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Association of the timing of evening eating with BMI *Z*-score and waist-to-height ratio among preschool-aged children in Finland

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Abstract

Later timing of eating has been associated with higher adiposity among adults and children in several studies, but not all. Moreover, studies in younger children are scarce. Hence, this study investigated the associations of the timing of evening eating with BMI *Z*-score and waist-to-height ratio (WHtR), and whether these associations were moderated by chronotype among 627 preschoolers (3–6-year-olds) from the cross-sectional DAGIS survey in Finland. Food intake was measured with 3-d food records, and sleep was measured with hip-worn actigraphy. Three variables were formed to describe the timing of evening eating: (1) clock time of the last eating occasion (EO); (2) time between the last EO and sleep onset; and (3) percentage of total daily energy intake (%TDEI) consumed 2 h before sleep onset or later. Chronotype was assessed as a sleep debt-corrected midpoint of sleep on the weekend (actigraphy data). The data were analysed with adjusted linear mixed effects models. After adjusting for several confounders, the last EO occurring closer to sleep onset (estimate = −0·006, 95 % CI (−0·010, −0·001)) and higher %TDEI consumed before sleep onset (estimate = 0·0004, 95 % CI (0·00003, 0·0007)) were associated with higher WHtR. No associations with BMI *Z*-score were found after adjustments. Clock time of the last EO was not significantly associated with the outcomes, and no interactions with chronotype emerged. The results highlight the importance of studying the timing of eating relative to sleep timing instead of only as clock time.

Keywords: **Late eating: Chrononutrition: Overweight: Obesity: Meal timing**

A relatively novel research area concerning the role of nutrition in the development of obesity, termed chrononutrition, examines food intake in the context of the innate circadian system ('internal clock')[1–3]. It generally examines three aspects of behavioural eating rhythms: the frequency of eating occasions (EO), the regularity of eating from day to day and meal to meal, and the timing of eating (e.g. clock time)[1,4].

Influenced by the daily environmental rhythms, such as light conditions or social interaction, the circadian clock system regulates most processes of the human body, having approximately a 24-h cycle[5,6]. Together with peripheral clocks, the so-called master clock in the suprachiasmatic nucleus governs the synchronised temporal organisation of hormones and enzymes involved in metabolic processes such as energy metabolism[5,6]. An accumulating body of research suggests that these innate rhythms can be disrupted in a way that leads to an increased risk of such adverse health outcomes as obesity[2,4,7,8]. The timing of eating has been identified as a factor that may contribute to these disruptions; eating at physiologically inappropriate times – in relation to the internal circadian rhythm – can have unfavourable health effects[4,9,10].

Several studies, although not all, have found an association between later timing of eating and higher adiposity among children and adults. However, studies in younger children are

Abbreviations: DLMO, dim-light melatonin onset; EO, eating occasion; PA, physical activity; %TDEI, percentage of total daily energy intake; %WHtR, waist-to-height ratio.

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scarce[11–14]. Moreover, later timing of eating has been operationalised in various ways such as having any meal at a relatively later time of day or higher energy intake after a certain clock time in the evening. A recent systematic review examined the association between later eating rhythm and adiposity in children and adolescents (2–18-year-olds); associations of 'higher energy intake around bedtime' and 'evening main meal skipping' with higher odds of overweight/obesity were found in meta-analyses[14]. For example, examining the distribution of daily energy intake across meals, Vilela *et al.*[15] found that higher energy intake at mid-afternoon or at lunch and supper at the age of 4 years was associated with higher odds of overweight/obesity at 7 years of age. However, in the review, most studies on younger children had investigated the evening main meal (its timing, energy intake or skipping it)[14]. One study found an association; out of six clusters the one with the earliest dinner timing, least screen time, longest sleep duration and average outside playtime had the lowest prevalence of overweight/obesity[16]. However, the extent to which the timing of dinner contributes to this association remains unknown.

Moreover, studying the timing of eating relative to sleep timing instead of clock time may be more relevant in this context, since it can better reflect the 'circadian timing of food intake'[14,17,18] which has been associated with adiposity in adults. For example, consuming daily energy content closer to dim-light melatonin onset (DLMO) (a robust marker of circadian phase and the beginning of biological night) was associated with higher body fat percentage[19]. Furthermore, even if sleep timing did not reflect the innate circadian timing, measuring the timing of eating relative to it is still a more individual and generalisable measure, since a certain clock time can correspond to a different point in the daily doings for different individuals and cultures. To our knowledge, no studies examining the timing of eating relative to sleep timing or other measures of circadian time exist among preschool-aged children.

