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Sleep duration and eating behaviours are associated with body composition in 5-year-old children: Findings from the ROLO longitudinal birth cohort study

Anna Delahunt[1], Marie C Conway[1], Ciara McDonnell[1,2,3], Sharleen L O Reilly[1,4], Linda M O Keeffe[5], Patricia M Kearney[5], John Mehegan[1], Fionnuala M McAuliffe[1]

[1]UCD Perinatal Research Centre, School of Medicine, University College Dublin, National Maternity Hospital, Dublin 2, Ireland

[2]Children's Health Ireland, Tallaght University Hospital, Tallaght, Dublin 24, Ireland

[3]Children's Health Ireland, Children's University Hospital, Temple Street, Dublin 1, Ireland

[4]School of Agriculture and Food Science, University College Dublin, Dublin 4, Ireland

[5]School of Public Health, College of Medicine and Health, University College Cork, Co Cork, Ireland

Corresponding Author: Professor Fionnuala M McAuliffe, UCD Perinatal Research Centre, School of Medicine, National Maternity Hospital, Dublin 2, Ireland, Phone: +353 1 6373216, Fax: +353 1 6627586, email: fionnuala.mcauliffe@ucd.ie

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Abstract

Inadequate sleep and poor eating behaviours are associated with higher risk of childhood overweight and obesity. Less is known about the influence sleep has on eating behaviours and consequently body composition. Furthermore, whether associations differ in boys and girls has not been investigated extensively. We investigate associations between sleep, eating behaviours and body composition in cross sectional analysis of 5-year-old children. Weight, height, body mass index (BMI), mid upper arm circumference (MUAC), abdominal circumference (AC) and skinfold measurements were obtained. Maternal reported information on child's eating behaviour and sleep habits were collected using validated questionnaires. Multiple linear regression examined associations between sleep, eating behaviours and body composition. Sleep duration was negatively associated with BMI, with 1-hour greater sleep duration associated with 0.24 kg/m^2 (B=0.24, CI= −0.42, −0.03, p=0.026) lower BMI and 0.21cm lower (B=−0.21, CI= −0.41, −0.02, p=0.035) MUAC. When stratified by sex, girls showed stronger inverse associations between sleep duration (hrs) and BMI (kg/m^2) (B=−0.32; CI= −0.60, −0.04, p= 0.024), MUAC (cm) (B=−0.29; CI= −0.58,0.000, p=0.05) and AC (cm) (B=−1.10; CI= −1.85, −0.21, p=0.014) than boys. Positive associations for 'Enjoys Food' and 'Food Responsiveness' with BMI, MUAC and AC were observed in girls only. Inverse associations between sleep duration and 'Emotional Undereating' and 'Food Fussiness' were observed in both sexes, although stronger in boys. Sleep duration did not mediate the relationship between eating behaviours and BMI. Further exploration is required to understand how sleep impacts eating behaviours and consequently body composition and how sex influences this relationship.

Keywords: Eating behaviours, Sleep duration, Body composition, Children

Introduction

Childhood overweight and obesity levels continue to be of worldwide concern with the World Health Organisation (WHO) regarding it as a major public health challenge [1]. European data from 2006- 2016 indicate that 17.9% of children aged 2-7 years have overweight and obesity and 5.3% have obesity, as defined by the International Obesity Task Force (IOTF) criteria [2]. Overweight and obesity rates appear to be stabilising in the Irish childhood population with most recent data estimating that childhood overweight and obesity affects 1 in 5 five-year olds [3-5]. Evidence of the impact of child sex on rates of overweight and obesity are conflicting. Data from 2016 found no differences in the worldwide rate of increase in overweight and obesity between girls and boys [5, 6], however recent data based on Irish children aged 6-7 years old, found that girls had higher levels of overweight and obesity than boys (20.4% girls/13.2% boys) [7].

Several studies [8-10] have examined the relationship between sleep and BMI and BMI z-score in children, with the majority showing that short sleep duration is associated with increased risk of obesity. Fewer studies [11, 12] have examined body composition measurements such as skinfold measurements, mid upper arm circumference (MUAC) and abdominal circumference (AC). The relationship between inadequate sleep and obesity may be influenced by a number of biological and behavioural pathways. Changes in hormone levels such as leptin and ghrelin [13], variations in the type and quantity of food eaten [14] , physical activity levels [15] and consequences of various eating behaviour styles have been considered as contributing factors [16].

A child's eating behaviour will influence the food choice and the amount of food eaten, which consequently can promote overweight and obesity [17]. Food approach eating behaviours such as food responsiveness and emotional overeating have been associated with obesity risk [18, 19]. Eating in the absence of hunger has also been associated with unhealthy BMI and increased adiposity among children [20]. It has been suggested that poor sleep and obesity may be interrelated through eating behaviour [16, 21]. Understanding this relationship is vital to better comprehend factors associated with overeating or undereating, and thereby help identify strategies for the prevention of childhood obesity [21]. Research concerning the underlying association between poor sleep and eating behaviours, such as how a child responds to food, emotional overeating and satiety response, is limited. Poor sleep may result in unhealthy eating habits such as eating when not hungry [16] or eating during times of stress

[22]. Poor sleep quality has been found to be associated with higher levels of emotional over-eating and increased food responsiveness [16]; thus, sleep duration and quality may influence risk of obesity through specific eating behaviour pathways [16].

