Sleep Medicine 40 (2017) 106–109

Contents lists available at ScienceDirect

Sleep Medicine

journal homepage: www.elsevier.com/locate/sleep

Brief Communication

The sex-specific interaction between food responsiveness and sleep duration explaining body mass index among children

Junilla K. Larsen [a, *, 1], E.F.C. Sleddens [b, 1], J.M. Vink [a], Nina van den Broek [a], S.P.J. Kremers [b]

[a] Behavioural Science Institute, Radboud University, PO Box 9140, 6500 HE Nijmegen, The Netherlands
[b] Department of Health Promotion, NUTRIM School of Nutrition and Translational Research in Metabolism, Maastricht University Medical Center+, Maastricht, The Netherlands

ARTICLE INFO

Article history:
Received 22 February 2017
Received in revised form
13 September 2017
Accepted 15 September 2017
Available online 12 October 2017

Keywords:
Body mass index
Children
Cross-sectional
Food responsiveness
Sex
Sleep

ABSTRACT

Objective/background: The inverse relationship between sleep duration and body mass index (BMI) has been well established and appears to be stronger among boys than girls. However, less is known about the mechanisms responsible for this sex-specific link. The main aim of the current study was to examine the sex-specific interaction between food responsiveness and sleep duration in explaining BMI among children. This sex-specific moderation will give more insight into a possible underlying food intake mechanism.
Patients/methods: In total, 206 caregivers filled out questionnaires on child's sleep duration and food responsiveness (49.5% boys; mean age = 9.5 years; standard deviation = 1.4 years). Child's weight and height were measured, after which age- and sex-specific standardized BMI values (referred to as zBMI here) were calculated. Descriptive statistics and regression analysis were conducted. A potential significant three-way interaction was further examined using simple slopes analysis and slope difference tests.
Results: A significant inverse correlation was found between sleep duration and zBMI for boys, but not for girls. Moreover, a significant and robust three-way interaction between sex, food responsiveness and sleep duration explaining child's zBMI was found. Slope difference tests indicate that the sleep–BMI slopes only significantly differed between high-food-responsive boys and high-food-responsive girls and between high-food-responsive boys and low-food-responsive boys.
Conclusions: These findings suggest that increased food intake might be a mechanism explaining the inverse sleep–BMI link among boys.

1. Introduction

The inverse relationship between sleep duration and body mass index (BMI) has been well established [1], and found to be stronger in boys than in girls [2]. Moreover, findings of a recent systematic review of randomized controlled trials indicate that successfully increased sleep duration has the potential to prevent excessive weight gain in children [3]. Together, these findings underscore the importance of sleep duration for BMI among children. However, less is known about the mechanisms that are responsible for this potential sex-specific link between sleep duration and BMI among children.

To date, increased food intake has proven to be a primary mechanism following experimental sleep restriction in adults [4] and some research suggests that it also is an important mechanism among children [5]. Reduced sleep duration may lower secretion of leptin, a hormone produced by adipocytes, which may induce hunger feelings, increased food intake, and subsequent increases in BMI [6,7]. Notably, leptin levels are generally lower among boys compared to girls [8] and one previous study found that sleep duration was positively correlated with morning leptin levels in boys only [9]. These findings may suggest that boys are more vulnerable to (further) decreasing leptin levels and subsequent increased hunger feelings, food intake and BMI after reduced sleep duration compared to girls.

If sex-specific differences in leptin-induced food intake after reduced sleep duration indeed explains the stronger inverse sleep–BMI relationship among boys, then one would expect that food responsiveness influences this relationship, particularly

* Corresponding author.
E-mail address: j.larsen@bsi.ru.nl (J.K. Larsen).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.sleep.2017.09.025
1389-9457/© 2017 Published by Elsevier B.V.

among boys. Food responsiveness refers to one's predominantly genetic susceptibility to the hedonistic qualities of food cues and lack of internal cues for hunger [10]. Notably, the influence of food responsiveness on the inverse sleep–BMI link among boys may not only be explained by their heightened vulnerability to decreasing leptin levels after reduced sleep duration, but also by their increased willingness to make greater efforts to get (food) rewards than girls [11].