Furthermore, one factor explaining the heterogeneity of findings regarding the association between later timing of eating and adiposity measures could be chronotype. Chronotype can be viewed from a more biological perspective as a conceptualisation of the individual differences in the human circadian rhythms[20–22] – as a 'phase of entrainment'[20]. In this case, the measures of chronotype estimate an individual's internal time from biomarkers that are regulated by the circadian system[20]. One common way to assess chronotype is based on sleep behaviour[20,22,23]; for instance, the Munich ChronoType Questionnaire (MCTQ) gathers information about the habitual timing of sleep and determines chronotype from the sleep midpoint on free days[24]. It has been hypothesised that chronotype could moderate the association between the timing of eating and health outcomes[23,25]; whether the timing of eating is aligned with the individual biological rhythms could influence its health effects. In a sample of US adults[18], an association between higher energy intake within 2 h before bedtime and higher BMI was significant only in later chronotypes. We are not aware of any studies investigating the moderation in young children.

Hence, the objective of this study was two-fold: (1) to examine the association of the timing of evening eating with BMI *Z*-score and waist-to-height ratio (WHtR) in preschool-aged children and (2) to explore whether chronotype moderates these associations. The timing of evening eating was operationalised as clock time and as relative to sleep onset time (three variables altogether). We hypothesised that an association would be found between later evening eating and higher BMI *Z*-score and higher WHtR. This study adds to the currently scant research on the associations between the timing of eating in the evening and adiposity among young children. Furthermore, this is among the first studies, if not the first, in this age group to measure the timing of eating relative to the timing of sleep and explore moderation by chronotype.

Materials and methods

Study design and participants

The present study is a secondary analysis of the cross-sectional survey, conducted in 2015–2016, of the DAGIS (Increased Health and Wellbeing in Preschools) research project in Finland[26–28]. The overall aim of the project was to promote preschool children's healthy energy balance-related behaviours and self-regulation skills and diminish socio-economic differences in them. The study was approved by the University of Helsinki Ethics Review Board in the Humanities and Social and Behavioural Sciences (#6/2015) in February 2015.

The details of the sample selection have been reported previously[26]. Briefly, the cross-sectional survey was conducted in eight municipalities from Western and Southern Finland, and the participants were recruited via preschools. The eligibility criteria for the preschools were (1) to have at least one group of 3–6-year-old children, (2) to offer early education only in the daytime, (3) to be Finnish or Swedish speaking and (4) to have income-dependent fees. Since there was an additional recruitment criterion of including only preschools that had a consent rate of more than 30 % in at least one of the groups, the data were collected in sixty-six preschools (43 % of invited), with a total of 864 children (24 % participation rate) and their caregivers giving written informed consent.

Anthropometric measurements – outcome variables

The children's body weight was measured with portable bench scales (CAS PB-100/200) to the nearest 0·01 kg. Height was measured with stadiometers (SECA 217) to the nearest 0·1 cm. Waist was defined as the midpoint between the top of the iliac crest and the lower margin of the last palpable rib, and waist circumference was then measured twice with measuring tapes (SECA 201) to the nearest 0·1 cm. The mean of these two measurements was computed. All measurements were conducted by trained researchers at the preschools. BMI was computed as body weight (kg)/height^2 (m). BMI *Z*-score computed according to age- and sex-specific Finnish references[29], and WHtR computed as the mean waist circumference (cm)/height (cm) were the final outcome variables.

Food record data

The time of day of EOs and energy intake for computing exposure variables were obtained from food records kept both at

home and at preschools[30]. The dates, including 2 weekdays and 1 weekend day, for filling the food record at home were assigned for each family but were negotiable if necessary. These 3 d were not always consecutive so that each day of the week would be well represented in the data. All foods and beverages that a child consumed outside preschool hours were to be recorded, as were the place and time of each consumption occasion. Caregivers received a validated Children's Food Picture Book[31] to assist them in reporting the portion sizes eaten. They could also use package labels or household measures, such as tablespoons, to estimate the amounts eaten.

Separate 2-d food records that were pre-coded were given to preschool personnel. They were instructed to record the children's food consumption at preschool on the same weekdays that the families kept a food record at home. Preschool personnel also received the Children's Food Picture Book for estimating portion sizes.

Research assistants reviewed the returned food records and contacted the participants if any data were incomplete or unclear. The food record data were processed using AivoDiet dietary software 2.2.0.0 (Mashie FoodTech Solutions Finland Oy), which yielded energy content for each reported food or beverage. The software utilised the Fineli Food Composition Database (Release 16, 2013) administered by the Finnish Institute for Health and Welfare. To take intra-individual variability in energy intake and in timing of eating into account as well as possible, children with data from less than 3 d were excluded (*n* 97).