However, the development of an unhealthy BMI in childhood is complex and multifactorial. Various influences shape children's food preferences and eating behaviours potentially predisposing them to unhealthy eating behaviours. Socio-economic status and parental education levels have been shown to influence type and quality of food eaten in childhood [23], with socio-economic disadvantage being linked with development of obesity in childhood and later life [24, 25] Environmental considerations such as family setting, parenting style [26] and parental feeding practices [27, 28] have all been shown to contribute to the development of eating behaviours in childhood.

Few studies have looked at the role of child sex in the relationship between sleep, eating behaviours and body composition, and results are mixed. A systematic review by Morrissey, Taveras (29) looking at sleep and BMI reported that, out of the 103 articles, in those that alluded to sex differences, nine indicated an association between sleep and overweight or obesity in boys only, whereas, three reported an association in girls only. These results suggest that child sex may play a role in how sleep impacts body composition but the mechanism behind this is currently not well understood.

Childhood overweight and obesity not only impacts the quality of life and health of the child, but can also track into adulthood [30] potentially influencing longer term health outcomes [31]. Preventative strategies that tackle modifiable factors such as adequate sleep duration and healthy eating behaviour are paramount in tackling this problem before it manifests.

This study aimed to investigate the association of sleep duration and eating behaviours on body composition in 5-year-old boys and girls. A secondary aim was to determine if the relationship between sleep and BMI is mediated by eating behaviours.

Methods

Population

This study presents secondary analysis from the ROLO longitudinal birth cohort study. The original ROLO study was a randomised control trial (RCT) of a low glycaemic index diet in pregnancy (ROLO study). Details of the ROLO study have been described previously [32]. In brief, secundigravid women who had previously given birth to a baby weighing over 4kg were recruited (n=800) from the National Maternity Hospital, Dublin from 2007-2011. Mothers were recruited < 18 weeks gestation, with a singleton pregnancy, had no previous history of gestational diabetes, and were over 18 years old. Mothers were randomised to either the intervention group which received dietary advice on a low glycaemic diet, or the control group who received routine antenatal care. The mothers and children born into this study (n=759) have been followed up as part of the ROLO longitudinal study. Mothers were invited for follow-up when their child turned 5 years old, with 401 mother child pairs returning at this timepoint. The current study is cross sectional in design, using data collected at the 5-year follow-up. Early maternal data was used for confounders in the analysis. Maternal education was self-reported and recorded at recruitment for the ROLO pregnancy study. Mothers selected one of the following categories; 'no schooling'; 'primary education only', 'some secondary level', 'complete secondary level', 'some third level (certificate/diploma)' or 'complete third level (higher-level degree)'.

Ethical approval was obtained from Our Lady's Children's Hospital Crumlin (OLCHC) and the National Maternity Hospital (NMH) Ethics Committees (Ethics reference number: GEN/279/12).

Anthropometric measurements

All measurements were obtained and calculated by a trained researcher. Mothers and child's weight (kg) was measured using a calibrated stand-on digital weighing scale (SECA 813) to the nearest 0.1 kg. Participants were measured in light clothing without shoes. Mothers and child's standing height was measured, without shoes, with head aligned in the Frankfort plain, using a free-standing stadiometer (SECA 217) and measurements recorded to the nearest 0.1cm. Body mass index (BMI) was calculated for mother and child as kilogram per square metre (kg/m^2). BMI z-score was calculated by subtracting the mean and dividing by the standard deviation [33]. For the child, obesity and overweight were categorised using the IOTF criteria [34, 35]. The child's head, neck, mid upper arm, chest, abdominal, hip and thigh circumferences were measured using a SECA ergonomic circumference measuring tape, to the nearest 0.1cm. Skinfold measurements including triceps, biceps, subscapular and thigh, were measured using a Holtain Tanner/Whitehouse skinfold callipers to the nearest 0.2mm. Measurements were recorded 3 times and the average calculated to improve reliability. The sum of skinfolds was calculated by the addition of the four skinfold thickness measurements to act as a marker of overall adiposity.

Sleep measurements

Sleep was recorded using the Child Sleep Habits Questionnaire (CSHQ), a 45-item, validated parental reported questionnaire that assesses sleep habits and sleep problems [(36)]. Mothers were instructed to rate the frequency of various sleep habits of a typical week (n=319). Sleep duration was calculated for each child based on usual amount of sleep per night in hours and minutes as reported by mothers and analysed as a continuous variable. Sleep requirements were based on national Health Service Executive (HSE) guidelines for recommended sleep for 5-year-old children of more than 11 hours per night [(37)].

Eating behaviour assessment

The Children's Eating Behaviour Questionnaire (CEBQ) [(38)] was completed by mothers (n=306) to evaluate their child's eating behaviours. This is a 35-item psychometric tool, which was designed to assess eating behaviour in children [(38)]. The CEBQ has been shown to have good internal and external reliability [(38, 39)] and has been validated against observational measures of eating behaviour [(40)] Each item response is graded on a 5-point Likert scale ('never to always') with 5 items within the CEBQ being reverse scored. A higher score indicates the child is more likely to express this eating behaviour. Each question relates to one of eight eating styles which can be classed as either 'Food approach' or 'Food avoidant'. The food approach category includes 'Food responsiveness' 'Enjoyment of food', 'Emotional Overeating' and 'Desire to drink'. The 'Food responsiveness' subscale contains five questions which assess a child's appetite and whether they display a heightened response to external food cues. The 'Enjoyment of food' subscale consists of four questions assessing a child's enjoyment and interest in food. The 'Emotional overeating' subscale contains four questions, which explore overeating as a reaction to negative emotions such as annoyance, worry, anxiety or boredom. The 'Desire to drink' subscale contains three questions assessing an increased desire for frequent beverage consumption. The 'Food avoidant' category includes 'Food fussiness', 'Emotional undereating', 'Slowness in eating' and 'Satiety responsiveness'. The 'Food fussiness' subscale includes six questions that assess food avoidance, selectivity and a lack of interest in food.' Emotional undereating' is assessed by four questions, exploring a child's inclination to limit food intake in times of negative and positive emotions, such as being upset, sad, happy or tired. 'Slowness in eating' comprises of four questions pertaining to the length of time a child takes to finish their meal, indicating a lack of interest in eating. The 'Satiety responsive' subscale consists of five questions, exploring a child's inability to respond to internal satiety cues and reduction in intake due to perceived fullness. In the current sample Cronbach's alpha for the CEBQ ranged from 0.695 to 0.928, thus all questions were included in the analysis.

