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Systematic review and meta-analyses of the relationship between short sleep and incidence of obesity and effectiveness of sleep interventions on weight gain in preschool children

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Summary

The aim of this study is to determine (a) whether short sleep is associated with the incidence of obesity and (b) whether interventions beneficial for sleep reduce weight gain in preschool children. We systematically searched PubMed, Embase, Web of Science and Cochrane up to 12/09/2019. (a) Studies that were included were prospective, had follow-up ≥1 year, with sleep duration at baseline and required outcome measures. (b) Intervention trials with sleep intervention and measures of overweight or obesity were included. Data were extracted according to PRISMA guidelines. (a) The risk of developing overweight/obesity was greater in short sleeping children (13 studies, 42 878 participants, RR: 1.54; 95% CI, 1.33 to 1.77; $p < 0.001$). Sleep duration was associated with a significant change in BMI z-score (10 studies, 11 cohorts and 29 553 participants) (mean difference: −0.02 unit per hour sleep; −0.03 to −0.01; $p < 0.001$). (b) Four of the five intervention studies reported improved outcomes: for BMI (−0.27 kg/m^2; −0.50 to −0.03; $p = 0.03$); for BMI z-score (−0.07 unit; −0.12 to −0.02; $p = 0.006$). Short sleep duration is a risk factor or marker of the development of obesity in preschool children. Intervention studies suggest that improved sleep may be beneficially associated with a reduced weight gain in these children.

KEYWORDS
meta-analysis, obesity, overweight, sleep deprivation

1 | INTRODUCTION

Childhood obesity has increased globally from an estimated 32 million in 1990 to 41 million in 2016 and is expected to reach 70 million by 2025.[1] Data from the National Child Measurement Program (NCMP) conducted by Public Health England in 2018–2019 indicate that, across England, in reception year (age 4/5 years), there are 22.6% of children with overweight or obesity.[2] This indicates that there are a significant number of children with overweight and obesity by the time they start school. The early years' age group may be a crucial group for obesity prevention,[3] especially given the evidence that, in more recently born cohorts of children, the trajectories of probable overweight or obesity developed at younger ages.[4]

Like most obesity prevention programmes, the UK Government's Childhood Obesity plan highlights food, healthy eating and physical activity as key target areas[3] but, given the limited success of such programmes, they may be insufficient to tackle the observed rise in childhood obesity levels.[1–4]

A child's usual sleep duration is affected by age and a number of different factors including social, psychological, behavioural, pathophysiological and environmental ones. Previous meta-analysis conducted in 2017 and 2018 showed that short sleep is associated with obesity and adverse changes in body mass index (BMI) in infants, children and adolescents.[5,6]

The aims of this study were, firstly, to conduct an updated systematic review and meta-analysis of sleep and obesity exclusively in pre-school children, and, secondly, to conduct a novel systematic review and meta-analysis of intervention studies in which a sleep component had been included. The aim of the latter study was to determine whether sleep improvements are associated with beneficial effects on weight gain.

2 | METHODS

2.1 | Search strategy and selection criteria

Systematic searches using the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines (PRISMA)[7] to identify studies that reported the longitudinal association between sleep duration and different measures of overweight, and obesity, and intervention studies where sleep modifications were used and weight outcomes measured were performed. Electronic searches were performed (from 1966 to 12th of September 2019) of PubMed, Embase Web of Science and Cochrane Central Register of Controlled Trials. The following 'Sleep terms' (sleep OR sleep disordered breathing OR bed time) in combination with 'Obesity terms' (BMI OR body mass index OR weight OR waist circumference OR waist OR WHR OR waist hip ratio OR obese OR overweight OR adiposity OR adipose tissue OR anthropometry OR body composition OR body constitution) and 'Study Population terms' (children OR adolescents OR pediatrics OR pediatric OR paediatric OR paediatrics OR infant OR preschool) with 'Study type terms (prospective OR cohort OR longitudinal) were used. The articles identified by the searches were reviewed along with any relevant references cited within them. There were no language restrictions.

2.2 | Inclusion and exclusion criteria

2.2.1 | Included studies

These had to fulfil the following criteria: (a) original published article, (b) study in preschool children (baseline mean age ≤5 years), (c) observational prospective design or intervention trials, (d) assessment of duration of sleep quantity as baseline exposure (aim 1) or sleep modification as intervention (aim 2), (e) follow-up of ≥1 year for incident outcomes and (f) one of the following outcomes: (i) incident cases of overweight and/or obesity (ii) prospective changes in BMI z-score or (iii) changes in BMI.

