Assessing the Influence of Sleep-Wake Variables on Body Mass Index (BMI) in Adolescents

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Abstract

Recent work has established an association between overweight/obesity and sleep duration, suggesting that short sleep duration and timing of sleeping may lead to overweight. Most of these studies considered sleep-length rather than any other aspects associated with the sleep and wake rhythm, e.g. chronotype, which is a measure of timing of sleeping (‘when to sleep’; based on the midpoint of sleep). The objective of this study was to assess the influence of different factors of the sleep-wake cycle and of co-variates on the Body Mass Index in a cross-sectional questionnaire study. Nine hundred and thirteen pupils (406 boys, 507 girls) from Southwestern Germany participated in this study. Mean age was 13.7 ± 1.5 (SD) years and range was between 11 – 16 years. We found that chronotype (β = .079) and social jetlag (β = .063) showed a significant influence on Body Mass Index (BMI), while sleep duration did not. Social jetlag is the absolute difference between mid-sleep time on weekdays and free days. Further, screen time (in front of TV, computer, β = .13) was positively related with BMI. Self-efficacy on nutrition (β = -.11), a psychological variable important in health-behaviour models, showed an influence with high scores on self-efficacy related to lower BMI. A high BMI was correlated with low fast-food consumption (β = -.12) suggesting that adolescents with high BMI may exert some control over their eating.

Keywords: adolescents, biological rhythms, chronotype, sleep duration, self-efficacy, screen time, overweight
gical clock when they can awake spontaneous rather than by an alarm clock (Wittmann, Dinich, Merrow, & Roenneberg, 2006). However, there is an on-going discussion about measuring chronotype by questionnaires, either by a clock-based questionnaire or by a circadian preference scale (Adan et al., 2012).

Recent studies showed that evening oriented adolescents (Fleig & Randler, 2009) and adults (Kanerva et al., 2012) showed a more unhealthy diet. In this study, we assessed the relationship between sleep-wake variables and overweight in adolescents, but in addition, we focus also on psychological and social variables (Magee, Iverson, Huang, & Caputi, 2008). More generally, there may be different mechanisms involved in the links between sleep-wake variables and BMI in childhood, adulthood and adolescence, e.g. when considering parental influence on sleep timing (Randler, Bilger, & Díaz-Morales, 2009).

There are some additional mediators or co-variates that might influence BMI, such as parental monitoring of eating behaviour, nutrition self-efficacy (Delahanty, Meigs, Hayden, Williamson, & Nathan, 2002), screen time (Li et al., 2010) and fast food consumption (Fleig & Randler, 2009). Parental monitoring has been found to a significant predictor in sleep duration (Randler et al., 2009), so we expected a similar influence on eating behaviour.

In addition to these well-known aspects self-efficacy has become an emerging topic in obesity research. Studies revealed a large body of evidence for the nutrition self-efficacy to enhance the motivation and the volition to change nutrition behaviour (Contento, Randell, & Basch, 2002; Luszczynska, Tryburcy, & Schwarzer, 2007). Self-efficacy in general mediates whether health-related actions are initiated, sustained or persisted (Schwarzer, 2008; Ziegelmann & Lippke, 2009). Different facets of healthy eating self-efficacy show strong correlations with BMI (Delahanty et al., 2002) and interventions aiming at eating self-efficacy showed effects on the BMI of the participating subjects (AbuSabha & Achterberg, 1997; Bas & Donmez, 2009; Roach et al., 2003). In this study, we focus on the relationship between sleep-wake variables and BMI, but we also take aspects of self-efficacy into account to expand previous work. We expect an influence of sleep-wake variables on BMI, but we further hypothesise that nutrition-related self-efficacy should be inversely correlated to BMI, that parental monitoring/control should be related to a lower BMI and that screen time and fast food consumption should be positively related to BMI.