Statistical analysis

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) (Version 24, IBM). The distribution and normality of continuous variables was determined by visual inspection of histograms and Q-plots. Mean and standard deviation (SD) were reported for normally distributed data with median and interquartile range (IQR) reported for non-normal data. Independent t-tests for normally distributed data were used to examine differences in body composition, eating behaviours and sleep duration between boys and girls. Chi-square tests were used to determine differences between boys and girls regarding BMI category, maternal education level and whether children met sleep requirements or not. Multiple linear regression analysis was performed on the full cohort of children and also stratified by sex. All analysis was adjusted for maternal education level, maternal BMI at the 5 year follow up, original RCT allocation group, child age at 5-year-old visit and whether the child had been breast fed or not. Mediation analysis was completed to determine whether the relationship between sleep and BMI is mediated by eating behaviours. The sum of the means of each of the four food approach subscales ('Enjoys food', 'Emotional overeating', 'Desire to drink' and 'Food responsiveness') were calculated to create the 'Mean food approach' variable. A 'Mean food avoidant' variable was obtained from the sum of the means of the four food avoidant subscales ('Food fussiness', 'Emotional undereating', 'Slowness in eating' and 'Satiety responsiveness'). In the mediation models, sleep duration was the independent variable, child BMI the dependent variable and 'Mean food approach' or 'Mean food avoidant' were the mediators. Mediation analysis was performed using PROCESS macro for SPSS version 3.5 [41]. PROCESS for SPSS uses a bootstrap approach to determine the significance of mediation effects [42]. This analysis estimates if the indirect effect of the independent variable (sleep) on the dependent variable (BMI) through the mediating variable (eating behaviours) is equivalent to the total effect of the independent variable on the dependent variable, minus its direct effect. Bootstrapped confidence intervals (CI) at 95% were used for 1000 resamples to test if the indirect effect of sleep duration on BMI was mediated through either ‘Mean food approach’ or ‘Mean food avoidant’ eating behaviours. Mediation occurred if the confidence interval of the indirect effect did not include 0. Mediation analysis was conducted with and without confounders, as described above.

Results

Descriptive statistics of the mother-child pairs are presented in Table 1. Child mean age was 5.1 years old, with a mean BMI of 16.2kg/m^2. Using the IOTF cut-offs for BMI [34], it was determined that 15.1% and 8.9% of children were categorised as having overweight or obesity respectively. Body composition measures, eating behaviours and sleep duration variables were considered normally distributed, therefore parametric tests were used. Girls had higher skinfold thickness measurements and higher mean scores for MUAC than boys. 61% of children met Irish Health Service Executives (HSE) sleep recommendations of 11 hours or more per night for 5-year-olds. Boys had higher mean scores for food fussiness than girls (p=0.001). Associations between sleep duration (hours) and body composition for the full group are shown in Supplementary Table 1. A 1-hour greater sleep duration was associated with 0.24 kg/m^2, (95% CI=-0.42, -0.03, p=0.026) lower BMI, 0.13 standard deviation (SD) (95% CI=-0.26, -0.01, p=0.038) lower BMI-z score and 0.21cm (95% CI =-0.410, -0.015, p=0.035) lower MUAC. When the group was stratified by child sex (Table 2), an inverse association was found between sleep duration and BMI (kg/m^2) (B=-0.32; 95% CI=-0.60, -0.04, p=0.024), BMI z-score (B=-0.18, 95% CI=-0.35, -0.02, p=0.029) MUAC (cm) (B=-0.29, 95% CI=-0.58,0.01, p=0.050) and AC (B=-1.10, 95% CI=-1.85, -0.21, p=0.014) in girls only.

Multiple linear regression analysis to examine associations between children’s eating behaviour and body composition was stratified by child sex as summarised in Table 3. Both girls and boys showed a positive association between ‘Enjoys food’ and BMI and MUAC. Significant positive associations were seen in girls only, between ‘Food responsiveness’ and BMI (kg/m^2) (B=0.09, 95% CI=0.36,2.21, p=0.007), MUAC (cm) (B=0.07, 95% CI=0.01,0.12, p=0.018) and AC (B=0.20, 95% CI=0.04,0.35, p=0.016). Associations were also found between ‘Mean food approach’ and BMI (B=0.20, 95% CI=0.09,0.31, p=<0.001), MUAC (B=0.157, 95% CI=0.040,0.274, p=0.009) and AC (B=0.41, 95% CI=0.07,0.74, p=0.018) in girls. A negative association between 'Food fussiness' and BMI (B=-0.05, 95% CI=-0.08, -0.007, p=0.020) and AC (B= -0.14, 95% CI=-0.27, -0.004, p=0.043) was found in boys only. Similarly, a negative association was only seen in boys between 'Mean food avoidant' and BMI and AC (B=-0.089, 95% CI=-0.17, -0.01,p=0.028; B=-0.31, CI= -0.58, -0.03, p=0.029). Results for the whole group are summarised in Supplementary Table 2.

