EDS. Applying the PAF methodology (Appendix), using the prevalence of EDS (19.1%) and of sleep disorders (as specified above, 11.3% + 8.3% + 2.8% = 22.4%) and this odds ratio of 1.7, provided a prevalence estimate for EDS-SD of 5.8 per cent. The balance of EDS (19.1%–5.8%) provided a prevalence estimate for EDS-Other of 13.3 per cent.

Table 2. Prevalences of the various categories of inadequate sleep (see text for references)

Prevalence of sleep disorders (insomnia, OSA, RLS)	**22.4%**
Prevalence of EDS	19.1%
(Odds ratio of EDS in people with sleep disorders)	(1.7)
Estimated prevalence of EDS-SD	5.8%

EDS = Excessive daytime sleepiness; SD = sleep disorders; OSA = obstructive sleep apnea.

The proportion of the community complaining of subjective insufficient sleep (with or without EDS) of 33 per cent was obtained from averaging the prevalence described in five recent studies of 51 [7], 24 [4], 28 [25], 28 [6], and 35 per cent [5]. In the study of Adams et al., they found that 65 per cent of those with EDS had such a complaint, yielding a balance of 20.7 per cent (i.e. 33% – 0.65*19.1%) of the community who have insufficient sleep without EDS [7].

Hence, the estimated prevalence of inadequate sleep in all its forms was 39.8 per cent, comprised of EDS-SD of 5.8 per cent, EDS-Other of 13.3 per cent, and Insufficient Sleep (without EDS) of 20.7 per cent.

Financial costs of inadequate sleep and its secondary outcomes

Health system costs

The estimated health system costs of sleep disorders and conditions attributed to inadequate sleep for the 2016–2017 financial year were $1.24 billion (Tables 3 and 4). This was comprised of the following: sleep disorders $158.3 million; congestive cardiac failure $9.1 million; coronary artery disease $77.8 million; stroke $47.5 million; type 2 diabetes $12.1 million; depression $271.8 million; medical costs of workplace injuries $423.3 million; and medical costs of motor vehicle accidents $238.9 million. Breakdowns of these costs by the various sources of inadequate sleep are provided in Tables 3 and 4.

Table 3. Breakdown of the costs of inadequate sleep by various categories

	Costs of various categories of inadequate sleep including costs of conditions associated with them			Total ($ billions)
	EDS-SD ($ billions)	EDS-Other ($ billions)	Insufficient Sleep ($ billions)	
Financial costs ($ billions)				
Health	0.50	0.52	0.22	1.24
Productivity				

Absenteeism	0.36	0.94	0.43	1.73
Presenteeism	0.73	2.22	1.68	4.63
Subtotal	2.60	6.11	3.48	12.19
Informal care	0.11	0.18	0.12	0.41
Other (nonmedical accident costs)				
Workplace accidents	0.05	0.16	0.08	0.29
Vehicle accidents	0.36	0.98	0.85	2.19
Subtotal	0.41	1.14	0.93	2.48
Deadweight loss	0.38	0.75	0.43	1.56
Total financial costs	4.00	8.71	5.17	17.88
Nonfinancial costs ($ billions)				
Loss of well-being	21.41	5.14	0.78	27.33
Total costs ($ billions)				
Financial + Nonfinancial	25.41	13.85	5.95	45.21

EDS = excessive daytime sleepiness; SD = sleep disorders.

Table 4. Breakdown of costs ($ billions) of inadequate sleep and the various conditions associated with it

	Costs of various categories of inadequate sleep not including costs of conditions associated with them			**Costs of conditions associated with ina**			
	EDS-SD	**EDS-Other**	**Insufficient Sleep**	**Heart D.**	**Stroke**	**Diabetes**	**Depress**
Financial costs ($ billions)							
Health	0.16	—	—	0.09	0.05	0.01	0.27

Other (nonmedical accident costs)	—	—	—	—	—	—	—
Deadweight loss	0.15	0.36	0.25	0.05	0.03	≤0.01	0.16
Total financial costs	1.29	3.38	2.32	0.46	0.27	0.04	1.46
Nonfinancial costs ($ billions)							
Loss of well-being	12.36	-	-	3.56	2.32	0.72	5.80
Total costs ($ billions)							
Financial + Nonfinancial Costs	13.65	3.38	2.32	4.02	2.59	0.76	7.26

EDS = excessive daytime sleepiness; SD = sleep disorders.

Informal care costs

The estimated total cost of informal care due to inadequate sleep in 2016–2017 was $413.2 million. A breakdown of these costs by the various types of inadequate sleep and the conditions attributable to them is provided in Tables 3 and 4.