Actigraphy data

The children were instructed to wear an ActiGraph w-GT3X-BT accelerometer (Actigraph) on their hip 24 h a day for 7 d (excluding only water-based activities). In this study, actigraphy data were used to assess sleep and physical activity (PA).

Estimates for evening sleep onset and morning wake-up times were obtained with an unsupervised, data-driven Hidden Markov Model (HMM)-based algorithm[32]. Non-wear time was defined with the R package GGIR for the processing of actigraphy data prior to using the HMM algorithm[33]. Children who had data for less than 16 h/d (from a noon-to-noon window) were excluded. The application of the HMM algorithm to the current data has been described in more detail in a previous paper[34]. Regarding wrist-worn actigraphy, the algorithm has been validated against polysomnography in adults[32]. The obtained sleep onset and wake-up times were used in computing two exposure variables describing the timing of eating relative to sleep onset, chronotype and average weekly sleep duration. As for the assessment of PA, epoch length was set at 15 s, and periods of ≥ 10 min with zero activity counts were considered as non-wearing times.

To compute chronotype, average weekly sleep duration and PA variables, the children were required to have data from at least 3 weekdays/weekday nights and 1 weekend d/night. A weekend night was defined as the night between Friday and Saturday or between Saturday and Sunday. Regarding sleep, the proportion of children from the sample (*n* 864) who did not meet the weekday criteria was 14 % (*n* 125), did not meet the weekend criteria was 13 % (*n* 113) and did not meet whole week criteria (3 + 1 d) was 16 % (*n* 136).

Exposure variables – timing of evening eating

Three variables were formed to describe the timing of evening eating:

1) clock time of the last EO, hereafter referred to as 'last EO',
2) time between the last EO and sleep onset, hereafter referred to as 'evening latency', and
3) percentage of total daily energy intake (%TDEI) consumed 2 h before sleep onset or later, hereafter referred to as '% TDEI before sleep onset'.

The following definition of an EO was used when constructing the last EO and evening latency variables: consumption of at least 104·6 kJ (25 kcal) within one separately reported occasion. Hence, the energy content of each food or beverage reported to have been consumed during one occasion was summed, and if this sum was at least 104·6 kJ (25 kcal) it was considered as one EO. This energy cut-off has been used among 8–11-year-olds[35], and even though 209·2 kJ (50 kcal) has also been used among younger children[15], the lower cut-off was chosen since younger children presumably eat less. This definition of an EO instead of, for example, researchers or participants defining them as dinner or evening snack was chosen mainly due to its neutrality; it does not require subjective interpretation and is therefore not influenced by, for instance, culture, which makes it more generalisable[36].

To compute the evening latency and the %TDEI before sleep onset variables, the children needed to have food record data and actigraphy sleep data from the same day. Only children whose sleep data matched all three food record days were included in this study, resulting in a basic analytic sample of 627 children (73 % of participants).

The *last EO* (≥ 104·6 kJ) corresponds to the last reported clock time before 00:00 in each food record day, since no EOs among the analytic sample were recorded between 00:00 and 05:40, and EOs recorded after 05:40 were considered as the first EO of a day. The *evening latency* was calculated by subtracting the last EO from the sleep onset time of the same evening. This way children whose last EO occurred after sleep onset had a negative value for this variable (*n* 5), and higher evening latency means that the last EO occurred earlier relative to sleep onset. The *%TDEI before sleep onset* was calculated as the %TDEI consumed 2 h before sleep onset or later for each food record day; energy intake of every EO (no energy requirement) whose reported time was equal to or later than 2 h before sleep onset was summed, and the sum was then converted to a %TDEI of that day. Hence, this variable also contains possible energy intake after sleep onset. Twelve children in the analytic sample had consumed energy after sleep onset on at least one of the food record days. The mean for 3 d was computed for all three variables, and these means were used in analyses.

Moderator – chronotype

To form the chronotype variable, the actigraphy-derived sleep onset and wake-up times were used to compute mean sleep duration for weekend and for weekdays, weighted weekly average of sleep duration ((weekday mean * 5 + weekend mean * 2)/7), and midpoint of sleep on the weekend. Sleep

duration was defined as total time between sleep onset and wake-up, and midpoint of sleep was defined as half of the time passed between sleep onset and wake-up[24].

