Int J Public Health (2012) 57:485–493
DOI 10.1007/s00038-011-0239-7

ORIGINAL ARTICLE

A quantile regression approach to re-investigate the relationship between sleep duration and body mass index in Taiwan

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Received: 23 September 2010 / Revised: 16 December 2010 / Accepted: 13 January 2011 / Published online: 15 February 2011

Abstract

Objective Previous studies on the relationship between sleep duration and body mass index (BMI) have shown inconsistent results by using estimation strategies within the framework of ordinary least squares (OLS). This study examined the relationship between sleep duration and BMI by using quantile regression to account for the potential heterogeneous effect of sleep duration on BMI in different BMI categories.

Methods The data of 2,392 adults were from the 2005 Panel Study of Family Dynamics in Taiwan. The dependent variable was BMI of the respondents. Both OLS and quantile regression models were used for comparison.

Results The OLS model does not show significant relationship, while the quantile regression model shows a U-shaped relationship between sleep duration and BMI beyond the 90th percentile in men (BMI = 28.69) and an inverse U-shaped relationship at the 30th percentile of BMI in women (BMI = 21.37).

Conclusions Quantile regression can provide information that may be masked by OLS in analyzing the relationship between sleep duration and BMI. Sleep modification with the aim to obtain the optimal sleep duration may help to reduce BMI in obese men.

Keywords Quantile regression · Sleep · Body mass index · Obesity

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Introduction

The increasing prevalence of obesity has become a serious health issue around the world (Low et al. 2009; Prentice 2006). It has been well established that the overweight and obese individuals have higher risks of various chronic diseases such as cardiovascular diseases, hypertension, type 2 diabetes, and certain types of cancer (Guh et al. 2009). The prevalence of overweight and obesity combined was 68.0% in US adults in 2007–2008 (Flegal et al. 2010), increased from 54.4% in 1988–1994 (Flegal et al. 1998). The prevalence of overweight and obesity in adults increased from 45% in 1986–1987 to 64% in 2002 in the United Kingdom (Leicester and Windmeijer 2004). The prevalence of obesity in the developing countries is also rising rapidly (Misra and Khurana 2008), even faster than the historical experience of the developed regions (Popkin and Gordon-Larsen 2004; Raymond et al. 2006). The annual rates of increase in the prevalence of overweight and obesity in Asia, North Africa, and Latin America are two to five times greater than in the US (Popkin and Gordon-Larsen 2004). This trend is likely due to the economic transition and introduction of the western life style. Taiwan, a developing country making progress to a developed one, is also facing an alarming trend of increase in obesity. The recent Nutrition and Health Survey in Taiwan 2005–2008 reports that the prevalence of overweight and obesity is 50.8% in adult men and 36.9% in adult women (Department of Health 2010). These numbers were increased from 33.4% in men and 31.7% in women in the 1993–1996 national survey (Lin et al. 2003). Therefore, the results based on data from Taiwan may help to alleviate the burden of obesity in many countries that are going through economic transition.

The duration of sleep has been proposed as one of the factors that may influence individual's body mass index

(BMI). The decline in self-reported sleep duration over the past half century is concurrent with the increase in the prevalence of obesity in many industrialized countries (Cappuccio et al. 2008). In addition, previous studies have shown that most weight-loss programs involving dietary control and/or exercise are effective in the short-term. However, more than 75% of the lost weight is re-gained after 5 years (Anderson et al. 2001), which nullifies most of the previous progress. Thus, other changes in life style, such as the duration of sleep, may be necessary for the maintenance of healthy body weight.

However, previous studies regarding the relationship between sleep duration and BMI have shown inconsistent results. Most studies on this issue are performed using cross-sectional data. In a meta-analysis study that involved 603,519 adults, the pooled odds ratio of sleeping less than 5 h per night for obesity is 1.55, compared to 7–8 h of sleep (Cappuccio et al. 2008). The same study also found a consistent and significant negative linear relationship between hours of sleep and BMI. A Finnish national survey reveals that those who sleep less than 6 h per night had higher risk for abdominal obesity, compared to those who sleep 7–8 h (Fogelholm et al. 2007).

Several cross-sectional studies reveal a U-shaped relationship between sleep duration and BMI (Bjorvatn et al. 2007; Chaput et al. 2007; Kripke et al. 2002). That is, both short and long sleep durations are associated with increased BMI. The optimal sleep duration appears to be 7–8 h per night. In Cancer Prevention Study II that involves more than 1.1 million US adults, women who sleep 7 h have the lowest BMI compared to the shorter or longer sleepers (Kripke et al. 2002). A U-shaped relationship is also found in Canadian adults with those who sleep 7–8 h per day showing the lowest incidence of overweight and obesity (Chaput et al. 2007). On the contrary, it has been shown that sleep duration is not associated with BMI in French men (Cournot et al. 2004).

Few longitudinal studies have also revealed conflicting results. In the National Health and Nutrition Examination Survey (NHANES) (Gangwisch et al. 2005) and Nurses' Health Study (Patel et al. 2006a, b), subjects who sleep less than 6 h have higher risk of becoming obese during the follow-up periods. Nevertheless, the lack of relationship between sleep duration and changes in BMI was reported in Whitehall II Study (Stranges et al. 2008) and Coronary Artery Risk Development in Young Adults (CARDIA) Sleep Study (Lauderdale et al. 2009).