Nonmedical cost of accidents

Applying the PAFs specified in Table 1 to the total number of workplace injuries and motor vehicle accidents in Australia in 2016–2017, it was estimated that 65828 workplace injuries and 66400 motor vehicle accidents were the result of inadequate sleep [43]. Based on our group's previous estimates, inflated to 2016–2017 dollars using the consumer price index, the estimated costs for each workplace injury were $1289 for legal costs, $886 for investigations, $1328 for travel costs, and $908 for aids and modifications, yielding a total cost of approximately $290.4 million [43]. The estimated nonmedical costs for motor vehicle accidents were $32973 per injury yielding a total cost of $2.19 billion [43]. Hence, the estimated total nonmedical costs of accidents in 2016–2017 were $2.48 billion.

The estimated total productivity losses from inadequate sleep in Australia in 2016–2017 were $12.19 billion, comprised of $5.22 billion in reduced employment, $0.61 billion in premature death, $1.73 billion in absenteeism, and $4.63 billion in presenteeism. Detailed breakdowns of these costs are provided in Tables 3–5.

Table 5. Summary of total productivity costs associated with inadequate sleep in Australia in 2016–2017 ($ millions)

Source of productivity loss	EDS-SD ($ millions)	EDS-Other ($ millions)	Insufficient Sleep ($ millions)	Total ($ millions)
Reduced employment				
Congestive cardiac failure	13.4	—	—	13.4
Coronary artery disease	150.9	—	—	150.9
Stroke	50.3	53.2	—	103.5
Type 2 diabetes	14.8	—	—	14.8
Depression	291.0	422.8	—	713.8
Workplace injuries	695.4	2,064.4	1,132.0	3,891.8
Motor vehicle accidents	55.3	150.4	129.2	334.9
Subtotal	1271.1	2690.8	1261.2	5223.1
Premature death				
Congestive cardiac failure	2.5	—	—	2.5
Coronary artery disease	88.3	—	—	88.3
Stroke	25.0	26.5	—	51.5
Type 2 diabetes	4.8	—	—	4.8
Depression	63.6	92.3	—	155.9
Workplace injuries	13.3	39.5	21.7	74.5
Motor vehicle accidents	38.4	104.3	89.6	232.3
Subtotal	235.9	262.6	111.3	609.7

Stroke	5.6	5.9	—	11.5
Type 2 diabetes	5.5	—	—	5.5
Depression	65.7	95.5	—	161.2
Workplace injuries	—	—	—	—
Motor vehicle accidents	13.9	37.7	32.4	84.0
No attributed conditions	252.5	796.5	396.7	1,445.7
Subtotal	364.6	935.6	429.1	1,729.3
Presenteeism				
No attributed conditions	731.5	2223.6	1677.1	4632.2
Subtotal	731.5	2223.6	1677.1	4632.2
Total	2603.1	6112.6	3478.7	12194.4

EDS = excessive daytime sleepiness; SD = sleep disorders.

Deadweight loss

Applying the rates of efficiency loss specified in the Methods section, the estimated total deadweight loss for 2016–2017 was $1.56 billion, which was comprised of efficiency losses from national health expenditure of $149.9 million, state health expenditure of $122.0 million, welfare payments of $14.2 million, lost consumer taxes of $492.6 million, lost company taxes of $743.2 million, and lost carer taxes of $33.8 million.

Nonfinancial costs of inadequate sleep and its various sources

The estimated total disability adjusted life years lost from inadequate sleep in 2016–2017 was 228162, consisting of 162598 YLDs and 65564 YLLs (Table 6). A breakdown is provided in Table 6. Multiplying YLDs by the value of a statistical life year of $132211 and YLLs by an average discounted value of a statistical life year of $89,021 and summing these yielded an estimated total cost of healthy life lost through inadequate sleep of $27.33 billion for 2016–2017 [52].

Table 6. Estimated disability adjusted life years (DALYs) lost from inadequate sleep in

Condition	EDS-SD (DALYs)	EDS-Other (DALYs)	Insufficient Sleep (DALYs)	Total (DALYs)
Congestive heart failure	1858	—	—	1858
Coronary artery disease	30833	—	—	30833
Stroke	11070	10390	—	21460
Type 2 diabetes	5688	—	—	5688
Depression	23371	24595	—	47966
Workplace injuries	2702	4790	2626	10118
Motor vehicle accidents	3679	7021	6029	16729
Inadequate sleep with no attributed condition	93510	—	—	93510
Total	172712	46795	8655	228162

EDS = excessive daytime sleepiness; SD = sleep disorders.