Chronotype was then assessed as a sleep debt-corrected midpoint of sleep on the weekend (free days) (MSF_{SC}) according to a formula from the MCTQ[20,37]: if mean sleep duration on the weekend was longer than mean sleep duration on weekdays, the MSF_{SC} was calculated as the mean midpoint of sleep on the weekend – (mean sleep duration on the weekend – weighted weekly average of sleep duration)/2. Otherwise, the mean midpoint of sleep on the weekend, as it is, was interpreted as the MSF_{SC}. Thus, the MSF_{SC} is a clock time and was treated as a continuous variable, like is usually done[20]. A higher MSF_{SC} reflects a later chronotype. The sleep debt correction has been adopted due to observations that all except very early chronotypes accumulate sleep debt during scheduled days, such as (pre)school days (in this case, weekdays), and compensate for it on free days (in this case, the weekend)[20]. The amount of sleep debt also increases with delaying chronotype[20].

Among adults, midpoint of sleep (including the sleep debt-corrected free day midpoint) assessed by MCTQ or actigraphy has been shown to positively correlate with DLMO[38–40]. Actigraphy-derived midpoint of sleep has also been reported to correlate with DLMO in 30–36-month-olds[41]. Moreover, it seems that questionnaire-derived midpoint of sleep and actigraphy-derived midpoint of sleep are highly comparable[42,43] – even in preschool-aged children[44].

Confounding factors

Evenson cut points[45] were applied to determine the amount of moderate to vigorous PA from the actigraphy data. A weighted weekly average ((weekday mean * 5 + weekend mean * 2)/7) for moderate to vigorous PA was computed to be used in analyses. In addition to moderate to vigorous PA, child's age and sex, and family's educational level, all reported by the caregivers, were used as confounding factors. A variable indicating the highest educational level in the family was categorised into three classes: (1) low (comprehensive, vocational or high school); (2) middle (bachelor's degree or equivalent) and (3) high (master's degree or licentiate/doctor). Moreover, sleep duration (weighted weekly average) derived from the actigraphy data as well as TDEI (3-d mean) calculated from the food record data were used as confounders. These confounding factors were chosen based on previous literature: factors used in studies similar to this one[13,14,17,18,46] or associated with the exposures and outcomes of this study[35,47,48].

Statistical analyses

In each analysis, all participants from the basic analytic sample (those with adequate data for exposure variables) (n 627) with the required variables were included; thus, participants with missing data were excluded from the analyses. The distributions and descriptive statistics of the study variables were analysed with SPSS statistics 28 (IBM). Sociodemographic background variables and the outcomes were compared between the analytic sample and those excluded from it by χ^2 test, t test or Mann–Whitney U test when applicable.

The research questions – associations of last EO, evening latency and %TDEI before sleep onset with BMI Z–score and WHtR as well as interactions with chronotype – were examined using statistical software R version 4.2.1 and Rstudio (R Core Team, 2022). The models used were linear mixed effects models (lme4 package). A variable that identified the child's family was entered as a random effect into the models to take the clustering of the participants due to living in the same household into account. The variables examined in this study were expected to correlate within a family, and the intraclass correlation coefficients (ranged from 0·37 to 0·4 in adjusted models) supported our rationale. The children in the analytic sample were from 566 different households, out of which sixty had two or more children participating in the study. The model fit was examined by checking the assumptions of the linear mixed effects models. Concerning WHtR, there was some deviation from the normality of residuals. Thus, the models were explored with log-transformed WHtR, which yielded adequately normally distributed residuals. However, since the significance of the results was similar in models with non-transformed WHtR, it was chosen for this paper for better interpretability.

Separate models were constructed for the three exposure variables. The models for testing the independent associations with BMI Z-score and WHtR were as follows: model 1 was a non-adjusted crude model, model 2 was adjusted with age and sex, model 3 was further adjusted with chronotype (MSF_{SC}), sleep duration, moderate to vigorous PA, family's educational level, and TDEI. In addition, removing TDEI from the model 3 was tested due to possible overadjustment, especially because TDEI might be on the causal pathway of how later eating impacts adiposity. That model is referred to as model 4. No multicollinearity was detected in the fully adjusted models (checked with performance package). Results from model 2 are displayed in Supplementary Table S1. The moderation by chronotype was explored last with interaction models with the chronotype x exposure variable (e.g. last EO) interaction terms[49]. A significance level of 0·1 was used for the interaction terms. Additionally, crude associations of chronotype with BMI Z-score and WHtR were tested. Results were presented as regression coefficient estimates and 95 % CI for the exposures and interaction terms. To further evaluate the effect sizes, pseudo-coefficient of determination (R^2) was computed for the fixed effects of each model.