2.2.2 | Excluded studies

Studies excluded were (a) case-control by design, (b) cross-sectional reports, (c) had only a meeting abstract or unpublished material available or (d) included individuals with sleep disordered breathing.

Where multiple reports from the same study have been published, we used those with the most detail and/or longest follow-up. Authors were contacted for raw data when not readily available from published reports.

2.3 | Data extraction

Data were independently extracted by three reviewers (M.A.M., S.B. and F.P.C.). Any difference regarding the inclusion of particular studies was resolved by arbitration. A total of 1719 search records yielded 866 potential studies after the removal of duplicates (Figure 1). One hundred and thirty studies proceeded to full-text evaluation from which we identified 28 prospective observational studies that had data suitable for meta-analysis (13 for overweight/obesity, 11 for BMI z-score and 10 for BMI). As per previous studies, relevant data were extracted and tabulated.[6] Five intervention studies were identified that were suitable for the second analysis.

2.4 | Exposure

Sleep in preschool children is different from that of adults.[8] The definition of 'short sleep' varied between studies and was defined by age as stated in Table 1. Risk ratios for short sleepers were compared to both middle and long sleepers or to a reference category.

2.5 | Outcome

Unless stated otherwise in Table 1, preschool children with obesity were defined either by a BMI > 95th and children who were overweight as >85th percentile according to local national growth charts or by international growth charts (see previous study for more detail). BMI z-scores also called BMI standard deviation (s.d.) scores, and changes in BMI, were also used for outcome data.

2.6 | Confounders

Each study adjusted for different confounders as shown in Table 1. The most adjusted model was used for the meta-analysis after

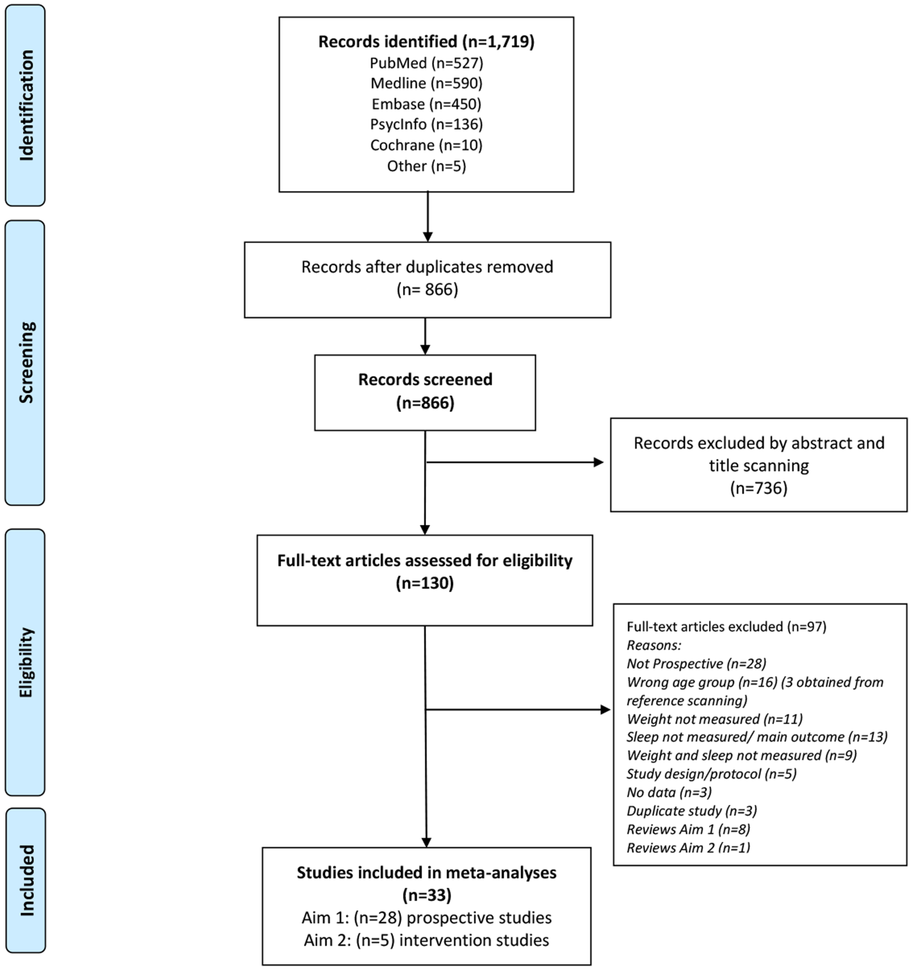


FIGURE 1 PRISMA flow chart

consideration of possible causal pathways. Country, gender and sample size were collected and used in stratified analyses of heterogeneity, publication bias and sensitivity.