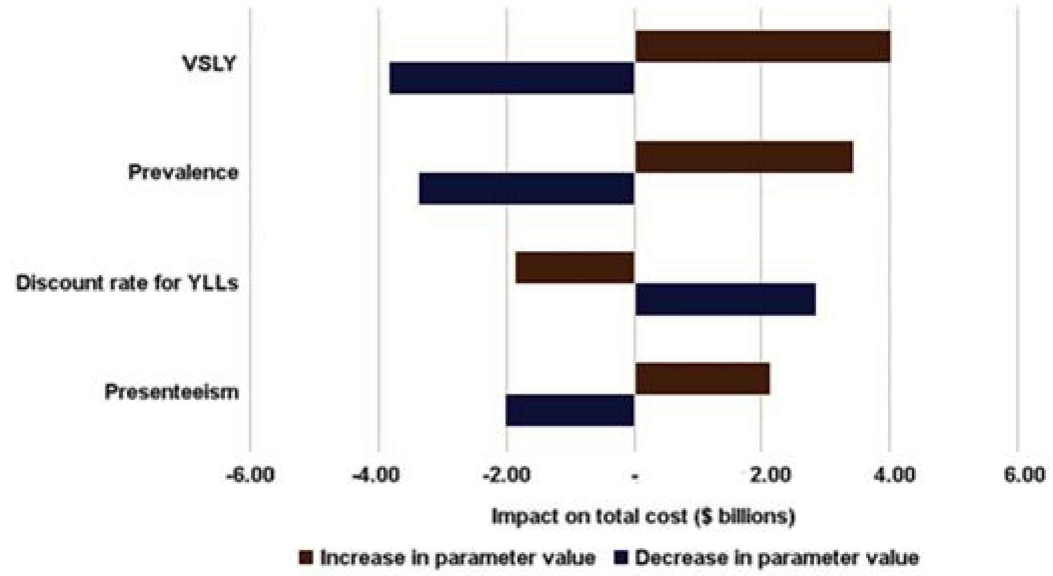
Total cost of inadequate sleep

Hence, the estimated total cost of inadequate sleep in Australia in 2016–2017 was $45.21 billion, comprising $17.88 billion in financial costs and $27.33 billion in loss of well-being.

Sensitivity analysis

The results of the sensitivity analysis are illustrated in Figure 1 and Table 7. They indicate that the total cost of sleep health was most sensitive to changes in the value of a statistical life year and the overall prevalence rate. The total cost of inadequate sleep was estimated to range from $41.38 billion to $49.21 billion in Australia in 2017 (Table 7).

Figure 1.



Sensitivity analysis (Tornado diagram) of the impact on total cost of inadequate sleep of variations in parameter values. VSLY = value of a statistical life year; YLL = years of life lost due to premature death.

Table 7. One-way sensitivity analyses

Variable	Financial	Loss of well-being	Total
Base case	17.88	27.33	45.21
Prevalence (base case = 39.8%)			
Lower (36.7%)	16.57	25.28	41.85
Upper (42.9%)	19.22	29.43	48.64
VSLY (base case = $132 210)			
Lower ($113 637)	17.88	23.49	41.38
Upper ($151 517)	17.88	31.33	49.21
Discount rate for YLLs (base case = 3%)			
Lower (0%)	17.88	30.17	48.05
Upper (7%)	17.88	25.48	43.36
Presenteeism (IS = 1.6%, EDS = 3.4%)			
Lower (IS = 1%, EDS = 2%)	15.86	27.33	43.19
Upper (IS = 2%, EDS = 5%)	20.01	27.33	47.34

Discussion

Recent surveys demonstrate that inadequate sleep is a substantial and growing problem in Australia and in nations with equivalent economies and demographics [1, 2, 5–7]. This inadequacy is due in part to untreated sleep disorders and in part to insufficient sleep because of work or other demands or lifestyle choice. It comes at the expense of compromised cognitive and psychomotor function, mood, and physical and emotional well-being [11–19]. These compromises adversely affect safety, productivity, and health and have substantial associated economic costs.

The purpose of the study was to quantify the economic costs associated with inadequate sleep in all its forms. However, although costs relating to health, productivity, informal care, accident risk, and deadweight losses accrue across the spectrum of inadequate sleep (Table 3), within this spectrum, different exposures and risks apply for EDS-Sleep, EDS-Other, and Insufficient Sleep (Table 1). For example, for congestive cardiac failure, coronary artery disease, and type 2 diabetes, sufficient evidence only exists for their costs to be estimated in relation to the proportions of these outcomes that are related to the sleep disorders (EDS-Sleep), but not than other sources of inadequate sleep. However, cerebrovascular disease and depression are more widely linked to include all sources of EDS (i.e. both EDS-Sleep and EDS-Other). Workplace injury and motor vehicle accidents are more widely linked still such that a proportion of their costs can be related to inadequate sleep in all its forms, although with varying odds ratios determined by the strength of their associations with the category of inadequate sleep under consideration (Table 1).