Previous studies that investigate the potential gender difference in the relationship between sleep duration and BMI also show contradictory results. Cancer Prevention Study II reports a U-shaped relationship between sleep duration and BMI in women, but a negative linear relationship in men (Kripke et al. 2002). A study on current and former French workers reports that short sleep duration is significantly associated with higher BMI in women, but not in men (Cournot et al. 2004). On the other hand, short sleep duration is associated with higher BMI in men, but not in women, in Scottish employees (Heslop et al. 2002).

In the current study, we hypothesize that the inconsistency of the existing empirical findings rises from the heterogeneous effect of sleep duration on BMI in the populations of different BMI categories. The estimation strategies of previous studies are mostly within the framework of ordinary least squares (OLS). The OLS specification is concerned with the marginal effects of the covariates on the conditional mean of the dependent variable. However, the effects of the covariates may be heterogeneous in the under-, normal-, and overweight populations. Consequently, OLS estimates would be unable to provide sufficient information in analyzing the issues related to BMI. On the other hand, quantile regression provides measures of the influence of covariates at multiple quantiles of the distribution of the dependent variable by relaxing the constant marginal effects of the explanatory variables under the OLS specification (Koenker and Bassett 1978). The particular quantiles used in the regression can be chosen based on areas in the distribution of the greatest interest. This flexibility gives quantile regression the advantage of modeling data with heterogeneous conditional distributions such as BMI. Recently, quantile regression has been applied to identify the effects of various socio-economic and health factors on BMI (McLaren et al. 2010; Shankar 2010; Stifel and Averett 2009). However, sleep duration is not included in these studies. In the present study, we employ quantile regression to investigate the relationship between sleep duration and BMI over the whole BMI distribution in adults based on the data from a national survey in Taiwan. The analysis is conducted separately for men and women to examine the gender difference.

Methods

Data and variables

The data used in this study was adopted from the 2005 Panel Study of Family Dynamics (PSFD) in Taiwan, conducted by the Institute of Economics, Academia Sinica. Academia Sinica, founded by the central government, is the most preeminent academic institution in Taiwan. A three-stage random sampling procedure is adopted in PSFD. In the first stage, a number of cities or towns are randomly selected with the probability proportional to their population sizes. In the second stage, communities or villages are randomly drawn from the selected geographical areas with the same method. In the third stage, individuals are randomly drawn from the selected communities or villages.

The PSFD sample mainly consists of three cohorts, individuals born 1934–1953, 1954–1963, and 1964–1978. The 1954–1963 cohort was first interviewed in 1999. The interviewing of the 1934–1953 cohort started in 2000, while the interviewing of the 1964–1978 cohort started in 2003. The questionnaires are not identical over the years. A module on sleep behavior is included in the 2005 PSFD questionnaire. The self-reported body weight is collected in the 2004–2005 PSFD, while the self-reported height is available only in the 2004 PSFD. The height is assumed to be constant between 2004 and 2005. The 2004 height and 2005 weight data are used to calculate BMI. After deleting observations with missing data, this study contains 2,392 respondents (1,121 men and 1,171 women). The definitions of variables are listed in Table 1.

Table 1 Definition of variables from 2005 Panel Study of Family Dynamics (PSFD) in Taiwan

Dependent variables	
BMI	A respondent's body mass index
Demographic characteristics	
Age	Age of the respondent
Male	Gender of the respondent
	Male = 1 if male; male = 0 if female
Married	Marital status
	Married = 1 if married
	Married = 0 if single, divorced, or widowed
Education	Years of schooling
North	Whether the respondent lives in northern Taiwan
	North = 1 if yes; north = 0 if No
South	Whether the respondent lives in southern Taiwan
	South = 1 if yes; south = 0 if no
Central	Whether the respondent lives in central Taiwan
	Central = 1 if yes; central = 0 if no
East	Whether the respondent lives in eastern Taiwan
	East = 1 if yes; east = 0 if no
Job characteristics	
Income	Average monthly labor income in $NT in the previous year divided by 10,000
Employment	Whether or not the respondent is employed
	Employment = 1 if yes; employment = 0 if no
Time allocation	
Sleep	Average daily sleep duration in hours
SleepSQ	Squared sleep duration
Exercise	Average weekly exercise time in minutes
Housework	Average weekly housework time in hours

Model

According to the Department of Health, Executive Yuan, Taiwan, overweight is defined as BMI between 24 and 27; obesity is defined as BMI greater than 27; and underweight is defined as BMI less than 18.5. The cutoff levels for overweight and obesity are mainly developed from the Nutrition and Health Survey, Taiwan. These levels are lower than the definitions suggested by World Health Organization, which are developed according to data from mostly Caucasian populations (Pan et al. 2004). The lower cutoff levels used in Taiwan and most Asian countries are based on the facts that at the same level of BMI, the Asians have a higher percentage of body fat and a higher prevalence of many obesity-related diseases, compared to the Caucasians (Pan et al. 2004). Furthermore, a prospective cohort study showed Taiwanese have equivalent relative mortality risks at lower BMI than their American counterparts (Wen et al. 2009).

