Chapter 9

Exercise, Diet, and Obese Adolescents: Association with Sleep Deprivation

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Chapter Outline

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SLEEP HABITS IN ADOLESCENTS

Sleeping an adequate number of hours is an important part of a healthy lifestyle. In various age groups from infancy to adolescence, a large number of studies have demonstrated a high prevalence of sleep disorders associated with a great amount of inadequate sleep hygiene practices including irregularity of schedule and napping, habitual use of sleep-disturbing substances such as alcohol, caffeine, or nicotine, and engaging in physically activating, emotionally upsetting, or mentally stimulating activities (watching television, reading, listening to music, or using the computer, among others), especially in the period preceding bedtime (Medicine, 2005). These sleep disturbances have medical, psychological, and social consequences, such as daytime sleepiness (Carskadon, Vieira, & Acebo, 1993; Carskadon, Wolfson, Acebo, Tzischinsky, & Seifer, 1998; Gau & Soong, 1995), poor school performance, behavioral problems (Dahl & Lewin, 2002) and emotional health concerns (Dahl & Lewin, 2002; Ohayon, Roberts, Zulley, Smirne, & Priest, 2000).

Sleep duration or total sleep time typically refers to the total amount of sleep obtained either during the nocturnal sleep episode or across the 24-h period. Several studies show that sleep duration declines considerably from the newborn period to late adolescence, but substantial individual variability remains at all ages. Sometimes a common problem is that parents think that children do not get enough hours of sleep for their age and tend to overestimate children’s sleep requirements (Ferber, 1990; Largo & Hunziker, 1984). This is a problem because if the time children spend in bed exceeds their actual sleep need, they may struggle at bedtime, awaken during the night, or awaken too early in the morning. An effective approach to improving these sleep problems is to adjust the time in bed to the real sleep requirement for each age range. Indeed, the average number of hours of sleep that a child (6–13 years) needs is 10–13h, compared with 14–16h required by an infant (0–6 years) (Iglowstein, Jenni, Molinari, & Largo, 2003). During adolescence (13–19 years), the number of hours of sleep required continues to decrease, with the average being approximately 8–9h each night (Strauch & Meier, 1988; Yarcheski & Mahon, 1994). Moreover, in adolescence a sleep pattern characterized mainly by a delay of the sleep period (adolescents tend to stay up later at night and sleep later in the morning) is characteristic and thus shows an age-related increase in eveningness circadian preference. The circadian phase delay of the sleep period is more important on weekends than on weekdays. Although most adolescents go to bed before 2 am on weekdays, a low percentage does during weekends, when most teenagers go to bed between 2 and 5 am and a small percentage go to bed later than 5 am (Vela-Bueno, Fernandez-Mendoza, & Olavarrieta-Bernardino, 2009). This usually happens because on weekdays the timing of the sleep period is highly determined by early wake times mandated by the school schedule and by greater parental control over bedtime than on weekends. Because of this, there is a tendency to extend sleep during weekends, and this aspect is also attributed to psychosocial factors on weekends.
According to the criterion of the National Sleep Foundation in America for the adolescent population, less than 8 h/night is defined as insufficient sleep (Lund, Reider, Whiting, & Prichard, 2010); however, 9 h/night is considered an optimal sleep duration at this age (Carskadon & Acebo, 2002). However, the data vary according to different countries. Whereas in European adolescents the average duration of daily sleep is around 8 h in both sexes (Garaulet, Ortega, et al., 2011), these results are higher than data obtained in Asian countries such as China (Liu, Zhao, Jia, & Buysse, 2008), India (Gupta et al., 2008), and South Africa (Reid, Maldonado, & Baker, 2002) (ranging from 7.1 to 7.8 h). The decreased sleep time seen in Chinese adolescents parallels findings reported for adolescents in the United States (Carskadon & Acebo, 2002). All of these studies show that the adolescents in most countries have insufficient sleep duration. This fact has pathological consequences that will be discussed in the next sections.