Results

Descriptives

The characteristics of the sample concerning the study variables are presented in Table 1. Of the children, 53 % were boys and the mean age was approximately 5 years. The middle educational level (bachelor's degree or equivalent) was most prevalent (42 %) among caregivers in this sample. The mean BMI Z-score among the children was −0·01 (SD 1·0), and median of WHtR was 0·49 (Q1 = 0·47, Q3 = 0·51). On average, the clock time of the children's last EO was 19:45, and it occurred 1·5 h before sleep onset on average. Moreover, the average proportion of TDEI

Table 1. Characteristics of the study sample (*n* 627)

Variable	*n*	%	Mean or median	SD or Q1/Q3	Min	Max
Sociodemographics						
Child's sex						
Girl	298	47·5				
Boy	329	52·5				
Highest education level in family*						
Low	135	21·5				
Middle	264	42·1				
High	226	36·0				
Missing	2	0·3				
Child's age (years)			4·7	0·9	2·8	7·2
Anthropometrics						
BMI *Z*-score†			−0·01	1·0	−3·5	3·0
Waist-to-height ratio‡ (cm)			0·49	0·47/0·51	0·42	0·65
Height (cm)			109·6	7·8	89·9	133·7
Weight‡ (kg)			18·6	16·8/21·0	12·3	36·6
Timing of evening eating						
Last EO§ (hh:mm)			19:45	00:38	17:50	21:19
Evening latency‖ (h)			1·5	0·6	−0·6	4·0
%TDEI before sleep onset‡,¶			13·8	8·6/19·6	0·0	37·5
Sleep variables						
Sleep onset** (hh:mm)			21:15	00:37	19:23	22:52
Sleep duration** (h)			9·7	0·5	8·1	11·2
MSF_{SC} (hh:mm)			02:17	00:39	00:24	04:18
Other lifestyle factors						
MVPA‡ (min/h)			5·3	4·2/6·4	2·0	11·5
Total daily energy intake‡ (kJ)			5672	5012/6462	3266	10 111

EO, eating occasion; %TDEI, percentage of total daily energy intake; MSF_{SC}, sleep debt-corrected midpoint of sleep on weekend (chronotype indicator); MVPA, moderate to vigorous physical activity.
* Low (comprehensive, vocational or high school), middle (bachelor's degree or equivalent) and high (master's degree or licentiate/doctor).
† Finnish references[29].
‡ Median, quartile 1 and quartile 3 are presented.
§ Clock time of last eating occasion.
‖ Time between last eating occasion and sleep onset (negative value if last eating occasion after sleep onset).
¶ Relative energy intake 2 h before sleep onset or later.
** Weighted weekly average.

consumed 2 h before sleep onset or later was 14 %. Children with missing data for the exposures did not differ from the children in the analytic sample regarding the child's sex or age, family's educational level, or the outcomes (online Supplementary Table S2).

Associations of the timing of evening eating with BMI Z-score

The results of the linear mixed effect models examining the associations of the exposure variables describing the timing of evening eating with BMI *Z*-score are displayed in Table 2. The last EO did not have a significant association with BMI *Z*-score. Both evening latency and %TDEI before sleep onset had a significant association with BMI *Z*-score in the crude models; higher evening latency was associated with lower BMI *Z*-score (estimate = −0·190, $P = 0·006$), and higher %TDEI before sleep onset was associated with higher BMI *Z*-score (estimate = 0·011, $P = 0·036$). These associations remained significant after adjustment for age and sex, but no longer in the fully adjusted models (model 3), although regarding evening latency the *P*-value was close to significance ($P = 0·068$). When TDEI was removed from the fully adjusted models (model 4), the association between evening latency and BMI *Z*-score remained significant (estimate = −0·172, $P = 0·022$). According to R^2 values, the fixed effects of all crude models as well as age- and sex-adjusted models explained approximately 1–2 % of the variance in BMI *Z*-score, and in model 3 (fully adjusted) this proportion was 8.

Associations of the timing of evening eating with waist-to-height ratio

The results of the linear mixed effect models examining the associations of the exposure variables describing the timing of evening eating with WHtR are displayed in Table 2. As in the case of BMI *Z*-score, the last EO was not associated with WHtR. Both evening latency and %TDEI before sleep onset were significantly associated with WHtR in the fully adjusted models (model 3); higher evening latency was associated with lower WHtR (estimate = −0·006, $P = 0·019$), and higher %TDEI before sleep onset was associated with higher WHtR (estimate = 0·0004, $P = 0·033$). These associations were significant both with and without TDEI as a confounder. According to R^2 values, the fixed effects of crude models explained approximately 0·2 % of the variance in WHtR, and the fixed effects of all adjusted models explained approximately 16–18 %.