To the best of our knowledge, the sex-specific influence of food responsiveness on the relationship between sleep and BMI has not been examined before, and it is important to examine as it may shed more light on a potential food intake mechanism explaining the sleep–BMI relation in children. Hence, the main aim of the current study is to examine the sex-specific interaction between food responsiveness and sleep duration in explaining BMI among children. We expect that the negative association between sleep duration and BMI will be stronger for food-responsive-boys than for girls.

2. Material and methods

2.1. Procedures and participants

Fourteen primary schools in the southern and middle part of the Netherlands participated in this study, between April 2014 and July 2016. Invitation letters for this study were handed out to fourth through eight graders (children between the ages of 7 and 12 years) at schools. Enclosed was an informed consent form, through which caregivers could give permission to participate, and the caregiver's questionnaire. The study protocol was approved by the IRB of the Radboud University, Nijmegen, the Netherlands (code number: ECSW2013-1811-143).

The total number of received consent forms was 216 (participation rate of approximately 20–25%). In total, 206 cases with complete data were available for analyses (ie 186 questionnaires were completed by mothers, 19 by fathers, and one by a grandmother). Children's mean age was 9.5 (standard deviation, SD = 1.4) years.

2.2. Measures

2.2.1. Sleep duration

Child's sleep duration was assessed by asking the caregiver to indicate what time their child usually goes to bed and wakes up, separately for nights before working days and weekend days. Mean sleep duration per night was calculated for each child.

2.2.2. Food responsiveness

Child food responsiveness (eg “My child is always asking for food”) as reported by caregivers was measured with the Food Responsiveness subscale (five items on a five-point Likert-type item scale from 0 (Never) to 4 (Always)) of the Children's Eating Behavior Questionnaire [12,13]. In the current study, Cronbach's alpha was 0.78.

2.2.3. Child zBMI values

Trained students and research assistants visited the primary schools to measure children's weight (Seca 803) and height (Seca Leicester 213). Each child's BMI (in kg/m^2) was then recoded into age- and sex-specific standardized BMI values (referred to as zBMI in this manuscript) and compared to the national reference population [14].

2.3. Data analyses

Our data comply with the suggested guidelines for normality, linearity and homoscedasticity [15]. IBM SPSS statistics 23 was used to perform univariate descriptive and correlational analyses. Bivariate correlations were conducted for boys and girls separately to assess associations between child sleep duration, food responsiveness, zBMI, and potential covariates (ie child's age, caregiver's education level and ethnicity). The regression analyses were performed in the R statistical program [16]. A potential significant three-way interaction between sleep duration, sex, and food responsiveness on child's zBMI was further examined with simple slopes analysis [17] and slope difference tests [18] using the “pequod” package [19].

3. Results

Background characteristics (Mean (*M*) and Standard Deviation (*SD*)) and correlations of the key study variables and potential covariates are depicted in Table 1. Child sleep duration was negatively associated with child's zBMI for boys, but not for girls. Food responsiveness was positively associated with child's zBMI for both boys ($r = 0.30$) and girls ($r = 0.33$). Child's age and caregiver's education and ethnicity correlated significantly with child's zBMI (all $p < 0.05$) and were therefore added to the moderation analysis as control variables.