**Different Factors in Sleep Duration and Quality**

Although many different aspects may be involved in sleep duration, such as cultural factors and social behaviors, other, more endogenous factors such as genetic factors may be also implicated. Indeed, it has been demonstrated that several clock genes are related to the duration of sleep or to the individual chronotype (eveningness or morningness). This is the case, for example, of some single nucleotide polymorphisms (SNPs) in Circadian Locomotor Output Cycles Kaput (CLOCK), an essential element of the positive regulatory arm in the human biological clock; for example, genetic variants in CLOCK 3111T/C, specifically carriers of the minor C allele, had: (1) shorter sleep duration, (2) delayed breakfast time, (3) evening preference, and (4) less compliance with a Mediterranean Diet pattern, compared with TT homozygotes (Garaulet, Sanchez-Moreno, et al., 2011). A further studied performed by our group also demonstrated that C carriers of CLOCK 3111T/C displayed a less robust circadian rhythm than TT and a delayed acrophase that characterizes evening-type subjects (Bandin et al., 2013). We also found highly consistent associations between morning/evening questionnaires across the different genotype categories at SIRT1 and CLOCK loci. Subjects carrying minor alleles at SIRT1 and CLOCK loci were more evening type than homozygotes for both major alleles (Garauleut et al., 2012). Other SNPs, such as those from the CKIA, PER2, or PER3, have been related to different disturbances in sleep such as advanced or delayed sleep phase disorders (Toh, 2008). More specifically, in adolescents it has been described that a PER2 gene variation is associated with alcohol consumption in interaction with sleep problems among Swedish adolescent boys (Comasco et al., 2010).

Moreover, it has been demonstrated that sleep patterns and quality differed between adolescents born preterm and term; indeed, adolescents born preterm demonstrated significantly earlier bed and wake times and sleep midpoints (approximately 22 min after adjusting for demographic and psychosocial factors) by actigraphy. They also had significantly fewer arousals and reported being more rested and alert in the morning, as well as less sleepy and fatigued. These findings support a growing body of evidence that perinatal factors may influence sleep phenotypes later in life. These factors may reflect developmental influences, as well as the influence of parenting styles on children’s sleep (Hibbs et al., 2013).

**Social Jet Lag**

Another relevant aspect to be considered in adolescence is the permanent social jet lag experienced by a number of adolescents, which results in chronic sleep loss. This concept refers to the discrepancies between social and biological timing. Social (e.g., school and work) schedules interfere considerably with individual sleep preferences in most of the population. Late chronotypes (evening type) show the largest differences in sleep timing between work and free days, leading to a considerable sleep debt on work days, for which they compensate on free days. The discrepancy between work and free days, between social and biological time, can be described as social jet lag (Wittmann, Dinich, Merrow, & Roenneberg, 2006). Among adolescents, some studies have demonstrated that social jet lag is also more frequent among evening types. Older adolescents and evening-oriented adolescents claimed later rising time and bedtime, shorter sleep length on weekdays, but longer sleep duration on weekends and greater social jetlag. Epidemiological studies have demonstrated that greater social jet lag is highly related to obesity (Collado Mateo, Diaz-Morales, Escribano Barreno, Delgado Prieto, & Randler, 2012). Results from a large-scale epidemiological study, have shown that beyond sleep duration, social jetlag is associated with increased body mass index (BMI). Indeed, living “against the clock” may be a factor contributing to the epidemic of obesity.

**RELATIONSHIP BETWEEN SLEEP HABITS AND OBESITY**

The World Health Organization designated obesity as one of the most important public health threats because of the significant impact of chronic conditions associated with obesity, such as hypertension and type 2 diabetes. Although obesity is less prominently associated with morbidity in adolescence than adulthood (Berenson et al., 1998), a strong precursor of obesity and related morbidity in adulthood has been observed. In fact, the percentage of adolescents who
are overweight or obese has more than doubled since 1974 (Swinburn et al., 2011), and if these trends continue, it is estimated that by 2020 three of four Americans and seven of 10 people in the United Kingdom will be overweight or obese (Wang, McPherson, Marsh, Gortmaker, & Brown, 2011). Indeed several studies have shown that 50–80% of obese adolescents will become obese in adulthood (Guo & Chumlea, 1999; Must & Strauss, 1999).

Because of their public health importance, obesity in adolescence should be closely monitored. For adults, BMI values at or above 25 indicate overweight and a BMI at or above 30 defines obesity (Troiano & Flegal, 1998). In the 1990s, Must and Strauss defined adolescent obesity as a BMI in excess of the 75th percentile for at least 2 years between the ages of 13 and 17 years (Must & Strauss, 1999). However, 1 year later, Cole et al. developed internationally acceptable cutoff points for BMI for overweight and obesity by sex, between the ages of 2 and 18 years, defined as a BMI of 25 and 30 kg/m² at age 18, obtained by averaging data from 13 European countries as well as Israel and the United States (Cole, Bellizzi, Flegal, & Dietz, 2000).