We found no strong associations between sleep duration and any of the eating behaviours for the full group (Supplementary Table 3). When stratified by gender , a negative association between sleep duration and 'Emotional undereating' (B=-0.68, 95% CI=-1.34, -0.02, p=0.045) was observed in girls (Table 4). The confidence interval for the association between sleep duration and food fussiness for boys spanned the null value, however, the unstandardised coefficient B and confidence interval demonstrate some clinical significance (B=-1.35, CI=-2.72, 0.0009, p=0.052), in that every 1 hour more of sleep was associated with a 1.35-point decrease in food fussiness score (Table 4).

Mediation analysis was performed to determine if eating behaviours mediated the relationship between sleep duration and BMI. Examining sleep as the independent variable, BMI as the dependent variable and 'Mean food approach' as the mediator, no relationship between sleep duration and 'Mean food approach' was observed. Therefore, these results did not meet conditions required for mediation analysis (Supplemental Figure 1). Supplemental Figure 2 presents the analysis using 'Mean food avoidant' as the mediator between sleep duration and BMI. The association between sleep duration and 'Mean food avoidant' was not significant (B=-0.43, 95% CI=-0.86,0.06, p=0.05). Sleep duration was associated with lower BMI kg/m^2 (B=-0.07, 95% CI=-0.14, -0.03, p=0.003); however, there was no evidence of a relationship between sleep duration and BMI (direct effect) in the model that included 'Mean food avoidant' (B=-0.20, 95% CI=-0.40,0.01, p=0.06). The indirect effect was not statistically significant as it included 0 (B=0.04, 95% CI=-0.004,0.101, p=0.03).This analysis suggests that both 'Mean food approach' and 'Mean food avoidant' eating behaviours did not mediate the relationship between sleep duration and BMI. Addition of confounders to the mediation models gave similar results therefore results are described without confounders.

Discussion

The current study found inverse associations between sleep duration and body composition, specifically BMI, BMI z-score, MUAC, and AC. Associations were also found between eating behaviours and body composition for the whole group and when stratified by sex. There was also some evidence of associations between sleep duration and food avoidant eating behaviours, although some results spanned the null. Eating behaviours did not mediate the relationship between sleep duration and BMI.

Our results concur with previous childhood studies, that support short sleep duration being associated with increased risk of childhood obesity [43-45]. Sleep duration is most often reported as demonstrating an inverse relationship with BMI and BMI z-score [46, 47]. Our analysis showed that a 1-hour greater sleep duration was associated with 0.21cm lower MUAC. Although MUAC is typically used to identify undernutrition and low fat free mass, there is emerging evidence that a strong linear relationship between MUAC and weight status exists [48-50]. As well as MUAC, few studies have examined the relationship between sleep duration and skinfold thicknesses [11]. We found that 1 hour more of sleep was associated with a potential reduction of 1.18mm in sum of skinfold thickness (95% CI= -3.05,0.69), though results spanned the null value. Our results indicate that decreased sleep duration is a factor not only influencing BMI and BMI z-score but also impacting body composition and adiposity markers in young children.

Interestingly, when our sample was stratified by child sex, inverse associations between sleep duration and BMI, BMI z-score, MUAC and AC were observed in girls only. Other studies have demonstrated that sex affects the relationship between sleep duration and obesity, but research is limited and results conflicted as to which sex is most affected; girls [43, 51] or boys [10, 15, 52]. These inconsistent results suggest that different aetiological mechanisms may be underlying the relationship between sleep and obesity across the sexes relating to hormone regulation such as leptin or ghrelin, variations in physical activity levels, energy imbalances, eating behaviours and pubertal influences [29, 43, 51, 52]. A potential reason for differences seen between boys and girls in our cohort, could be that girls who are deprived of sleep will spend less time engaged in physical activity [51] and this may predispose them to increased sedentary behaviours, thus creating a positive energy balance. The concurrent influence of inadequate sleep, low physical activity and high levels of screen time in children aged 7-12 years old have been shown to increase obesity risk [15].

There is growing evidence that one of the main pathways in which inadequate sleep influences weight gain is through increased food intake and increased vulnerability to eat [53, 54]. To date, the majority of research in this area has been with adults. Results have pointed to factors such as increased periods of wakefulness providing more opportunity to eat, a greater demand for energy to sustain the longer periods of being awake and increased predisposition to snacking behaviour, as possible explanations of increased dietary intake [53, 55]. An experimental study in school aged children demonstrated that children who had an increase in average nightly sleep of 2 hours, 21 minutes resulted in a lower caloric intake and lower weight than those with shorter sleep duration [56]. Previous studies have indicated that changes in leptin and ghrelin levels may be influenced by sleep deprivation and thus impact appetite and satiety responses [13, 57]. However, findings from these early studies have not been replicated [58),. There is also limited research available as to whether the effect of short sleep duration on leptin and ghrelin is specific to sex [59]. If hormonal influences are not the main driving force behind increased food intake, specific eating behaviours may offer some explanation. Our findings are similar to previous research that observed a link between food approach eating behaviours and childhood adiposity [60-63]. Behaviours such as food responsiveness reflect a child's tendency to want and enjoy food [64]. Poor response to internal satiety cues or over-responsiveness to external food signals such as the presence or smell of foods are implicated in higher energy intakes and subsequent risk of overweight/obesity [38, 40, 62]. Preschool children with higher food approach eating behaviours scores have been shown to be at risk of higher weight status with significant differences been found between weight status groups for 'food responsiveness', 'enjoyment of food', 'emotional overeating', and 'satiety responsiveness' [63]. The reasons girls may differ to boys in relation to food approach eating behaviours and body composition as we observed, has not been explored widely. Whilst previous studies have controlled for child sex [61, 65], few have examined the effect of sex separately.