Methods

Participants

Nine hundred and thirteen pupils (406 boys, 507 girls) from Southwestern Germany participated in this study. Mean age was 13.7 ± 1.5 (SD) years and range was between 11 – 16 years. Socioeconomic status was not measured but all participants were from middle schools (‘Realschule’) with parents from the middle class. Eight schools participated in the study but 44% of the data were from one single school. More than 95% of the participants were Caucasian. Participation was voluntary, unpaid and anonymous. Participants were informed prior to the questionnaire that this study was carried out to seek information about the sleep-wake cycle and different aspects of adolescents’ life-habits, including nutrition. The completion of the questionnaire took between 30 and 55 minutes depending on the age of the children and was done during one regular school lesson. The study has been approved by Regierungspräsidium Stuttgart (Az74 - 6499.2/101/1). Written consent was obtained from all adolescents and from the parents.
Measurement Instruments

Sleep-Wake-Variables — Subjects were asked for rise time and bed time on weekdays and on the weekend (free days) to calculate proxies of sleep length and the midpoint of sleep on free days (adopted from Roenneberg et al., 2004). The mid-sleep time on free days (MSF) is calculated from the two questions sleep-onset time and wake time days on which there are no school or social obligations. MSF is the mid-point between these two times. The measure differs from that in (Ronneberg et al., 2004) because it uses rise times and bed times. To account for sleep debt acquired during the week, the algorithm proposed in (Ronneberg et al., 2004) was used to calculate the midpoint of sleep on free days corrected for sleep debt. The algorithm is: corrected MSF = MSF - 0.5*(SDF - (5*SDW + 2*SDF)/7) with SDF is sleep duration on free days, and SDW is sleep duration on weekdays. Additionally, average sleep duration was measured by calculating (5 * weekday sleep length + 2 * free day sleep length) / 7. ‘Social jetlag’ can be quantified by calculating the absolute difference between mid-sleep on workdays (MSW) and mid-sleep on free days (MSF) (Wittmann et al., 2006).

Body Mass Index — Weight and height were asked for to calculate Body Mass Index (BMI). To assist pupils, a ruler and a weigh were present in the classroom. Although this was based on self-report, studies showed that these self-report measures are highly reliable in adolescents but generally underestimate overweight (Brener, Mcmanus, Galuska, Lowry, & Wechsler, 2003). However, as we did not classify our subjects into categories (where the underestimation of overweight could be considerable), we used the values for correlational analysis. BMI was transformed to z-scores for each gender and age group separately to remove the effects of age and gender from the relationship.

Psychological Factors — Self-efficacy related to the nutritional behaviour (NSE) was measured with a questionnaire adopted from Lach (2003) and Schaal (2013). Within the nutrition-related self-efficacy subjects responded to five Likert-scaled items dealing with self-efficacy related to internal (e.g. ‘I am sure to eat healthy even if I have ravenous appetite for something special’) or external (e.g. ‘I am sure to eat healthy even if I am opposed to specific stressors (boredom, loneliness, too much work, conflicts, …)’) influences. Responses ranged from 1 (‘I completely disagree’) to 4 (‘I totally agree’). The scale showed an acceptable internal consistency of Cronbach’s α 0.70 in the present sample (see Schaal, 2013).

Covariates — Screen time was calculated by the mean of two items i) TV, video, DVD as one item and ii) Computer/Internet as the other item scaled from more than 4 hours daily, 3-4 hours daily, 1-2 hours/daily, 30 min daily, no min/day. Fast-food consumption was assessed based on six-point scale from 1 = almost daily to 6 = never. Parental monitoring was based on a 4-point Likert scale ‘My parents take care that I am on a healthy diet’ from 1 fully disagree to 4 = fully agree.

Statistical Analyses — All data were treated as continuous data in the calculations based on Pearson’s correlations and multiple regressions. Sleep duration, chronotype and social jetlag were inter-correlated and are calculated from the same basic data, thus two statistical approaches were used. In the first, each variable was tested singly and second, a principal component analysis (PCA) with varimax rotation was applied to create one single response variable. The factors scores from (regression) from the PCA were saved and used for further calculations. SPSS 19 was used for analyses.
Results

Descriptive statistics are presented in Table 1. Weight ranged from 27.5 kg to 90.0 kg in girls (mean ± SD: 52.8 ± 10.3 kg) and from 28.8 kg to 100.0 kg in boys (57.2 ± 13.2 kg). In girls, BMI was on average 19.9 ± 3.1 (range 13.0 to 32.2), and 20.1 ± 2.9 (range 14.0 to 33.8) in boys.