BMI is not a monotonous indicator of health since too high or too low of the level would lead to less favorable health conditions. The constant coefficient in OLS model reports only the central tendency of the marginal effects of covariates on the dependent variable. It may lead to the incompleteness in describing the relationship between socio-economic covariates and BMI. Different from OLS, quantile regression employed in this study derives solution by minimizing the sum of absolute deviations under specific quantiles (Koenker and Hollack 2001). It enables the investigation of covariates on BMI changes across the entire distribution of BMI. Thus, the different impact of the same covariate on the higher or lower tails of BMI distribution may be revealed. Several studies have shown that quantile regression can provide more information than OLS in exploring the effects of various socio-economic factors on BMI (McLaren et al. 2010; Shankar 2010; Stifel and Averett 2009).

Denoting B_i as the BMI of the individual i, the regression specification of the θth conditional quantile of B can be expressed as:

$$B_i = x_i'\beta^\theta + \varepsilon_i^\theta$$

where β^θ is the vector of parameters that depend on θ; ε_i^θ is the corresponding error. The quantile regression estimation is obtained by minimizing the asymmetric weighted sum of absolute derivation:

$$\min_\beta \left[\sum_{i:B_i \geq x'\beta} \theta|B_i - x_i'\beta^\theta| + \sum_{i:B_i \leq x'\beta} (1-\theta)|B_i - x_i'\beta^\theta| \right]$$

The most important feature of the quantile regression is that the explanatory variables' marginal effects, β^θ, may vary over different quantiles. That is, quantile regression estimates the heterogeneous marginal effects across the entire BMI conditional distribution. Therefore, the more complete picture of the conditional distribution will be revealed.

Results

The means and standard deviations of the variables in different BMI categories in men and women are presented in Tables 2 and 3, respectively. The estimations of BMI using OLS and quantile regressions in men are presented in Table 4. The OLS model shows that neither *Sleep* nor *SleepSQ* is significantly associated with BMI in men. However, quantile regression shows that there is a U-shaped relationship between sleep duration and BMI beyond the 90th percentile (BMI = 28.69). That is, the coefficient of *Sleep* is negative, while the coefficient of *SleepSQ* is positive. This result indicates that the shorter or longer sleep duration is associated with higher BMI in men with BMI > 28.69.

The estimations of BMI using OLS and quantile regressions in women are presented in Table 5. Similar to the results in men, *Sleep* and *SleepSQ* are insignificant in the OLS model in women. However, quantile regression shows that at the 30th percentile of BMI (BMI = 21.37), BMI shows an inverse U-shaped relationship with sleep duration as *Sleep* has a positive coefficient and *SleepSQ* has a negative coefficient. This result suggests that at this particular BMI level, the shorter or longer sleep duration is associated with lower BMI in women. *Sleep* and *SleepSQ* are statistically insignificant at other BMI quantiles.

Discussion

The OLS and quantile regression results in this study support our hypothesis that the inconsistency of previous empirical findings lies in the heterogeneity of the effect of sleep duration on different BMI levels. The OLS results of our data show that sleep duration is not significantly associated with BMI in either men or women. However, we discover the significant relationships between sleep duration and BMI in certain BMI percentiles by using quantile regression to account for the potential heterogeneous effect of sleep duration. Similarly, previous studies that utilize quantile regression are also able to reveal significant relationships between various covariates and BMI in certain quantiles when OLS models show insignificant results (McLaren et al. 2010; Shankar 2010). Our results highlight the importance of examining the effects of covariates across the entire distribution of BMI.

Our results suggest a U-shaped relationship between sleep duration and BMI above the 90th percentile of BMI in men. This U-shaped relationship is consistent with the findings from some earlier literatures (Bjorvatn et al. 2007; Chaput et al. 2007; Kripke et al. 2002). However, this relationship may be only significant in obese men.

Table 2 Descriptive statistics of variables in different BMI categories in men, from 2005 Panel Study of Family Dynamics (PSFD) in Taiwan

	Underweight		Normal		Overweight		Obesity	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BMI	17.42	1.02	21.92	1.43	25.37	0.82	29.51	2.61
Sleep	7.02	1.42	7.39	1.39	7.29	1.28	7.11	1.39
Age	54.82	13.38	48.78	12.14	49.67	11.21	49.08	11.67
Education	9.26	4.81	10.64	3.87	10.65	4.01	10.45	3.88
Income	20.64	22.52	35.79	41.04	39.12	36.57	42.55	103.07
Exercise	17.83	30.30	35.06	51.82	37.25	50.27	36.21	50.96
Housework	7.74	12.49	4.94	7.66	4.91	5.84	4.40	6.51
Dichotomous variables	Numbers (%)		Numbers (%)		Numbers (%)		Numbers (%)	
Married	14 (60.87)		437 (79.17)		354 (86.98)		194 (81.72)	
North	11 (47.83)		248 (44.93)		187 (45.95)		122 (51.05)	
Central	5 (21.74)		118 (21.38)		85 (20.88)		45 (18.83)	
South	6 (26.09)		163 (29.53)		108 (26.54)		59 (24.69)	
East	1 (4.30)		23 (4.17)		27 (6.63)		13 (5.44)	
Employment	13 (56.52)		445 (80.62)		337 (82.80)		182 (76.15)	
n	23		552		407		239	

The definition of variables is shown in Table 1

Underweight: BMI < 18.5; normal: 18.5 ≦ BMI < 24; overweight: 24 ≦ BMI < 27; obesity: BMI ≧ 27

Table 3 Descriptive statistics of variables in different BMI categories in women, from 2005 Panel Study of Family Dynamics (PSFD) in Taiwan