Variation in genetic activity between boys and girls could contribute to both children's weight status and their susceptibility to eating in response to the presence of foods [66]. Genetics may also impact eating behaviour directly or indirectly through environmental influences such as parental modelling of the child's eating behaviour's [66]. Parental feeding strategies are strongly influential in how and what a child will eat. Several studies have shown that repeated exposure to a variety of foods in infancy will lead to a broader acceptability of foods during weaning and in later childhood [67, 68]. Parental style of feeding is also influential on a child's development of feeding behaviour. Feeding practices such as excessive parental control, pressuring to eat or using rewards to encourage feeding have all been shown to affect a child's eating behaviour [69-71]. Furthermore, differences have been demonstrated in the type of feeding style used by a parent between male and female children [71]. Another important consideration when exploring the development of eating behaviours in childhood and risk of obesity is how available or accessible food is within the home [72]. It has been demonstrated that the type of food and drink available in the home environment, such as lower fruit and vegetable sources or higher sugar sweetened beverage availability, is associated with obesity risk and less healthy dietary patterns [73, 74]. Lower income families, due to multiple jobs or shift work, may be away from home at irregular or longer intervals which may impact whether meals are prepared at home or not [75]. When considering childhood obesity risk, it is crucial to reflect on the complex influence family environment has on shaping childhood eating behaviours. Further exploration is warranted in relation to how family environmental factors impact differs between boys' and girls'.

Our cohort of boys presented with significantly higher scores for food fussiness than girls. In addition, inverse associations between food avoidant eating behaviours and body composition markers were observed in boys only. Evidence is conflicting regarding the impact of food avoidant eating behaviours such as fussy eating on weight status. Some previous research has reported negative associations between food avoidant eating behaviours and childhood adiposity and obesity tendencies [63, 65, 76, 77] whilst others have demonstrated no relationship [78, 79]. Children with food avoidant eating behaviours typically limit fruit and vegetables within their diet which may lead to poorer overall quality of diet and increased intake of more energy dense foods, which could in turn contribute to overweight and obesity. Alternatively, food avoidant eating behaviours may negatively affect a child's growth and development due to poor weight gain or nutritional status as a consequence of inadequate intake. Our findings show negative associations between food avoidant eating behaviours and boy's body composition whereas food approach behaviours were more strongly positively associated with girl's body composition. Early assessment of childhood eating styles could prove useful in identifying those who are susceptible to unhealthy weight gain or those at risk of poor growth. Childhood obesity commonly tracks into adulthood; therefore, early intervention to prevent the manifestation of eating behaviours known to be associated with unhealthy body weight is fundamental in curtailing further increases in obesity.

Inadequate or poor-quality sleep may drive behavioural and physiological changes that consequently affect eating behaviour [16]. This relationship could be bidirectional in that eating behaviours may have a causal role in contributing to poor or inadequate sleep. Contrary to expectations we found no significant associations between food approach eating behaviours and sleep duration (Table 4). In addition, food approach eating behaviours did not mediate the relationship between sleep duration and BMI. In contrast to our findings previous work has demonstrated that poor sleep quality and duration may influence risk of obesity through certain eating behaviour pathways [16, 54]. Our differing results may be explained by age differences or socioeconomic background between cohorts. Of interest in our results was that sleep duration was inversely associated with food fussiness in both sexes. In boys, who in this cohort had higher scores for food fussiness than girls, 1 hour more sleep was associated with 1.3 points reduction in food fussiness score, although the confidence interval spanned the null. This finding requires further exploration as improved sleep could offer benefits in the treatment or prevention of food fussiness, which could be easily incorporated into advice and resources used to help parents and caregivers address this behaviour.
In the present study we demonstrated that both short sleep duration and some eating behaviours were associated with body composition in 5-year-old children. However, neither food approach or food avoidant eating behaviours mediated the relationship between sleep duration and BMI. Our results demonstrated differences between boys and girls, in the relationship between sleep duration and body composition and in the relationship between eating behaviours and body composition, suggesting that distinctive underlying mechanisms may be at play between the sexes.

Increasing our understanding of what specifically drives the development of obesity in relation to child sex would offer benefits both clinically and in the public health setting. This knowledge could help in the planning of effective obesity prevention initiatives and enable the provision of targeted support and resources for parents and caregivers. Clear advice about a child's sleep requirements and potential barriers to achieving adequate sleep should be available for health care providers, parents and caregivers. At 5 years old, our cohort are at a crucial age to tackle unhealthy weight gain before it becomes an embedded problem.

Further investigations are warranted to better understand our perceived sex differences in relation to what the pathways are involved in the sleep and obesity connection and the influence of eating behaviours on this. As we continue to study this same cohort at their 9-11 years old follow up, the availability of longitudinal data will help us to clarify our findings.