Exploring moderation by chronotype

The results of the interaction models examining the moderation by chronotype in the associations of the timing of evening eating

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Table 2. Associations of the timing of evening eating with BMI *Z*-score and waist-to-height ratio, and interactions with chronotype. Separate models for each exposure variable

		Model 1§ *n* 596–598			Model 3‖ *n* 594–595			Model 4¶ *n* 594–595		
Exposure	Outcome	Estimate	95 % CI	*P*	Estimate	95 % CI	*P*	Estimate	95 % CI	*P*
Last EO*	BMI *Z*-score	−0·046	−0·171, 0·079	0·470	0·008	−0·138, 0·155	0·880	0·041	−0·108, 0·189	0·595
	WHtR	−0·002	−0·007, 0·002	0·255	−0·001	−0·005, 0·004	0·806	>0·000	−0·005, 0·004	0·933
Evening latency†	BMI *Z*-score	−0·190	−0·325, −0·056	0·006	−0·142	−0·287, 0·003	0·068	−0·172	−0·319, −0·026	0·022
	WHtR	−0·004	−0·009, >0·000	0·053	−0·006	−0·010, −0·001	0·019	−0·006	−0·011, −0·001	0·012
%TDEI before sleep onset‡	BMI *Z*-score	0·011	0·001, 0·021	0·036	0·006	−0·004, 0·017	0·264	0·009	−0·001, 0·020	0·093
	WHtR	0·0003	−0·000, 0·001	0·054	0·0004	>0·000, 0·0007	0·033	0·0003	0·0001, 0·0007	0·021
Last EO x MSF_{SC}	BMI *Z*-score	−0·084	−0·265, 0·098	0·367						
	WHtR	−0·002	−0·009, 0·004	0·447						
Evening latency x MSF_{SC}	BMI *Z*-score	0·060	−0·128, 0·249	0·532						
	WHtR	0·007	−0·001, 0·013	0·250						
%TDEI before sleep onset x MSF_{SC}	BMI *Z*-score	−0·002	−0·017, 0·013	0·784						
	WHtR	−0·000	−0·001, >0·000	0·798						

EO, eating occasion; WHtR, waist-to-height ratio; TDEI, total daily energy intake; MSF_{SC}, sleep debt-corrected midpoint of sleep on weekend (chronotype indicator).
* Clock time of last eating occasion.
† Time between last eating occasion and sleep onset (negative value if last eating occasion after sleep onset).
‡ Relative energy intake 2 h before sleep onset or later.
§ Model 1 = unadjusted.
‖ Model 3 = adjusted for age, sex, chronotype, sleep duration, moderate to vigorous physical activity, family's educational level and TDEI.
¶ Model 4 = TDEI removed from model 3.
Linear mixed effects models with family as a random effect (R package 'lme4').

with BMI *Z*-score and WHtR are also presented in Table 2. None of the interaction terms were statistically significant. However, later chronotype was significantly associated with lower BMI *Z*-score in an unadjusted model (estimate: −0·124, 95 % CI (−0·245, −0·002), $P = 0·046$), but chronotype was not associated with WHtR.

Discussion

The objective of this study was to investigate the associations of the timing of evening eating with adiposity measures among preschool-aged children, and, additionally, to explore whether these associations depend on chronotype. To our knowledge, this was the first study in this age group to measure the timing of evening eating relative to sleep onset and to explore the moderation by chronotype in this context. The last EO occurring later relative to sleep onset and higher %TDEI consumed 2 h before sleep onset or later were associated with higher WHtR after adjustment for several possible confounders. In this sample, the clock time of the last EO was not associated with BMI *Z*-score or WHtR, and the investigated associations did not depend on chronotype.

Comparison with previous studies and interpretation

Research on the associations of later timing of eating with adiposity is scant in children, especially younger children, and the results have been somewhat inconsistent. One likely reason is the highly variable definitions and operationalisations of later timing of eating, which make it difficult to compare study findings. The significant positive association between %TDEI before sleep onset and WHtR found in the present study is in line with the meta-analysis showing that 'higher energy intake around bedtime' increased the odds of overweight/obesity[14]. However, the four studies included in that meta-analysis did not directly measure the timing of energy intake in relation to sleep onset but instead definitions like 'consuming over 25 % of total energy intake after 9 pm' and 'having the most energy-dense snack for the evening snack' were used[14]. Moreover, only one of the studies, where the exposure was the distribution of daily energy intake across meals, included preschool-aged children[15].