	Underweight		Normal		Overweight		Obesity	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BMI	17.61	0.93	21.97	2.16	25.97	0.54	29.67	3.88
Sleep	7.35	1.93	7.14	1.42	7.18	1.42	7.27	1.47
Age	46.72	12.68	48.92	11.45	54.29	10.29	53.31	11.30
Education	10.32	5.11	9.53	4.70	7.68	4.55	6.81	4.75
Income	17.90	24.06	19.96	27.88	11.15	19.13	14.36	31.91
Exercise	21.66	31.79	30.91	40.78	29.70	33.64	26.02	39.43
Housework	15.06	17.44	16.13	14.48	17.42	14.70	17.16	14.42
Dichotomous variables	Numbers (%)		Numbers (%)		Numbers (%)		Numbers (%)	
Married	30 (56.60)		599 (79.02)		113 (75.84)		165 (78.20)	
North	27 (50.94)		354 (46.70)		60 (40.27)		73 (34.60)	
Central	8 (15.09)		150 (19.79)		34 (22.82)		52 (24.64)	
South	18 (33.96)		219 (28.89)		38 (25.50)		64 (30.33)	
East	0 (0.00)		35 (4.62)		17 (11.41)		22 (10.43)	
Employment	28 (52.83)		489 (64.52)		62 (41.61)		106 (50.23)	
n	53		758		149		211	

The definition of variables is shown in Table 1

Underweight: BMI $<$ 18.5; normal: 18.5 $\leqq$ BMI $<$ 24; overweight: 24 $\leqq$ BMI $<$ 27; obesity: BMI $\geqq$ 27

A causal link between short sleep duration and increased BMI has been proposed but lacks clear evidence. Leptin, a hormone that can suppress appetite and increase energy expenditure, could play an important role (Friedman 2009). It has been reported that short sleep durations are associated with lower leptin concentrations relative to the predicted levels by fat mass (Chaput et al. 2007). Furthermore, inadequate sleep may be associated with irritability, impatience, and feeling tired and stressed, which may reduce the determination to follow a diet or exercise routine (Gangwisch et al. 2005).

The mechanism responsible for the relationship between longer sleep durations and higher BMI is even less clear. The metabolic changes induced by short sleep are absent in long sleepers (Knutson et al. 2007). It is possible that the obese subjects are more likely to suffer from sleep apnea and self-report higher average sleep times, since they are often unaware of their disrupted sleep patterns and require longer sleep durations to compensate for poor sleep quality (Gangwisch et al. 2005). In addition, it has been shown that those who sleep more than 9 h per day had the highest level of caloric and fat consumption, compared to normal and short sleepers (Patel et al. 2006a, b). The reduced time for physical activity in long sleepers is also a possibility. However, it is noteworthy that the relationship between sleep duration and BMI remains significant after controlling for physical activity and/or caloric intake in several studies (Gangwisch et al. 2005; Patel et al. 2006a, b). It suggests that other factors may also be involved.

Unexpectedly, we discover an inverse U-shaped relationship between sleep duration and BMI in women with normal weight (the 30th percentile of BMI, BMI $= 21.37$). To our knowledge, this concave relationship has not been reported in the literature. It is possible that in this group of normal-weight women, those who sleep longer are better rested. Therefore, they are more active and spend more energy during their awakened time. Those who sleep shorter may have more time to spend on physical activity. Indeed, it has been shown that the short sleepers perform more vigorous physical activity than the average sleepers (Chaput et al. 2008). This relationship requires further investigation.

The gender differences in the relationship between sleep duration and BMI have been reported, although the results are inconsistent. In a 15-year follow-up study, sleep duration is a significant negative predictor for BMI in women, but not in men (St-Onge et al. 2010). In addition, a population study in US adults shows a U-shaped relationship between sleep duration and BMI in women, but a negative linear relationship in men (Kripke et al. 2002). However, gender effect is absent in the relationship between sleep duration and BMI in Canadian young adults (Chaput et al. 2007) and Spanish elderly (Lopez-Garcia et al. 2008).

Table 4 The estimations of BMI from ordinary least square (OLS) and quantile regressions in men, from 2005 Panel Study of Family Dynamics (PSFD) in Taiwan