The strengths of the current study include the use of validated child sleep and eating behaviour questionnaires, accurate objective anthropometry and body composition measurements. We included several body composition parameters to allow assessment of both weight status and body adiposity as fat distribution has been associated with cardiovascular risk and obesity in young children [80]. The present study has a number of limitations. It is exploratory in design; thus, power and sample size calculations were not included for this secondary analysis. Loss to follow-up of the study population may have resulted in selection bias. The sample included a high proportion of mothers that had achieved tertiary or higher education level which has previously been shown to be associated with being more likely to participate in research [81]. As per the selection criteria for the original RCT, all children were second born children whose older sibling was macrosomic at birth. This may have resulted in a cohort who are potentially obesogenic. Data on sleep, children's eating behaviours and body composition were all measured at 5 years old; therefore, the cross-sectional nature of this study limits the ability to establish the direction of the relationships found or assess causality. Future studies with sufficient power are required to allow us to further investigate associations between sleep, eating behaviours and body composition. Although important potential confounders were included in this analysis, other potential confounders such as physical activity levels and screen time exposure which are known to be important contributors to childhood obesity risk, would be important for inclusion in future analyses. Family environmental factors such as parental feeding style, parental feeding behaviours, family income and food availability all play a role in eating behaviour and weight status. Other limitations include that sleep is measured via mother's self-report which may lead to inaccurate reporting of sleep duration. A more objective method of measuring sleep such as actigraphy would strengthen our findings. We examined sleep duration in this study, however the inclusion of factors such as sleep efficiency, timing and quality should be considered as part of the relationship between sleep and obesity [29].

Conclusions

This analysis found associations between sleep duration and body composition parameters and associations between eating behaviours and body composition. Further exploration into the link between sleep duration and eating behaviours and how that affects body composition is warranted. At age 5, both prevention of obesity and ensuring adequate growth using modifiable factors such as instilling healthy sleep patterns and eating behaviours is paramount. Public health messages that provide clear and uniform guidelines on sleep recommendations would support parents and caregivers. Development of concise screening questions could assist health care professionals to assess children's eating behaviours and sleep patterns. Further research is needed to clarify age and sex specific effects in the relationship between sleep and body composition, and what role of eating behaviours on play on this. What factors might be protective for girls in preventing unhealthy weight or body composition needs further investigation. Analysis using longitudinal data is warranted to investigate the long-term relationship and direction in the associations between sleep, eating behaviours and body composition.

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Ethical approval: The ROLO and ROLO Kids studies were carried out in accordance with the Helsinki Declaration of 1975 as revised in 1983 with institutional ethical approval from the National Maternity Hospital in November 2006 for the original ROLO study and for the ROLO Kids 6 month and 2-year follow-up in May 2009. The Current Controlled Trials registration number for the ROLO study was ISRCTN54392969. The ROLO Kids 5-year follow-up were approved by the Ethics (Medical Research) Committee in Our Lady's Children's Hospital, Dublin, REC reference: GEN/279/12.

Conflict of Interests: None.

Authorship Contributions: FMMA were responsible for the project conception, AD, FMMA and MCC designed the research and analysis plan, JM collated the database, AD analysed the data and performed statistical analysis, AD wrote the paper and all other authors reviewed and approved the final manuscript.

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Table 1: General characteristics of ROLO mothers and 5-year-old children

	Whole group (n=401)			Boys (n=191)			Girls (n=210)			
	n (%)	Mean	SD	n (%)	Mean	SD	n (%)	Mean	SD	P-value
Child age (years)	401	5.10	0.15	191(48.0)	5.17	0.15	210 (52.0)	5.17	0.14	
Child BMI (kg/m^2)	386	16.22	1.33	183	16.25	1.26	201	16.19	1.40	0.63
Child BMI z- score	384	0.43	0.86	183	0.47	0.89	201	0.39	0.83	0.36
Abdominal circ. (cm)	383	55.33	4.26	183	55.23	4.34	200	55.42	4.19	0.66
MUAC (cm)	383	17.71	1.35	183	17.56	1.18	200	17.86	1.47	0.03
Triceps skinfold (mm)	363	10.02	2.61	176	9.62	2.43	187	10.39	2.73	0.01
Biceps skinfold (mm)	373	6.00	2.02	178	5.74	1.94	195	6.24	2.07	0.02
Subscapular skinfold	359	6.17	1.92	175	5.81	1.48	184	6.53	2.21	<0.001
Thigh skinfold	352	16.30	5.56	171	15.39	5.70	181	17.20	5.30	0.002
Child Eating Behaviours										
Food responsive	306	12.40	4.10	141	12.31	3.85	165	12.58	4.30	0.58
Emotional overeating	306	6.59	2.06	141	6.48	2.09	165	6.70	2.04	0.35
Enjoys food	306	14.93	3.02	141	14.74	3.28	165	15.08	2.79	0.33
Desire to drink	306	8.00	2.70	141	8.31	2.89	165	8.33	7.58	0.98
Mean food approach	306	10.50	2.03	141	10.46	2.02	165	10.53	2.05	0.76
Satiety response	306	15.20	3.30	141	15.23	3.13	165	15.33	3.40	0.79
Slowness eating	306	12.10	3.10	141	12.05	3.23	165	12.28	3.00	0.52
Emotional under eating	306	10.70	3.40	141	10.93	3.56	165	10.67	3.36	0.52