The moderation analysis showed a significant three-way interaction between sex, food responsiveness, and sleep duration on child's zBMI ($b = 0.35$, standard error (SE) = 0.14, $t = 2.37$, $p = 0.019$). This interaction remained significant in a reduced model without covariates ($b = 0.40$, SE = 0.15, $t = 2.69$, $p = 0.008$). The simple slopes are visually represented in Fig. 1. Simple slopes analysis revealed that the inverse sleep–BMI relation was only statistically significant among high-food-responsive boys ($b = -0.51$, SE = 0.16, $t = -3.17$, $p = 0.002$), but not among low-food-responsive boys ($b = -0.08$, SE = 0.13, $t = -0.59$, $p = 0.558$) and girls (low food responsiveness: $b = -0.29$, SE = 0.18, $t = -1.66$, $p = 0.098$; high food responsiveness: $b = -0.04$, SE = 0.15, $t = -0.25$, $p = 0.801$). Slope difference tests indicate that the sleep–BMI slopes differed between high-food-responsive boys and high-food-responsive girls ($t = 2.21$, $p = 0.028$) and between high-food-responsive boys and low-food-responsive boys ($t = 2.17$, $p = 0.031$). None of the other comparisons were significant.

4. Discussion

The negative relationship between sleep duration and BMI is well established, and growing evidence suggests this link is causal. However, less is known about the mechanisms responsible for this link. The current study found evidence for two moderators that in interaction may give some insight into why shorter sleep duration may lead to a higher BMI in children. Less sleep was only significantly associated with higher zBMI among boys with higher food responsiveness, and not among lower-food-responsive boys and among girls. This suggests that, in line with some first experimental findings among children [5], increased food intake might be a mechanism explaining the inverse sleep–BMI link among boys.

Notably, the inverse sleep–BMI association that differed between high- and low-food-responsive boys and between high-food-responsive boys and high-food-responsive girls may be explained by sex-specific vulnerabilities to leptin-induced increased food intake after reduced sleep duration [9]. In addition, boys also make higher efforts to get (food) rewards [11] and may thus also more actively search for food rewards in case of heightened food responsiveness compared to girls, particularly when they are sleep deprived. Although we found rather similar correlations between food responsiveness and BMI for boys and

Table 1
Means, standard deviations, and bivariate correlations between child sleep duration, food responsiveness, age- and sex-specific standardized body mass index (zBMI) values and potential covariates for boys ($N = 102$) and girls ($N = 104$).

		1	2	3	4	5	6
1. Child sleep duration (mean h/day)		–	−0.12	−0.15	−0.28**	−0.03	0.08
2. Food responsiveness (0–4)		0.01	–	0.33***	0.06	−0.09	0.21*
3. zBMI values		−0.28**	0.30**	–	0.32***	−0.18†	0.32***
4. Child age (months)		−0.57***	0.06	0.32***	–	−0.04	−0.15
5. Caregiver education[a]		0.02	0.06	−0.18†	−0.08	–	−0.17†
6. Caregiver ethnicity[b]		−0.17	0.10	0.13	0.03	−0.06	–
Boys	Mean	10.60	0.82	−0.15	114.44	–	–
	Standard deviation	0.61	0.61	1.22	15.44	–	–
Girls	Mean	10.79	0.97	−0.16	113.96	–	–
	Standard deviation	0.51	0.66	1.10	16.31	–	–

***$p \leq 0.001$, **$p \leq 0.01$, *$p \leq 0.05$, †$p \leq 0.10$. Correlations below the diagonal are for boys, correlations above the diagonal are for girls; for caregiver's education (as reported by questionnaire completer) there were two missing values; point-biserial correlations were run for caregiver education and ethnicity.

[a] 1 = Low level of education (primary school, pre-vocational school, and lower general secondary education): $n = 19$ (9.3%); 2 = medium level of education (higher general secondary education, pre-university secondary education, and intermediate vocational education): $n = 98$ (48.0%); 3 = High level of education (higher vocational education and university): $N = 87$ (42.6%).

[b] 1 = Dutch origin (both caregivers born in the Netherlands): $N = 179$ (86.9%); 2 = non-Dutch origin (one or both caregivers born outside the Netherlands: $N = 27$ (13.1%)).