To the best of our knowledge, no previous studies have used similar measures of the timing of eating relative to sleep onset as here in young children. One study among adolescents found a negative association of 'dinner-to-bed time' with risk of overweight and abdominal obesity[50], although it is unclear whether dinner was the last EO of the day. Among adults, for example, one study found a positive association between evening latency and prevalence of overweight/obesity[17], while two found no association[13,46]. On the other hand, in a US study among young adults, a group with a higher body fat percentage had their latest 'caloric event' closer to DLMO than a group with a lower body fat percentage[19]. In addition, consuming a higher percentage of daily energy content between 4 h before DLMO and sleep onset correlated with higher body fat percentage, and the clock time of the last EO, in turn, was not associated with body fat percentage[19]. Hence, while the timing of sleep onset may not completely correspond to more robust measures of the start of the biological night, like the DLMO, which is considered the gold standard measure, our results support the notion that examining the circadian timing of eating rather than clock time could be more relevant when investigating associations with adiposity – also in young children. However, future studies could consider measuring eating in relation to DLMO in preschool-aged children, although measuring DLMO is cumbersome, especially in younger children.

No significant interactions with chronotype were found in the present study. Among adults, for example, a higher %TDEI consumed within 2 h before bedtime was associated with

increased odds of overweight/obesity only among later chronotypes (assessed as MSF_{SC}) in one study[18], whereas a longitudinal association between higher %TDEI consumed after 20:00 and higher risk of obesity did not depend on chronotype (assessed with a short version of the MEQ) in another study[51]. Based on our results, it can be postulated that later evening eating and chronotype might not interact in predicting adiposity in preschool-aged children. Possible reasons for this may be that chronotype is on average notably earlier in young children[23,37], and the relationship between sleep timing and circadian phase (markers like melatonin and body temperature) appears to be age-dependent as well[52]. Furthermore, the variability of chronotype may be too small among this age group; at least in some samples of older children or adolescents the standard deviation of actigraphy-derived sleep midpoint on the weekend was somewhat bigger than in this sample (ranging from 0:52 to 1:19)[53–55]. It may also be that the assessment of chronotype as midpoint of sleep is impaired because preschool-aged children's bedtimes and wake-up times are more or less dictated by their caregivers. Therefore, sleep timing may not accurately reflect the internal biological rhythms of a child. It should be highlighted, overall, that studies examining the timing of eating and sleep in young children cannot be directly compared with studies in older children and adults, particularly because of differences in determinants of when one eats and sleeps. Furthermore, studies on the innate biological rhythms of young children are scarce.

There are several proposed mechanisms of how later eating could contribute to adiposity, and the function of the circadian system is suggested to underlie the mechanisms – at least to some extent[4,9,10]. For example, circadian variations in factors or processes involved in energy metabolism and the regulation of energy balance, such as in the thermic effect of food, may play a role[4,9]. Regarding specifically the proximity of eating to sleep onset, it is known that postprandial glucose remains higher in the evening or night than in the morning[4,56]. This combined with the fact that the rise in melatonin levels begins 2–3 h before habitual bedtime, and that melatonin suppresses insulin release suggests that eating close to sleep onset may be detrimental to blood glucose regulation and weight control[56]. However, the influence of nutrient composition, among other properties of the food consumed, needs to be kept in mind [57]. Furthermore, in addition to different physiological responses to meals depending on the time of day, there is also evidence that the timing of eating could influence the circadian system, specifically the entrainment and synchronisation of peripheral clocks, and possibly lead to metabolic disturbances[4,9].

Eating later in the evening may also lead to an overall higher energy intake[4]. For example, in an adult sample, later timing of the last meal and shorter duration between the last meal and sleep onset were associated with greater total energetic intake[58]. However, it is unclear whether this association exists among young children because their eating and bedtime are largely regulated by caregivers. If TDEI is on the causal pathway from later eating to adiposity, adjustment for it is problematic[59]. Regardless, the associations of evening latency and %TDEI before sleep onset with WHtR in the present study remained significant after adjusting with TDEI. Similarly, for example, an association between higher energy intake at lunch and supper than at other meals and higher odds of overweight/obesity remained significant after adjustment for TDEI in one study[15]. However, in the present study, there was a significant negative association between evening latency and BMI *Z*-score when TDEI was removed from the fully adjusted model. Future studies could examine the role of TDEI, especially as a possible mediator in the association between later eating and adiposity.

It should be kept in mind that the current study examined only the timing of eating in the evening, and the timing of other daily EO may also have relevance[12,14]. Therefore, investigating, for example, the timing of all daily EO simultaneously is also important. However, in Finland, at least the mealtimes in preschools are rather fixed, and thus, the largest inter-individual variation in the timing of eating on preschool days likely arises outside preschool hours, that is, evening in most cases. Moreover, even though several lifestyle factors were adjusted for in the current study, disentangling the independent effects of later eating on the development of overweight/obesity is difficult, since numerous aspects in eating and in other energy balance-related behaviours also have an impact and may in fact have synergistic effects. Furthermore, regarding the present study, it could be speculated whether the association between evening latency and WHtR was driven more by sleep onset than the timing of eating; higher evening latency in this sample may have been more dependent on later sleep onset than the time of the last EO, and later sleep onset on weekdays was associated with lower BMI and WHtR in a previous study using the current sample[34]. Additionally, there was a significant unadjusted association between later chronotype and lower BMI *Z*-score in this study. All in all, research to unveil the causal relationships and mechanisms is warranted.