Food fussiness	306	18.40	5.80	141	19.60	5.67	165	17.50	5.91	0.001
Mean food avoidant	306	14.10	2.80	141	14.46	2.77	165	13.90	2.82	0.11
Sleep per night (hrs)	319	10.82	0.79	157	10.75	0.82	159	10.70	0.79	0.63
Slept ≥ 11hours (n (%))	196 (61.0)	-	-	97 (63.0)	-	-	99 (60.0)	-	-	0.58
BMI Category† (n (%))										
Healthy	291 (76.0)	-	-	130 (71.0)	-	-	161 (80.0)	-	-	
Overweight	58 (15.1)	-	-	35 (19.2)	-	-	23 (11.4)	-	-	0.88
Obese	34 (8.9)	-	-	17 (9.3)	-	-	17 (8.5)	-	-	
Maternal Education (n (%))										
Some 2nd level	13 (3.2)	-	-	8 (4.7)	-	-	5 (2.7)	-	-	
Complete 2nd level	51 (12.7)	-	-	25 (14.8)	-	-	26 (14.2)	-	-	
Some 3rd level	72 (18.0)	-	-	40 (23.7)	-	-	32 (17.5)	-	-	0.29
Complete 3rd level	216 (53.9)	-	-	96 (56.8)	-	-	120 (66.0)	-	-	

† International Obesity Task Force age- and sex specific BMI cut-offs for defining weight status in children 2-18 years; P- value from Independent t tests for differences between boys and girls; P-value from Chi- square test for differences in BMI category, met sleep requirements and maternal education level between boys and girls. Mean food approach refers to the sum of the means of the four food approach eating behaviours (Food Responsive, Emotional Overeating, Enjoys Food, Desire to Drink). Mean food avoidant refers to the sum of the means of the four food avoidant eating behaviours (Satiety Response, Emotional Undereating, Slowness Eating, Food Fussiness); Statistically significant (p<0.05)

Table 2: Association between 1-hour sleep duration and body composition for boys and girls

	Sleep duration (hrs)							
	Boys				Girls			
	B	95% CI		P-value	B	95% CI		P-value
		Lower	Upper			Lower	Upper	
BMI (kg/m^2)	-0.152	-0.447	0.142	0.308	-0.320	-0.597	-0.042	0.024
BMI z-score	-0.117	-0.324	0.090	0.266	-0.185	-0.350	-0.020	0.029
MUAC (cm)	-0.175	-0.450	0.099	0.208	-0.290	-0.581	0.000	0.050
Abdo circumference (cm)	0.029	-0.996	1.055	0.955	-1.103	-1.852	-0.208	0.014
Triceps SF (mm)	-0.062	-0.617	0.473	0.825	-0.146	-0.700	0.408	0.603
Subscapular SF (mm)	0.050	-0.299	0.398	0.777	-0.313	-0.766	0.140	0.174
Thigh SF (mm)	-0.206	-1.510	1.098	0.755	-0.814	-1.889	0.261	0.137
Sum of skinfolds (mm)	-0.192	-2.959	2.575	0.891	-1.665	-4.299	0.969	0.212

BMI: body mass index; SF: skinfold thickness; Sum of skinfolds=Triceps, Subscapular, Thigh; MUAC: mid upper arm circumference; Multiple linear regression models adjusted for maternal BMI, breastfed ever, child age, control v non-control, maternal education; Statistically significant (p value < 0.05)

Table 3: Association between eating behaviours and body composition for boys and girls

		Food approach														
		Desire to drink			**Enjoys food**			**Food responsiveness**			**Emotional overeating**			**Mean food approach**		
	Gender	**B**	**95% CI**	**P-Value**	**B**	**95% CI**	**P-value**	**B**	**95% CI**	**P-value**	**B**	**95% CI**	**P-Value**	**B**	**95% CI**	**P-Value**
BMI (kg/m^2)	**Boys**	-0.054	-0.133,0.026	0.186	0.079	0.018,2.869	0.047	0.012	-1.051,1.363	0.799	-0.064	-3.933,0.457	0.120	0.018	-0.094,0.129	0.756
	Girls	-0.010	-0.075,0.096	0.811	0.134	0.521,3.445	0.008	0.092	0.356,2.214	0.007	0.127	-0.160,3.844	0.071	0.200	0.090,0.310	<0.001
BMI z- score	**Boys**	-0.037	-0.093,0.019	0.194	0.053	0.004,0.101	0.034	0.006	-0.035,0.047	0.735	-0.055	-0.130,0.020	0.149	0.006	-0.072,0.084	0.880
	Girls	0.009	-0.042,0.060	0.731	0.077	0.028,0.126	0.002	0.052	0.021,0.083	0.001	0.072	0.004,0.139	0.038	0.115	0.049,0.181	0.001
Sum of skinfolds (mm)	**Boys**	-0.195	-0.940,0.550	0.604	-0.061	-0.713,0.592	0.854	0.057	-0.487,0.601	0.835	-0.238	-1.236,0.756	0.636	-0.157	-1.103,0.880	0.765
	Girls	-0.045	-0.881,0.792	0.915	-0.032	-0.803,0.798	0.939	0.387	-0.133,0.908	0.142	0.881	-0.223,1.984	0.116	0.587	-0.526,1.701	0.297
MUAC (cm)	**Boys**	-0.015	-0.090,0.060	0.694	0.071	0.007,0.135	0.030	0.019	-0.036,0.073	0.498	0.002	-0.098,0.102	0.966	0.056	-0.048,0.159	0.290
	Girls	0.015	-0.075,0.104	0.723	0.090	0.002,0.177	0.045	0.067	0.012,0.123	0.018	0.137	0.019,0.255	0.023	0.157	0.040,0.274	0.009
Abdominal circ	**Boys**	-	-	0.455	0.19	-	0.118	0.04	-	0.674	-	-	0.411	0.07	-	0.714

(cm)		0.098	0.376,0.179		2	0.050,0.433		3	0.160,0.246		0.155	0.526,0.217		2	0.315,0.459	
	Girls	0.059	-0.196,0.314	0.645	0.134	-0.119,0.386	0.297	0.196	0.038,0.354	0.016	0.407	0.071,0.743	0.018	0.408	0.072,0.743	0.018