Sleep deprivation in adolescence is a reality and has increased dramatically in the past half century. Throughout the literature there are numerous studies showing that poor or inadequate sleep duration increases the risk of various pathologies such as hypertension, cardiovascular disease, and most importantly, obesity (Shiromani, & Horvath, & Redline, & Van Cauter, & 2012). Indeed, a large study (n=9588) in which weight and sleep duration was measured during the years 1982–1984 and self-reported weights in 1987 and 1992 in the United States demonstrated that those who had less than 4 h of sleep a night were 73% more likely to be obese than those who had the recommended 7–9 h of rest (Gangwisch, Malaspina, Boden-Albala, & Heymsfield, 2005). Moreover, those who averaged 5 h of sleep had 50% greater risk, and those who had 6 h had 23% more (Figure 1) (Gangwisch et al., 2005).

Different causes could explain the relationship between reduced sleep duration and obesity in adolescence. A recent study demonstrated that in European adolescents (HELENA study), short sleep duration was associated with higher adiposity markers (Garaulet, Ortega, et al., 2011). The authors concluded that this association could be related to terms found in the energy balance equation: a combination of increased food intake and more sedentary habits (Garaulet, Ortega, et al., 2011). These data are consistent with those obtained by Van Cauter and Knutson, who postulated that both lower energy expenditure and excess of energy intake could be implicated in this interaction (Van Cauter & Knutson, 2008). On the one hand, epidemiological studies indicate that sleep deprivation may induce irregular eating habits such as increased snacking between meals, and could lead to obesity by increasing the time available to eat (Garaulet, Ortega, et al., 2011; Gluck, Venti, Salbe, Votruba, & Krakoff, 2011; Nishiura, Noguchi, & Hashimoto, 2010). One possible explanation resides in the fact that insufficient sleep increased the loss of lean body mass in obese adults (Nedeltcheva, Kilkus, Imperial, Schoeller, & Penev, 2010). Amino acids released from protein degradation may stimulate hypothalamic activity that increases appetite (Karmani et al., 2011). It is also known that inadequate sleep duration could produce alterations in leptin and/or ghrelin; both are involved in the mechanisms of hunger/satiety, thereby increasing the risk of overeating and, consequently, weight gain (Van Cauter & Knutson, 2008). On the other hand, it has also been suggested that sleep duration could lead to obesity by decreasing energy expenditure (increasing tiredness) as well as changes in thermoregulation (Garaulet, Ortega, et al., 2011; Gluck et al., 2011; Nishiura et al., 2010). Figure 2 summarizes the potential mechanisms by which sleep deprivation may predispose adolescents to obesity. These processes are detailed in the next sections.

**ENERGY INTAKE, SLEEP, AND OBESITY**

As mentioned earlier, the association between short sleep duration and obesity could be due to total energy intake. Indeed, a crossover inpatient study performed in 15 men and 15 women who were studied under short (4 h/night) and habitual (9 h/night) sleep conditions, in random order, for 5 nights showed that the reduction in sleep increased energy intake by 300 kcal (St-Onge et al., 2011). This study also showed that the effect was mostly due to increased consumption of fat, notably saturated fat, during short sleep, and this higher energy intake was not compensated by increased energy expenditure.

More specifically in adolescents, several epidemiological studies also reported associations between poor sleep duration and increased energy intake. Particularly, adolescents had an increased preference for high-caloric foods, most of which came from fat and fewer from carbohydrates (Beebe, Miller, Kirk, Daniels, & Amin, 2011; Nishiura et al., 2010; Weiss et al., 2010). Other studies confirmed associations...
between short sleep and consumption of calorie-dense foods, but did not allow for an examination of macronutrient content. A recent study in European adolescents demonstrated that those considered to be shorter sleepers had a lower probability of having adequate food habits than those who slept more than 8 h per day (Garaulet, Ortega, et al., 2011). When the authors analyzed the results obtained from a food frequency questionnaire, they found that shorter sleepers did not consume an adequate amount of fruit, vegetables, and fish. Also, consumption of chips, pizza, hamburgers, pasta dishes, and snacks was higher compared with that of adolescents who slept more than 8 h per day. These data coincide with the observational study of Hitze et al., who found that short sleep was related to a lower nutritional score characterized by low consumption of healthy items (whole-grain products, milk products, fruit, vegetables and potatoes, and fish) and high consumption of risk-related items (white bread, meat products, soft drinks, fast food, and sweets) (Hitze et al., 2009). Similarly, other studies demonstrated that short sleep duration is associated with lower dietary quality in adolescents. For example European adolescents with insufficient and borderline insufficient sleep scored lower on the Diet Quality Index for Adolescents with Meal index (DQI-AM) than adolescents with optimal sleep duration (Bel et al., 2013). The DQI-AM was used to calculate overall dietary quality, considering the components’ dietary equilibrium, dietary diversity, dietary quality, and a meal index. This supports the hypothesis that the health consequences of insufficient sleep may be mediated by the relationship of insufficient sleep to poor dietary quality.