Variables	OLS	Underweight		Normal			Overweight				Obesity		
		(BMI < 18.5)		(18.5 ≦ BMI < 24)			(24 ≦ BMI < 27)				(BMI ≧ 27)		
		(q < 1.96)		(1.96 ≦ q < 47.13)			(47.13 ≦ q < 80.44)				(q ≧ 80.44)		
		$q = 1$	$q = 2$	$q = 10$	$q = 25$	$q = 40$	$q = 48$	$q = 50$	$q = 65$	$q = 80$	$q = 85$	$q = 90$	$q = 95$
BMI		17.58	18.51	20.32	22.20	23.51	24.07	24.22	25.40	26.93	29.41	28.69	30.39
Sleep	−0.0917	−0.0841	−0.2142	0.0533	−0.2809	0.1068	0.2379	0.3750	−0.1388	−0.0411	−0.9525	−1.5034	−2.3847
	(−0.23)	(−0.17)	(−0.21)	(0.12)	(−0.58)	(0.27)	(0.51)	(1.06)	(−0.41)	(−0.07)	(–1.35)	(−2.23)**	(−2.29)**
SleepSQ	−0.0063	0.0154	0.0200	−0.0023	0.0125	−0.0175	−0.0282	−0.0373	−0.0048	−0.0120	0.0442	0.0834	0.1288
	(−0.23)	(0.51)	(0.31)	(−0.08)	(0.38)	(−0.64)	(−0.89)	(−1.54)	(−0.21)	(−0.28)	(0.92)	(1.85)*	(1.86)*
Housework	−0.0210	−0.0667	0.0038	−0.0205	−0.0254	−0.0150	−0.0130	−0.0132	−0.0076	−0.0108	−0.0055	−0.0119	−0.0414
	(−1.49)	(−21.11)**	(0.06)	(−1.14)	(−1.71)*	(1.03)	(−0.84)	(−0.96)	(−0.64)	(−0.43)	(−0.19)	(−0.37)	(−0.86)
Exercise	0.0025	0.0043	0.0064	0.0029	0.0040	−0.0004	0.0020	0.0017	0.0023	0.0023	0.0001	−0.0035	0.0072
	(1.23)	(0.99)	(0.47)	(1.00)	(1.77)*	(−0.17)	(0.91)	(0.91)	(1.31)	(0.68)	(0.02)	(−0.87)	(0.94)
Education	−0.0273	−0.0257	−0.0157	0.0330	0.0282	0.0003	−0.0212	−0.0125	−0.0443	−0.0683	−0.0902	−0.1113	−0.1074
	(−0.88)	(−0.60)	(−0.11)	(0.79)	(0.81)	(0.01)	(−0.60)	(−0.42)	(−1.60)	(−1.20)	(−1.42)	(−1.65)*	(−0.91)
Age	−0.0021	−0.0390	−0.0269	0.0103	0.0136	0.0065	0.0116	0.0109	−0.0100	−0.0214	−0.0297	−0.0255	−0.0223
	(−0.19)	(1.90)**	(−0.50)	(0.67)	(1.07)	(0.57)	(0.93)	(1.04)	(−1.05)	(−1.08)	(−1.31)	(−1.10)	(−0.52)
Married	0.5615	0.8759	0.8943	0.9322	1.0116	0.8730	0.8347	0.9516	0.6004	−0.0438	0.2494	0.4256	0.9123
	(2.12)**	(2.15)**	(0.71)	(2.62)***	(3.38)***	(3.15)***	(2.76)***	(3.71)***	(2.56)**	(−0.09)	(0.47)	(0.77)	(0.92)
Employment	−0.2830	0.8446	0.8561	0.3081	−0.0114	−0.0242	−0.0246	−0.2326	−0.5765	−0.8369	−1.1590	−1.5078	−0.9126
	(−0.98)	(2.00)**	(0.66)	(0.85)	(−0.04)	(−0.08)	(−0.08)	(−0.85)	(−2.31)**	(−1.59)	(−2.03)**	(−2.59)***	(−0.86)
Income	0.0026	0.0066	0.0059	0.0043	0.0029	0.0025	0.0021	0.0020	0.0015	0.0018	0.0024	0.0070	0.0035
	(1.37)	(3.45)***	(1.51)	(2.83)***	(1.84)*	(1.89)*	(1.54)	(1.72)*	(1.41)	(0.68)	(0.90)	(2.36)**	(1.11)
North	−0.7791	−2.0536	−1.3550	−1.1186	−0.9854	−1.1121	−0.9287	−0.8114	−0.7479	−0.4587	−0.2394	−0.0568	−0.1797
	(−1.72)*	(−5.44)***	(−0.66)	(−1.88)*	(−2.00)**	(−2.35)**	(−1.80)*	(−1.87)*	(−1.89)	(−0.55)	(−0.26)	(−0.06)	(−0.10)
Central	−1.0509	−1.2811	−0.8178	−1.2322	−1.3638	−1.4350	−0.9987	−0.8652	−0.9529	−0.8116	−0.6896	−0.4543	−0.8207
	(−2.21)**	(−1.82)*	(−0.37)	(−1.95)*	(−2.62)***	(−2.88)***	(−1.84)*	(−1.89)*	(−2.28)***	(−0.93)	(−0.72)	(−0.46)	(−0.45)
South	−1.1360	−0.7963	−0.8209	−1.3853	−1.0441	−1.4432	−1.2919	−1.1613	−1.1091	−0.8080	−0.5866	−0.6411	−1.1171
	(−2.40)**	(−4.82)***	(−0.38)	(−2.29)**	(−2.07)**	(−2.98)***	(−2.44)**	(−2.60)***	(−2.73)***	(−0.96)	(−0.63)	(−0.67)	(−0.64)
Constant	26.4565	20.0242	19.7967	19.2339	22.6802	23.8299	23.7872	23.3392	28.3978	30.8848	35.7212	38.4783	43.1031
	(15.75)***	(7.09)***	(3.29)***	(9.31)***	(11.31)***	(14.03)***	(12.27)***	(15.52)***	(19.64)***	(11.07)***	(11.47)***	(12.20)***	(8.88)***
R^2 or pseudo R^2	0.0204	0.0946	0.0727	0.0235	0.0232	0.0139	0.0139	0.0136	0.0119	0.0141	0.0163	0.0233	0.0313

The definition of variables is shown in Table 1

[a] *SleepSQ* squared sleep duration

Significance levels: *** $P < 0.01$; ** $P < 0.05$; * $P < 0.1$; *t statistics* are in parenthesis

Table 5 The estimations of BMI from ordinary least square (OLS) and quantile regressions in women, from 2005 Panel Study of Family Dynamics (PSFD) in Taiwan