Furthermore, the clinical relevance of the associations found needs to be investigated. Under one per cent of the variance in WHtR was explained by evening latency or %TDEI before sleep onset alone (crude models). Together with confounders, the percentage was approximately 18. Moreover, the estimates of the associations were rather small. It will be important to establish whether changes in the timing of evening eating can result in significant changes in adiposity measures. If enough evidence accumulates, recommendations about the timing of eating might be incorporated into nutrition recommendations. In that case, investigating the causes of later eating will be important to determine how evening eating could be curtailed, perhaps, for example, by emphasising the importance of the first meals of the day. This knowledge might then be used to improve mealtime or food provision practices and food education in preschools, for instance.

Strengths and limitations

The current study has several strengths, but some limitations must also be addressed. The sample size was comparatively large. Another strength related to the sample was its socio-economic diversity (albeit still quite highly educated)[26]. However, the participation rate was rather low (24 %), which could have caused a somewhat selected data. For example, participating children may have had more health-conscious families or high socio-economic background. This could be

expected to have attenuated unfavourable health associations such as between later eating and adiposity. Nonetheless, we did find significant associations.

Concerning the measures of this study, one major strength is that food record data and actigraphy data were collected for the same 3 d, enabling accurate calculation of the variables regarding the timing of eating relative to sleep onset. Moreover, an advantage of the food record is that it is not affected by recall bias; it provides more reliable and accurate data on the timing of EOs than questionnaire methods about usual mealtimes. Another strength, regarding specifically the current study, is the detailed collection of the food record data[30], for example, portion size estimation was aided with a food picture book designed for the DAGIS project. However, a limitation in measuring the timing of eating is that both start and end times of EOs were not reported, and it cannot be known whether the reported time was the starting time. Furthermore, food intake assessment is subject to under- or overreporting due to, for instance, social desirability, and misreporting might be more pronounced when the reporter is a proxy such as a parent[60]. Moreover, not examining the timing of eating separately for weekdays and weekend days may have affected the results, but this choice was made due to a marked decrease in sample size for weekend days.

Objective measurement of sleep with actigraphy is another strength, since discrepancies between objective and subjective measures of sleep have been detected[61]. However, actigraphy also has its limitations. Specifically, the performance of a hip-worn actigraphy in measuring sleep is still unclear since the assessment of sleep is usually done with a wrist actigraphy. However, at least one study demonstrating good validity in children exists[62], and the HMM-based algorithm used in the present study appears promising for hip placement as well[34].

The (sleep debt-corrected) midpoint of sleep on free days is a widely used and validated measure of chronotype, albeit primarily in adults[23]. In the current study, it is unknown whether the participating children were able to sleep freely (e.g. without being woken up by their parents) on the weekend when sleep was measured. This introduces a source of error, since this assessment of chronotype requires sleeping according to one's innate sleep need on free days. Moreover, the measurement period of 7 d might be too short to take into account intra-individual variability in sleep timing for assessing chronotype[43], and the midpoint of sleep on the weekend comprised the mean for only one or two nights. Different chronotype instruments differ in what they precisely measure as well as in other properties; for instance, midpoint of sleep may measure chronotype as more of a state than a trait compared with the MEQ[43], and the MEQ chronotype might correspond better to genetic tendency for morningness than midpoint of sleep[63]. Therefore, future studies could assess chronotype with different measures, including biological markers like DLMO (although hardly feasible in young children), to investigate whether they moderate the association of the timing of eating relative to sleep onset with adiposity in children. This may be fruitful also because, in the present study, sleep timing was included both in the timing of eating and in the chronotype assessment.

Importantly, due to the cross-sectional nature of this study, inferences about causal relationships cannot be made. Additionally, there might still be unknown or unmeasured confounders. These may include daytime sleep which was not measured in this study.

Conclusions

Our findings suggest that later eating relative to sleep onset is associated with higher WHtR in preschool-aged children – any consumption occurring later as well as the amount of energy consumed at this later timing may have relevance. Furthermore, since the clock time of the last EO was not associated with WHtR or BMI *Z*-score, our results highlight the importance of examining the timing of eating in relation to sleep timing, or other markers of circadian time, when studying associations with adiposity – among young children as well. Further research is warranted to confirm causal relationships and the clinical relevance of the findings.

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There are no conflicts of interest.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114523002350

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