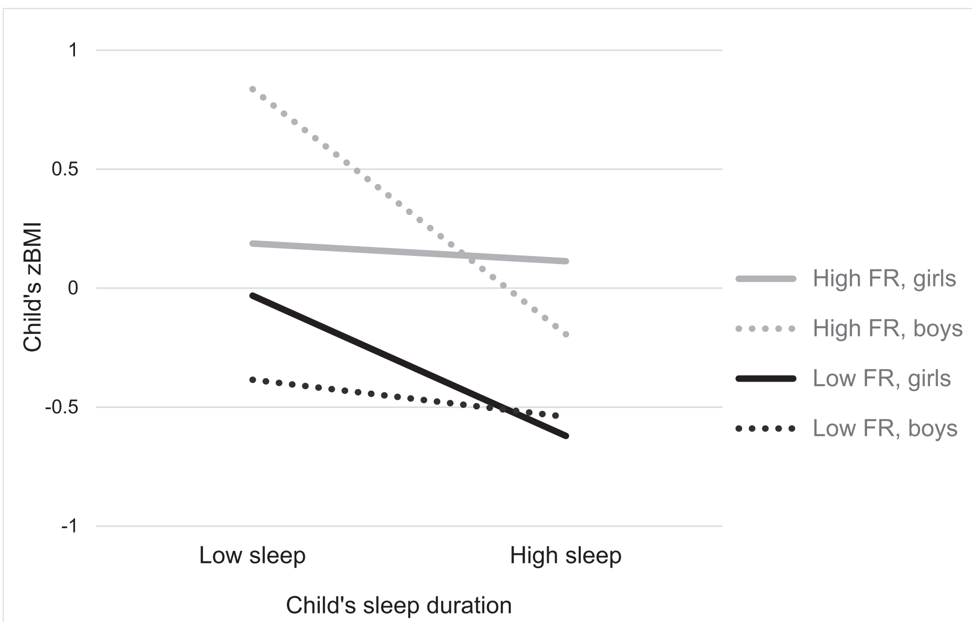

Fig. 1. Simple slopes describing child's age- and sex-specific standardized BMI (zBMI) predicted by the three-way interaction between child's sleep duration, food responsiveness (FR) and sex.

girls, it should be noted that previous research has reported stronger positive associations between food responsiveness and BMI among boys compared to girls [20].

Although our findings are new, they are limited by the cross-sectional design, meaning that no causal inferences can be made. Moreover, we used a self-report survey to assess average sleep duration, as has been used widely in epidemiological research. A sleep diary may give more valid insight into how much people have actually slept during the night [21]. It should be noted, however, that we asked about average time points of going to bed and waking up, separately for week and weekend days. These questions have been argued to have the advantage because they are somewhat less biased than simple recall questions about average hours of sleep [22] and are also used in validated sleep questionnaires to assess children's sleep duration [23]. Finally, our participation rate is relatively low, but rather comparable to other studies using active consent procedures [24].

To conclude, the sex-specific interaction of food responsiveness moderating the sleep–BMI relation is interesting and future experimental research should further examine the proposed gender-specific mechanisms (ie higher efforts to get rewards and reduced leptin levels) explaining this interaction. Moreover, future prospective research should further examine the causal order of effects and alternative models (eg sleep duration–food responsiveness–BMI with moderated mediation by sex).

Acknowledgements

This research was funded by the Netherlands Heart Foundation (project number 2014T037) awarded to Ester Sleddens, and a small internal research grant from the Behavioural Science Institute (ie Developmental Psychopathology) of the Radboud University. The authors would like to acknowledge the following who provided assistance on the project: Elise Arends, Tessa de Bruijn, Wieneke de Groot, Dorinde den Boer, Farah Mirzakhel, Melanie Oldenkater, Charlotte Peters, Lieke Raaijmakers, Hannah Schiffers, Joyce Schut, Lindsay Stassar, Joyce van Stiphout, and Nadia Verhoeff.

Conflict of interest

The authors have no conflicts of interest to declare.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2017.09.025.