Variables	OLS	Underweight		Normal			Overweight			Obesity			
		(BMI<18.5)		(18.5≦BMI<24)			(24≦BMI<27)			(BMI≧27)			
		(q<4.6)		(4.6≦q<58.87)			(58.87≦q<81.99)			(q≧81.99)			
		q=2	q=5	q=10	q=30	q=50	q=60	q=70	q=80	q=82	q=85	q=90	q=95
BMI		17.22	18.67	19.38	21.37	23.23	24.03	25.15	26.67	27	27.53	28.58	30.73
Sleep	0.6055	1.4179	0.4913	0.5730	1.2468	0.4438	0.2390	0.2171	−0.0865	−0.3613	−0.5917	−0.7029	−1.5348
	(1.52)	(1.25)	(1.37)	(1.32)	(2.77)***	(0.88)	(0.51)	(0.53)	(−0.13)	(−0.55)	(−0.95)	(−0.80)	(1.19)
SleepSQ[a]	−0.0375	−0.0998	−0.0379	−0.0419	−0.0842	−0.0279	−0.0063	−0.0006	0.0150	0.0349	0.0535	0.0532	0.1054
	(−1.37)	(−1.40)	(−1.57)	(−1.48)	(−2.72)***	(−0.81)	(−0.20)	(−0.02)	(0.34)	(0.78)	(1.25)	(0.87)	(1.18)
Housework	−0.0114	0.0214	−0.0013	−0.0098	−0.0090	−0.0196	−0.0148	−0.0115	0.0010	−0.0013	−0.0038	−0.0153	−0.0023
	(−1.45)	(0.68)	(−0.13)	(−1.09)	(−0.99)	(−1.98)**	(−1.59)	(−1.34)	(0.07)	(−0.10)	(−0.27)	(−0.84)	(−0.10)
Exercise	−0.0017	0.0007	0.0021	0.0035	−0.0021	−0.0010	−0.0026	−0.0002	−0.0078	−0.0073	−0.0085	−0.0112	−0.0085
	(−0.63)	(0.06)	(0.63)	(1.02)	(−0.69)	(−0.30)	(−0.78)	(−0.05)	(−1.44)	(−1.41)	(−1.60)	(−1.40)	(−1.00)
Education	−0.1617	−0.0171	−0.0616	−0.0745	−0.0954	−0.1351	−0.1492	−0.2357	−0.2601	−0.2425	−0.2553	−0.2139	−0.2624
	(−5.06)***	(−0.19)	(−1.49)	(−1.98)**	(−2.59)***	(−3.38)***	(−3.82)***	(−6.51)***	(−4.28)***	(−3.94)***	(−4.08)***	(−2.58)***	(−2.65)***
Age	0.0265	0.0149	0.0013	0.0314	0.0500	0.0484	0.0379	0.0237	0.0195	0.0328	0.0232	0.0292	−0.0095
	(1.98)**	(0.31)	(0.07)	(1.92)*	(3.25)***	(2.89)***	(2.35)**	(1.57)	(0.78)	(1.31)	(0.89)	(0.83)	(−0.23)
Married	0.2847	0.5898	0.8224	0.5645	0.3142	0.4553	0.4829	0.5583	0.6399	0.6461	0.2994	−0.5301	−0.6548
	(1.14)	(0.58)	(2.46)***	(1.97)**	(1.11)	(1.46)	(1.59)	(2.00)**	(1.37)	(1.41)	(0.64)	(−0.84)	(−0.73)
Employment	−0.4095	0.4886	0.2129	0.5324	−0.0993	−0.6614	−0.7758	−0.9448	−0.2942	−0.1279	−0.2369	−0.5990	−0.0634
	(−1.53)	(0.46)	(0.59)	(1.68)	(−0.33)	(−1.99)**	(−2.37)**	(−3.26)***	(−0.61)	(−0.27)	(−0.48)	(−0.89)	(−0.07)
Income	0.0009	0.0027	−0.0001	−0.0064	−0.0042	0.0007	−0.0011	0.0082	0.0061	0.0055	0.0052	0.0031	0.0033
	(0.24)	(0.29)	(−0.04)	(−2.31)**	(−1.02)	(0.15)	(−0.22)	(2.85)***	(1.33)	(1.20)	(1.10)	(0.45)	(0.56)
North	−2.2878	−1.5165	−2.2479	−1.6600	−2.0888	−2.6652	−2.3247	−2.2614	−1.8122	−1.7566	−1.6975	−2.4079	−2.9855
	(−5.08)***	(−1.97)**	(−3.70)***	(−3.08)***	(−4.05)***	(−4.74)***	(−4.35)***	(−4.50)***	(−2.25)**	(−2.20)**	(−2.02)**	(−2.14)**	(−1.93)*
Central	−2.0270	−1.2458	−2.0032	−1.4543	−1.9762	−2.3544	−1.9546	−1.6637	−1.4547	−1.0756	−1.0903	−2.1516	−2.6901
	(−4.25)***	(−1.41)	(−3.16)***	(−2.58)***	(−3.63)***	(−3.95)***	(−3.43)***	(−3.11)***	(−1.68)*	(−1.26)	(−1.21)	(−1.78)*	(−1.63)
South	−2.3892	−1.7469	−2.3241	−1.9538	−2.2722	−2.8909	−2.2511	−2.1633	−1.8813	−1.7442	−1.2069	−2.5053	−3.0101
	(−5.21)***	(−1.90)*	(−3.80)***	(−3.56)***	(−4.34)***	(−5.05)***	(−4.11)***	(−4.21)***	(−2.27)**	(−2.12)**	(−1.38)	(−2.16)**	(−1.94)*
Constant	23.7883	12.7525	19.0607	17.9089	17.5163	23.1606	24.7307	26.4997	28.9142	29.0955	31.0885	34.4202	41.8909
	(13.96)***	(2.26)**	(10.58)***	(8.77)***	(9.06)***	(10.83)***	(12.31)***	(14.58)***	(10.07)***	(10.21)***	(11.17)***	(9.05)***	(8.59)***
R^2 or Pseudo R^2	0.0936	0.0556	0.0395	0.0489	0.0721	0.068	0.0728	0.0801	0.0703	0.0697	0.0674	0.0677	0.0685