Table 1
Descriptive Statistics of the Sleep Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time weekday</td>
<td>6:13</td>
<td>0:25</td>
</tr>
<tr>
<td>Rise time weekend</td>
<td>9:43</td>
<td>1:29</td>
</tr>
<tr>
<td>Bed time weekday</td>
<td>21:45</td>
<td>0:56</td>
</tr>
<tr>
<td>Bed time weekend</td>
<td>23:48</td>
<td>1:35</td>
</tr>
<tr>
<td>Social jetlag</td>
<td>2:46</td>
<td>1:07</td>
</tr>
<tr>
<td>Midpoint of sleep</td>
<td>4:15</td>
<td>1:18</td>
</tr>
<tr>
<td>Average sleep length</td>
<td>8:53</td>
<td>0:55</td>
</tr>
<tr>
<td>Screen time</td>
<td>2.64</td>
<td>0.68</td>
</tr>
<tr>
<td>Fastfood consumption</td>
<td>3.24</td>
<td>1.10</td>
</tr>
<tr>
<td>Nutrition related self-efficacy</td>
<td>3.16</td>
<td>0.75</td>
</tr>
<tr>
<td>Parental control</td>
<td>3.16</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Less than 1% of the participants had average sleep duration below 6 hours and 2% had sleep duration below 6 hours on weekdays. 17.5% of the participants were considered as overweight (11.8% overweight, 5.7% obese). Short sleep duration, late chronotype and high social jetlag were associated with higher BMI (Table 2).

Table 2
Correlation Between Body Mass Index (BMI; z-transformed) and Sleep-Wake Variables and Co-Variates

<table>
<thead>
<tr>
<th>Variable</th>
<th>Body Mass Index BMI (Z-scored)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSFsc midpoint of sleep</td>
<td>.095**</td>
</tr>
<tr>
<td>Social jetlag</td>
<td>.078*</td>
</tr>
<tr>
<td>Average sleep length</td>
<td>-.071*</td>
</tr>
<tr>
<td>Screen time</td>
<td>.118***</td>
</tr>
<tr>
<td>Fastfood consumption</td>
<td>-.067*</td>
</tr>
<tr>
<td>Nutrition related self-efficacy</td>
<td>-.111**</td>
</tr>
<tr>
<td>Parental control</td>
<td>-.065*</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01, ***p < .001.

Social jetlag was correlated with midpoint of sleep ($r = .847$), and with average sleep duration ($r = -.246$). Midpoint of sleep was correlated with average sleep duration ($r = -.510$). All three contributed to the factor solution (principal component with varimax rotation, based on the Eigen-value > 1 criterion): midpoint of sleep loaded with .964 on the first component, sleep duration negatively with -.638, and social jetlag with .878.

The four different regression models are depicted in Table 3. In all four models, screen time, fast food consumption, and nutrition related self-efficacy had a significant influence. A high amount of screen time was related to a higher BMI. Self-efficacy was negatively related to BMI, thus, children and adolescents that were confident to retain a
healthy diet even during adverse conditions or circumstances had a lower BMI. The extent to which parents exerted control about healthy eating was not related to BMI, but tended to be significant ($p < .1$) concerning social jetlag. Interestingly, fast food consumption was inversely related to BMI.

Table 3

| Regression of Sleep-Wake Variables, Screen Time, Fast-Food Consumption, Self-Efficacy and Parental Control on BMI (z-Scored for Age and Sex) |
|---|---|---|---|---|
| Midpoint of Sleep | Social Jetlag | Sleep Duration | Factor Score |
| Beta | Sig. | Beta | Sig. | Beta | Sig. | Beta | Sig. |
| Sleep variable | .079 | .028 | .063 | .070 | -.057 | .102 | .084 | .020 |
| Screen time | -.129 | .001 | -.127 | .001 | -.123 | .001 | -.131 | .001 |
| Fast-food consumption | -.111 | .001 | -.109 | .001 | -.113 | .001 | -.112 | .001 |
| Nutrition related self-efficacy | -.050 | .137 | -.057 | .085 | -.054 | .107 | -.049 | .148 |

Midpoint of sleep and social jetlag were also significant predictors, but average sleep duration was not. When composing the variables together in a single response variable, this variable also produced a significant effect.