		Food avoidant														
		Food fussiness			**Emotional undereating**			**Satiety response**			**Slowness to eat**			**Mean food avoidant**		
	Gender	**B**	**95% CI**	**P-Value**	**B**	**95% CI**	**P-value**	**B**	**95% CI**	**P-value**	**B**	**95% CI**	**P-Value**	**B**	**95% CI**	**P-Value**
BMI (kg/m^2)	**Boys**	-0.046	-0.085, -0.007	0.020	-0.023	-0.086,0.040	0.464	-0.039	-0.109,0.032	0.276	-0.057	-0.126,0.013	0.062	-0.089	-0.169, -0.010	0.028
	Girls	0.006	-0.335,0.046	0.785	-0.036	-0.106,0.033	0.306	-0.082	-0.150, -0.014	0.019	-0.071	-0.150,0.007	0.074	-0.057	0.141,0.027	0.179
BMI z- score	**Boys**	-0.029	-0.056, -0.002	0.039	-0.015	-0.059,0.029	0.505	-0.023	-0.073,0.026	0.354	-0.039	-0.088,0.010	0.114	-0.057	-0.113, -0.001	0.047
	Girls	0.006	-0.018,0.030	0.624	-0.024	-0.065,0.017	0.255	-0.044	-0.084, -0.003	0.037	-0.046	-0.092,0.001	0.055	-0.031	-0.081,0.019	0.220
Sum of skinfolds (mm)	**Boys**	-0.108	-0.475,0.260	0.562	-0.059	-0.645,0.526	0.841	0.378	-0.274,1.030	0.252	0.038	-0.614,0.690	0.908	0.001	-0.753,0.755	0.998
	Girls	0.210	-0.185,0.604	0.292	-0.189	-0.868,0.489	0.580	-0.250	-0.925,0.426	0.464	-0.324	-1.092,0.444	0.404	-0.027	-0.849,0.759	0.948
MUAC (cm)	**Boys**	-0.02	-0.061,0.0	0.193	-0.02	-0.080,0.	0.474	-0.02	-0.087,0.0	0.532	-0.04	-0.111,0.0	0.166	-0.05	-0.131,0.0	0.143

		4	12		1	037		1	45		6	19		6	19	
	Girls	0.001	-0.041,0.044	0.957	-0.012	-0.085,0.061	0.745	-0.060	-0.132,0.012	0.099	-0.107	-0.188, -0.027	0.010	-0.055	-0.143,0.032	0.212
Abdominal circ (cm)	**Boys**	-0.140	-0.275, -0.004	0.043	-0.144	-0.361,0.073	0.192	-0.175	-0.419,0.068	0.156	-0.138	-0.380,0.104	0.263	-0.308	-0.584, -0.033	0.029
	Girls	-0.013	-0.134,0.108	0.833	0.035	-0.172,0.242	0.739	-0.187	-0.392,0.017	0.073	-0.166	-0.400,0.068	0.163	-0.117	-0.367,0.133	0.357

BMI: body mass index; SF: skinfold thickness; Sum of Skinfolds: Biceps, Triceps, Subscapular, Thigh; MUAC: mid upper arm circumference; circ: circumference; All multiple linear regression models controlled for maternal BMI , breastfed ever, control v non-control, maternal education, child age; Mean food approach refers to the sum of the means of the four food approach eating behaviours (Food Responsive, Emotional Overeating, Enjoys Food, Desire to Drink). Food Avoidant refers to the sum of the means of the four food avoidant eating behaviours (Satiety Response, Emotional Undereating, Slowness Eating, Food Fussiness); Statistically significant ($p<0.05$)

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Table 4: Association between 1-hour sleep duration and eating behaviours for boys and girls

	Sleep duration (hrs)							
	Boys				Girls			
	B	95% CI		P-value	B	95% CI		P-value
		Lower	Upper			Lower	Upper	
Food responsiveness	0.153	-0.785	1.090	0.748	-0.086	-0.950	0.778	0.845
Emotional overeating	-0.198	-0.707	0.312	0.444	-0.182	-0.587	0.244	0.377
Enjoys food	0.387	-0.391	1.165	0.327	0.106	-0.443	0.656	0.703
Desire to drink	0.483	-0.196	1.162	0.161	-0.128	-0.674	0.417	0.642
Mean food approach	0.205	-0.288	0.695	0.409	-0.074	-0.481	0.333	0.721
Satiety response	-0.672	-1.439	0.095	0.085	-0.021	-0.694	0.652	0.951
Slowness to eat	0.102	-0.680	0.884	0.798	0.066	-0.526	0.657	0.827
Emotional undereating	0.236	-0.663	1.106	0.591	-0.678	-1.340	-0.016	0.045
Food fussiness	-1.354	-2.718	0.009	0.052	-0.469	-1.615	0.677	0.420
Mean food avoidant	-0.438	-1.110	0.234	0.199	-0.276	-0.829	0.277	0.326

All multiple linear regression models adjusted for maternal BMI, breastfed ever, child age, control v non-control, maternal education; Mean food approach refers to the sum of the means of the four food approach eating behaviours (Food Responsive, Emotional Overeating, Enjoys Food, Desire to Drink). Mean food avoidant refers to the sum of the means of the four food avoidant eating behaviours (Satiety Response, Emotional Undereating, Slowness Eating, Food Fussiness); Statistically significant (p value < 0.05)