The definition of variables is shown in Table 1

[a] *SleepSQ* squared sleep duration

Significance levels: $***P < 0.01$; $** P < 0.05$; $* P < 0.1$; *t statistics* are in parenthesis

We cannot rule out that obesity may affect sleep duration as the obese subjects are prone to obstructive sleep apnea and hypoventilation (Berger et al. 2009; Vgontzas 2008). However, other factors such as inflammation, insulin resistance, and central neural functions may also be responsible for these sleep disturbances (Vgontzas 2008). In addition, it has been suggested that obesity can be subtyped according to its different effect on sleep quality and duration, possibly due to different levels of hypothalamic–pituitary–adrenal axis activity and pro-inflammatory cytokines (Vgontzas et al. 2008). The effect of obesity on sleep duration requires further investigation.

There are some limitations to our study. Firstly, the information on sleep duration was self-reported. It has been shown that self-reported sleep duration is similar to the results collected using actigraphy (Lockley et al. 1999), although it may be biased by systematic over-reporting (Lauderdale et al. 2008). Secondly, the body weight information in this study was also self-reported. It has been revealed that obesity prevalence estimates based on self-reported information may be biased as women tend to underreport their weight and men tend to overreport their height (Ezzati et al. 2006).

In conclusion, the results of this study suggest that quantile regression can provide information that may be masked by OLS in analyzing the relationship between sleep duration and BMI in adults. The gender difference is apparent in the determinants of BMI. Sleep counseling or treatment with the aim to obtain the optimal sleep duration may help to reduce BMI in obese men.

Conflict of interest The authors declare that they have no competing interests.

References

Anderson JW, Konz EC, Frederich RC, Wood CL (2001) Long-term weight-loss maintenance: a meta-analysis of US studies. Am J Clin Nutr 74:579–584

Berger KI, Goldring RM, Rapoport DM (2009) Obesity hypoventilation syndrome. Semin Respir Crit Care Med 30:253–261

Bjorvatn B, Sagen IM, Oyane N, Waage S, Fetveit A, Pallesen S, Ursin R (2007) The association between sleep duration, body mass index and metabolic measures in the Hordaland Health Study. J Sleep Res 16:66–76

Cappuccio FP, Taggart FM, Kandala NB, Currie A, Peile E, Stranges S, Miller MA (2008) Meta-analysis of short sleep duration and obesity in children and adults. Sleep 31:619–626

Chaput JP, Despres JP, Bouchard C, Tremblay A (2007) Short sleep duration is associated with reduced leptin levels and increased adiposity: results from the Quebec family study. Obesity 15:253–261

Chaput JP, Despres JP, Bouchard C, Tremblay A (2008) The association between sleep duration and weight gain in adults: a 6-year prospective study from the Quebec Family Study. Sleep 31:517–523

Cournot M, Ruidavets JB, Marquie JC, Esquirol Y, Baracat B, Ferrieres J (2004) Environmental factors associated with body mass index in a population of Southern France. Eur J Cardiovasc Prev Rehabil 11:291–297

Department of Health (2010) Nutrition and Health Survey in Taiwan, Department of Health. http://nahsit.survey.sinica.edu.tw. Accessed 22 Apr 2010

Ezzati M, Martin H, Skjold S, Vander Hoorn S, Murray CJ (2006) Trends in national and state-level obesity in the USA after correction for self-report bias: analysis of health surveys. J R Soc Med 99:250–257

Flegal KM, Carroll MD, Kuczmarski RJ, Johnson CL (1998) Overweight and obesity in the United States: prevalence and trends, 1960–1994. Int J Obes Relat Metab Disord 22:39–47

Flegal KM, Carroll MD, Ogden CL, Curtin LR (2010) Prevalence and trends in obesity among US adults, 1999–2008. JAMA 303:235–241

Fogelholm M, Kronholm E, Kukkonen-Harjula K, Partonen T, Partinen M, Harma M (2007) Sleep-related disturbances and physical inactivity are independently associated with obesity in adults. Int J Obesity 31:1713–1721

Friedman JM (2009) Leptin at 14 y of age: an ongoing story. Am J Clin Nutr 89:973S–979S

Gangwisch JE, Malaspina D, Boden-Albala B, Heymsfield SB (2005) Inadequate sleep as a risk factor for obesity: analyses of the NHANES I. Sleep 28:1289–1296

Guh DP, Zhang W, Bansback N, Amarsi Z, Birmingham CL, Anis AH (2009) The incidence of co-morbidities related to obesity and overweight: a systematic review and meta-analysis. BMC Public Health 9:88