Discussion

The results presented here add to previous knowledge about sleep duration and overweight (Anic et al., 2010; Baron et al., 2011; Chaput & Tremblay, 2007; Chaput et al., 2006; Chaput et al., 2012; Eisenmann et al., 2006; Lumenget al., 2007; Roenneberg et al., 2012; Snellet al., 2007; Taveraset al., 2008) but suggest that chronotype and social jetlag – rather than average sleep duration – may be the more important statistical predictors of the BMI (Roenneberg et al., 2012), and thus, should be incorporated in studies dealing with overweight and obesity in adolescents. Moreover, it seems that not sleep duration alone may be the most relevant variable but chronotype as measured by the midpoint of sleep. However, the approach based on creating a single variable out of the three by a principal component analysis also showed a significant influence. Thus it may be a better solution for further studies to calculate different variables and to unify them by a statistical method. As adolescent are strongly influenced by school start times (which remain rather similar during school life), the developmental change towards late chronotype during puberty inevitably results in sleep loss according to later bed times (Dollman, Ridley, Olds, & Lowe, 2007), which may have severe consequences for obesity. Especially during adolescence, there is an abrupt change in chronotype from morning to evening types at around the age of 12-14 years (Randler, 2011) suggesting that adolescents at this age are especially high at risk.

Further, the study shows that incorporating some additional variables is important because adolescents have not the full control over their eating, and parental monitoring might be a predictor of BMI. However, perceived parental influence seems weak, which might be related to the age group of our study when adolescents become increasingly independent from their parents.
Importantly, psychological aspects – in detail the self-efficacy – have an impact on the dietary behaviour and thus on the BMI. Individuals who perceive themselves as self-efficient with respect to their dietary behaviour had a lower BMI. This stresses the importance of self-efficacy as a health-related behaviour in the relationship between sleep and overweight.

Interestingly, we found BMI inversely correlated with fast-food consumption. We suppose that individuals who are less satisfied with their weight may be more nutrition conscious in terms of not eating so much fast food. This engagement with dietary questions according to the personal self-perception would be stronger for individuals with a higher BMI than for subjects with a lower one who won’t care about it. This at the first sight confusing result is in line with findings of Sabiston and Crocker (2008) who reported similar effects also in adolescents. According to them research should also focus on longitudinal designs to follow the progression of BMI and diet. But also those adolescents that are underweight may have poorer nutrition and tend towards fast foods, which could also explain the inverse relationship.

Another aspect may be the circadian timing of hormone secretion, especially of leptin and ghrelin which are responsible for energy balance. Hormones of the somatotropic and the hypothalamo-pituitary adrenal axis are involved in sleep regulation (Kluge, Schüssler, Zuber, Yassouridis, & Steiger, 2007), e.g. ghrelin administered around sleep onset increased slow-wave-sleep (Kluge et al., 2007). Also, in the morning, cortisol levels are higher in morning types than in evening given same wake and wake times (Randler & Schaal, 2010), and cortisol and ghrelin affect each other. Further, ghrelin injected in the early morning did not alter sleep but enhanced cortisol (Kluge et al., 2007). We know from melatonin that it is dependent on chronotype, i.e. late chronotypes have a later melatonin peak. Therefore, it might be possible that hormones responsible for energy balance are also time- and chronotype dependent. This could explain why evening types often skip breakfast (Meule, Roeser, Randler, & Kübler, 2012).

Biological and endocrine changes during adolescence period may affect lipid metabolism, circadian preference, nutritional behaviours and sources of interests (screen time, physical activities…). These pubertal transitions occur principally between ages 10 to 16 which were the age of our study population. Therefore, the study population may be very heterogeneous concerning age. Perhaps in the future, studies might focus on a small age range or analyse age groups separately (given high sample sizes).

Limitations
In general, this study was correlational and cross-sectional, thus it is limited and we cannot infer causality. In addition, the study was based on self-report which might be critical concerning some variables (BMI, see below) and others not (e.g. sleep variables).

One limitation of the study is the self-reporting of weight and height which usually leads to an underestimation of BMI. This systematic under-reporting of weight may have affected the results and it may have reduced the power to detect an effect (because fewer children are at the heavier end of the BMI spectrum). However, we placed a ruler and a weigh in the classroom for the pupils which could have improved the self-reporting.

The NSE scale has been recently developed and seems an appropriate tool for adolescents but needs further evaluation to provide convergent and discriminant validity. Further, we did not measure social deprivation.

Further studies should also collect data on other aspects like physical activity but epidemiological studies in schools always face the problem of time constraints and willingness to participate.
Conclusions
To advance the field further, chronotype should be incorporated in further research in obesity. Further, researchers and clinician may be aware of the bed times as one possible point for interventions to prevent obesity. Recent studies suggest that chronotype could be – at least to some extent – changed to morningness when parents set the bed times (Randler et al., 2009).

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References


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