Along the same lines, in a previous work Nedeltcheva et al. showed that bedtime curtailment was accompanied by an increased consumption of snacks (Nedeltcheva et al., 2010). Indeed, Weiss et al. observed that those short sleepers also consumed approximately 500 kcal from snacks more than those who slept more (Weiss et al., 2010). The causes of this association could be that: (1) short sleep duration produces an alteration in the levels of satiety hormones, i.e., decreased leptin and increased ghrelin, which can lead to an increase in hunger and appetite (Chaput, Despres, Bouchard, & Tremblay, 2007; Spiegel, Tasali, Penev, & Van Cauter, 2004); or (2) when we sleep less, we simply have more time and/or more opportunities to eat, and sleeping short hours in an obesity-promoting environment may facilitate the excessive consumption of energy from snacks but not meals (Figure 1).

Furthermore, sleep deprivation has been found to hinder attention and impulse control, thus leading to increased hedonistic eating. An interesting recent study showed that short sleep duration resulted in changes in neuronal activity when subjects were exposed to food stimuli, and the authors observed that brain regions associated with motivation and desire were affected (St-Onge et al., 2012). This fact could indicate an increased propensity for seeking food in individuals who have poor sleep duration.

These findings support the idea that short sleep duration or sleep deprivation is related to altered dietary quality, possibly leading to obesity (increasing BMI, waist and hip circumference, and body fat percentage) and other diet-associated health problems.

**ENERGY EXPENDITURE, SLEEP, AND OBESITY**

The other side of the equation of energy balance implicated in the association between short sleep and obesity is energy expenditure. Numerous studies demonstrated a direct...
association between short sleep duration and decreased energy expenditure. Currently, adolescents frequently adopt habits that are not compatible with good sleep. Among inadequate sleep hygiene practices, some are more minutes watching television or using computers, especially in the period preceding bedtime, and more minutes spent inactive. These activities involve a decrease in energy expenditure by increasing fatigue, as well as changes in thermoregulation (Van Cauter & Knutson, 2008) (Figure 1). In this sense, a study by Garaulet et al. in which accelerometers (an objective method of choice to assess physical activity and sedentary time in a free-living environment (Westerterp, 2009)) were used showed that European adolescents who spent more time in sedentary behaviors was significantly higher among shorter sleepers than in those adolescents who slept at least 8 h per day (Garaulet, Ortega, et al., 2011). Indeed, in this study short sleepers reported more time watching television. These data coincide with several studies from the United Kingdom in which the authors showed that most television viewing carried out or near bedtime reduced sleep time (Owens et al., 1999). Currently, it is a fact among adolescents that factors such as social opportunities, extracurricular activities, academic demands, and part-time jobs contribute to delayed bedtimes (Dahl & Lewin, 2002) and to an eveningness circadian preference (sleep and wake times delayed) (Dahl & Lewin, 2002). This was demonstrated in Belgium: Adolescents who watched more television, spent more time playing video games, and used the Internet went to bed later, spent less time in bed on weekdays, and reported higher levels of tiredness during the day (Van den Bulck, 2004).

Numerous studies show recommendations for increasing adolescents’ sleep duration together with increasing physical activity and limiting television, video game, and computer use, particularly before bedtime (Moreno, Furtner, & Rivara, 2010). Recommendations are related to results showing that adolescents who engaged in more than 3.5 h of physical activity per week had more favorable measures of sleep quality, such as higher sleep efficiency and more slow-wave sleep than those who engaged in 3.5 h or less (Brand et al., 2010). In addition, other works demonstrated that average sleep duration among adolescents who participated in 15 or more minutes of vigorous physical activity five or more times per week was greater than for those who performed exercise only one time per week (Delisle, Werch, Wong, Bian, & Weiler, 2010). From these studies, it could be deduced that short sleep duration increases tiredness in adolescents and as a consequence they become more sedentary and adopt new habits that promote obesity.

**CONCLUSION**

The research reviewed here suggests that short sleep duration may increase the risk of obesity via several pathways related to a misbalance on both sides of the equation of energy balance: food intake and energy expenditure. Healthy habits in food intake and physical activity are recommended to improve sleep duration and quality. Furthermore, improving the correspondence between biological and social clocks will contribute to the management of obesity in adolescents.

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