Heslop P, Smith GD, Metcalfe C, Macleod J, Hart C (2002) Sleep duration and mortality: the effect of short or long sleep duration on cardiovascular and all-cause mortality in working men and women. Sleep Med 3:305–314

Knutson KL, Spiegel K, Penev P, Van Cauter E (2007) The metabolic consequences of sleep deprivation. Sleep Med Rev 11:163–178

Koenker R, Bassett G Jr (1978) Regression quantile. Econometrica 46:33–50

Koenker R, Hollack KF (2001) Quantile regression. J Econ Perspect 15:143–156

Kripke DF, Garfinkel L, Wingard DL, Klauber MR, Marler MR (2002) Mortality associated with sleep duration and insomnia. Arch Gen Psychiatry 59:131–136

Lauderdale DS, Knutson KL, Yan LL, Liu K, Rathouz PJ (2008) Self-reported and measured sleep duration: how similar are they? Epidemiology 19:838–845

Lauderdale DS, Knutson KL, Rathouz PJ, Yan LL, Hulley SB, Liu K (2009) Cross-sectional and longitudinal associations between objectively measured sleep duration and body mass index: the CARDIA Sleep Study. Am J Epidemiol 170:805–813

Leicester A, Windmeijer F (2004) The ‘fat tax’: economic incentives to reduce obesity. The Institute for Fiscal Studies Briefing Notes BN49. http://www.ifs.org.uk/bns/bn49.pdf. Accessed 10 June 2010

Lin YC, Yen LL, Chen SY, Kao MD, Tzeng MS, Huang PC, Pan WH (2003) Prevalence of overweight and obesity and its associated factors: findings from National Nutrition and Health Survey in Taiwan, 1993–1996. Prev Med 37:233–241

Lockley SW, Skene DJ, Arendt J (1999) Comparison between subjective and actigraphic measurement of sleep and sleep rhythms. J Sleep Res 8:175–183

Lopez-Garcia E, Faubel R, Leon-Munoz L, Zuluaga MC, Banegas JR, Rodriguez-Artalejo F (2008) Sleep duration, general and abdominal obesity, and weight change among the older adult population of Spain. Am J Clin Nutr 87:310–316

Low S, Chin MC, Deurenberg-Yap M (2009) Review on epidemic of obesity. Ann Acad Med Singapore 38:57–59

McLaren L, Auld MC, Godley J, Still D, Gauvin L (2010) Examining the association between socioeconomic position and body mass index in 1978 and 2005 among Canadian working-age women and men. Int J Public Health 55:193–200

Misra A, Khurana L (2008) Obesity and the metabolic syndrome in developing countries. J Clin Endocrinol Metab 93:S9–S30

Pan WH, Flegal KM, Chang HY, Yeh WT, Yeh CJ, Lee WC (2004) Body mass index and obesity-related metabolic disorders in Taiwanese and US whites and blacks: implications for definitions of overweight and obesity for Asians. Am J Clin Nutr 79:31–39

Patel SR, Malhotra A, Gottlieb DJ, White DP, Hu FB (2006a) Correlates of long sleep duration. Sleep 29:881–889

Patel SR, Malhotra A, White DP, Gottlieb DJ, Hu FB (2006b) Association between reduced sleep and weight gain in women. Am J Epidemiol 164:947–954

Popkin BM, Gordon-Larsen P (2004) The nutrition transition: worldwide obesity dynamics and their determinants. Int J Obes Relat Metab Disord 28(Suppl 3):S2–S9

Prentice AM (2006) The emerging epidemic of obesity in developing countries. Int J Epidemiol 35:93–99

Raymond SU, Leeder S, Greenberg HM (2006) Obesity and cardiovascular disease in developing countries: a growing problem and an economic threat. Curr Opin Clin Nutr Metab Care 9:111–116

Shankar B (2010) Obesity in China: the differential impacts of covariates along the BMI distribution. Obesity 18:1660–1666

Stifel DC, Averett SL (2009) Childhood overweight in the United States: a quantile regression approach. Econ Hum Biol 7:387–397

St-Onge MP, Perumean-Chaney S, Desmond R, Lewis CE, Yan LL, Person SD, Allison DB (2010) Gender differences in the association between sleep duration and body composition: the Cardia Study. Int J Endocrinol. doi:10.1155/2010/726071

Stranges S, Cappuccio FP, Kandala NB, Miller MA, Taggart FM, Kumari M, Ferrie JE, Shipley MJ, Brunner EJ, Marmot MG (2008) Cross-sectional versus prospective associations of sleep duration with changes in relative weight and body fat distribution: the Whitehall II Study. Am J Epidemiol 167:321–329

Vgontzas AN (2008) Does obesity play a major role in the pathogenesis of sleep apnoea and its associated manifestations via inflammation, visceral adiposity, and insulin resistance? Arch Physiol Biochem 114:211–223

Vgontzas AN, Bixler EO, Chrousos GP, Pejovic S (2008) Obesity and sleep disturbances: meaningful sub-typing of obesity. Arch Physiol Biochem 114:224–236

Wen CP, David Cheng TY, Tsai SP, Chan HT, Hsu HL, Hsu CC, Eriksen MP (2009) Are Asians at greater mortality risks for being overweight than Caucasians? Redefining obesity for Asians. Public Health Nutr 12:497–506