References

[1] Fatima Y, Doi SAR, Mamun AA. Sleep quality and obesity in young subjects: a meta-analysis. Obes Rev 2016;17:1154–66.
[2] Chen X, Beydoun MA, Wang Y. Is sleep duration associated with childhood obesity? A systematic review and meta-analysis. Obesity 2008;16:265–74.
[3] Yoong SL, Chai LK, Williams CM, et al. Systematic review and meta-analysis of interventions targeting sleep and their impact on child body mass index, diet, and physical activity. Obesity 2016;24:1140–7.
[4] Spaeth AM, Dinges DF, Goel N. Effects of experimental sleep restriction on weight gain, caloric intake, and meal timing in healthy adults. Sleep 2013;36:981–90.
[5] Hart CN, Carskadon MA, Considine RV, et al. Changes in children's sleep duration on food intake, weight, and leptin. Pediatrics 2013;132:e1473–80.
[6] Taheri S, Lin L, Austin D, et al. Short sleep duration is associated with reduced leptin, elevated ghrelin, and increased body mass index. PLoS Med 2004;1:e62.
[7] Spiegel K, Leproult R, L'Hermite-Balériaux M, et al. Leptin levels are dependent on sleep duration: relationships with sympathovagal balance, carbohydrate regulation, cortisol, and thyrotropin. J Clin Endocrinol Metab 2004;89:5762–71.
[8] Blum WF, Englaro P, Hanitsch S, et al. Plasma leptin levels in healthy children and adolescents: dependence on body mass index, body fat mass, gender, pubertal stage, and testosterone. J Clin Endocrinol Metab 1997;82:2904–10.
[9] Storfer-Isser A, Patel SR, Babineau DC, et al. Relation between sleep duration and BMI varies by age and sex in youth age 8–19. Pediatr Obes 2012;7:53–64.
[10] Carnell S, Haworth CM, Plomin R, et al. Genetic influence on appetite in children. Int J Obes 2008;32:1468–73.
[11] Chelonis JJ, Gravelin CR, Paule MG. Assessing motivation in children using a progressive ratio task. Behav Process 2011;87:203–9.
[12] Wardle J, Guthrie CA, Sanderson S, et al. Development of the children's eating behaviour questionnaire. J Child Psychol Psychiatry 2001;42:963–70.
[13] Sleddens EFC, Kremers SPJ, Thijs C. The children's eating behaviour questionnaire: factorial validity and association with body mass index in Dutch children aged 6–7. Int J Behav Nutr Phys Act 2008;5:49.
[14] Fredriks AM, Van Buuren S, Wit JM, et al. Body index measurements in 1996–7 compared with 1980. Arch Dis Child 2000;82:107–12.
[15] Tabachnick BG, Fidell LS. Using multivariate statistics. Boston (MA): Allyn and Bacon; 2001.
[16] R Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2017.
[17] Aiken LS, West SG, Reno RR. Multiple regression: testing and interpreting interactions. Newbury Park, CA: Sage; 1991.
[18] Dawson JF, Richter AW. Probing three-way interactions in moderated multiple regression: development and application of a slope difference test. J Appl Psychol 2006;91:917–26.
[19] Mirisola A, Seta L. pequod: Moderated Regression Package. R package version 0.0-5. 2016. https://CRAN.R-project.org/package=pequod.
[20] Fulkerson JA, Hannan P, Rock BH, et al. Food responsiveness, parental food control and anthropometric outcomes among young American Indian children: cross-sectional and prospective findings. Ethn Dis 2013;23:136–42.
[21] Miller CB, Gordon CJ, Toubia L, et al. Agreement between simple questions about sleep duration and sleep diaries in a large online survey. Sleep Health 2015;1:133–7.
[22] Lauderdale DS. Commentary on "Agreement between simple questions about sleep duration and sleep diaries in a large online survey". Sleep Health 2015;1:138–9.
[23] Galland BC, Taylor BJ, Elder DE, et al. Normal sleep patterns in infants and children: a systematic review of observational studies. Sleep Med Rev 2011;16:213–22.
[24] Courser MW, Shamblen SR, Lavrakas PJ, et al. The impact of active consent procedures on nonreponse and nonreponse error in youth survey data: evidence from a new experiment. Eval Rev 2009;33:370–95.