Our partitioning of inadequate sleep into the EDS-SD, EDS-Other, and Insufficient Sleep categories was guided by these considerations. EDS, as determined by an ESS > 10, was used in this partitioning to assign some of those who complain of inadequate sleep into the EDS-SD or EDS-Other categories, depending on whether they have evidence of a coexisting sleep disorder. As this recognizes, EDS does not capture all inadequate sleep. However, it provided a helpful means of partitioning the wider inadequate sleep group category for the purposes of our analysis. The partitioning helped ensure a conservative estimate of costs: for example, although those with a sleep disorder and ESS > 10 were included in the EDS-SD category, those with sleep disorders with subjective sleepiness but not EDS were included in the Insufficient Sleep category and those with sleep disorders but no EDS or subjective sleepiness were excluded from the analysis (the

Although there have been previous economic analyses of the cost of sleep disorders and of productivity losses associated with poor sleep, there has been no previous attempt to cost inadequate sleep from the health and safety perspectives, as well as productivity, as this analysis has done. Its key finding is that the estimated total cost of inadequate sleep in Australia in 2016–2017 was $45.21 billion, comprising $17.88 billion in financial costs and $27.33 billion in loss of well-being. This equates to approximately $6,117 per person affected in both financial and wellbeing costs. Sensitivity analysis demonstrated that these estimates were robust to variations in the key inputs.

This is a substantial cost to the economy. The estimated 2016–2017 financial costs of $17.88 billion are equivalent to 1.55 per cent of Australian gross domestic product ($1155.0 billion) for the year [66]. The estimated nonfinancial costs of $27.33 billion are equivalent to 4.6 per cent of the total Australian burden of disease cost for the year [56]. The Australian population in 2016–2017 was 24.8 million people and so, assuming they are generalizable across economies with similar (Organization for Economic Cooperation and Development) characteristics, the various costs would have to be adjusted for the population under consideration. For the United States, the costs would be factored up by a multiple of 13 to match the 2016 US population of 323.1 million people, yielding an equivalent estimate of the total cost of inadequate sleep in this population of over $585 billion for 2016–2017.

It is critical that such economic evaluations are done, as economic decisions demand them. It is a basic political and administrative responsibility to allocate resources based on costs and likely returns on investment: dollars are the lingua franca of politics and business. In public health expenditure terms, sleep health languishes behind issues such as healthy diet, regular exercise, moderation of alcohol intake, and smoking cessation as a priority for attention and expenditure. In the meantime, the pressures on sleep health are increasing, both through aging and weight-related increases in sleep disorders, as well as demands from competing work, family, social, and social media activities. The data in this report illustrate that, besides their impact on individual and societal well-being, there is a substantial monetary cost to these issues.

In setting national health priorities, Australian governments have attempted to identify issues that involve high communal illness and injury burden with associated high societal and financial cost for focused attention through public education, regulation, and other initiatives to effect improvements in

These data suggest that sleep health now merits similar attention. The situation is likely to be similar in equivalent economies [22, 67].

Large though these estimates are, they may well underestimate the economic impact of poor sleep health as the issues of education, learning, intellectual development, and behavior in children and adolescents have not been considered [68, 69]. These problems have both an immediate impact and an influence on longer term economic health, further underlining the importance of good sleep health to national well-being.

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Notes

Conflict of interest statement. None declared.

Appendix

Methodology to Calculate Population Attributable Fractions

Population attributable fractions (PAFs) were used to estimate the share of total costs attributable to inadequate sleep where there was sufficient evidence of an association between inadequate sleep and other health conditions. PAFs were calculated using the following method based on Eide and Heuch [24]. First, the following two equations were solved simultaneously:

$$q1.s1 + q2.s2 = p1 \quad (1)$$

$$(q1/(1 - q1)) \,/\, (q2/(1 - q2)) = OR \quad (2)$$

where q1 is the probability of having the particular condition given that an individual has a sleep condition; q2 is the probability of having the particular condition given that an individual does not have a sleep condition; s1 is the share of people with a sleep condition = probability of having a sleep

After solving these equations for q1 and q2, the following equation is derived:

$$\mathrm{PAF} = \frac{(q1 - q2).\mathrm{s1}}{\mathrm{p1}} \tag{3}$$

Equation (3) is used to determine the proportion of each condition that can be said to be attributable to EDS-SD, EDS-Other, or Insufficient Sleep.

Where epidemiological studies reported relationships in terms of a hazard ratio, the hazard ratios were assumed to be roughly equivalent to relative risk ratios. The PAF was calculated using the following equation:

$$\mathrm{PAF} = \mathrm{s1}.\,(\mathrm{RR} - 1)\ /\ (\mathrm{s1}.\,(\mathrm{RR} - 1)\ + 1) \tag{4}$$

where s1 is the share of people with sleep condition = probability of having sleep condition; RR is the relative risk ratio.

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