2.6.1 | Intervention studies

The five studies included in the systematic review of intervention studies are described in Table 2. Of these, four studies were suitable for meta-analysis. Three for change in BMI and three for change in BMI z-score following intervention.

2.7 | Statistical analysis

The quality of the studies included was evaluated by the Downs and Black Quality Index score system, with a maximum score of 20 for nonrandomized studies.[42]

We calculated an estimate of relative risk (risk ratio RR) from either odds ratios (OR) or hazard ratios (HR) with 95% confidence intervals or regression coefficient β (95% CIs) for changes in BMI z-score or BMI as a continuous outcome so as to estimate the quantitative relation between short sleep duration and overweight or obesity. Data were requested from authors if necessary. If required, the SE of either the RR or β was calculated algebraically from the 95% CIs.

A random effect model weighted by the inverse of the variance was used.[43] By comparison with the reference category to estimate, the pooled risk and 95% CI of risk of development of overweight/obesity or the mean difference in BMI z-score or BMI with each additional hour of sleep.

Heterogeneity between studies was tested by Q-statistic and quantified by H-statistic and I^2-statistic.[44] Publication bias was detected using funnel plot asymmetry and quantified using the Egger's regression test[45,46] where appropriate. Publication bias was corrected by the 'Trim and fill' method.[47] Sensitivity analysis was used to determine the influence of individual studies in the meta-analysis by omitting one study at a time to determine the extent of the that study on the observed estimates. Potential sources of heterogeneity were determined by using subgroup analysis (e.g., impact of geographic location). Egger's test was conducted using Stata V16 (StataCorp LLC, 2019). Trim and fill were carried out using RStudio (R Core Team, 2019).

TABLE 1 Included studies

Author	Year Published	Country	Cohort	Quality Score	Recruit-ment Year(s)	Age at Baseline Sleep Measure-Ment(s)	Duration of Follow-up
Agras[9]	2004	USA	Recruited from well newborn nurseries in San Francisco (*n* = 150)	12	Unreported	3 y	5.5 y
Reilly[10]	2005	UK	Avon longitudinal study (ALSPAC) (*n* = 5493)	17	1991–1992 (mothers)	2.5 y	4.5 y
Snell[11] (Young)	2007	USA	Longitudinal child development supplement of the panel survey of income dynamics (*n* = 720 [young cohort])	16	1997	Young: 3–7.9 y	5.5 y
Taveras[12]	2008	USA	Project viva (*n* = 915)	18	1999–2002*,[a]	0.5 y	2.5 y
Touchette[13]	2008	Canada	Quebec longitudinal study of child development (*n* = 1138)	17	1997–1998	2.5 y	4.5 y
Bell[14]	2010	USA	Longitudinal analysis of panel survey of income dynamics (PSID chid development supplements (CDS) (0–4 y *n* = 822) (5–13 y *n* = 983)	16	1997	Younger cohort: Mean (SD): 2.67 (1.42)	5 y
Carter[15]	2011	New Zealand	Birth cohort (*n* = 244)	16	2001–2002	3 y	4 y
Hiscock[16]	2011	Australia	Longitudinal study of Australian children a) ≤1 y (*n* = 3857) b) 4–5 y (*n* = 3844)	18	2004	a) Mean (sd): 8.7 (2.5) mo, or 0.725 y b) Mean (SD): 56.8 (2.6) mo, or 4.73 y	2 y
Diethelm[17]	2011	Germany	Dortmund nutritional and anthropometric longitudinally designed (DONALD) study (*n* = 481)	15	Ongoing since 1985	1.5 y	5.5 y
Klingenberg[18]	2012	Denmark	SKOT cohort (*n* = 211)	16	2006–2007	0.75 y (9 mo)	2.25 y (2 y and 3 mo)
Miller[19]	2014	USA	Participants in Headstart, low income families in Midwest (*n* = 273)	16	Unreported	Mean (SD): 4.11 (0.54) years	1 y
Magee[20]	2014	Australia	Waves 1 to 3 of 4 to 5-y old cohort longitudinal study of Australian children (n = 2,984)	18	2004	4 y	4 y
Speirs[21]	2014	USA	STRONG kids (*n* = 247)	13	Unreported	2–3 y	1 y
Scharf[22]	2014	USA	Early childhood longitudinal study-birth cohort (*n* = 8950)	15	2001	4 y	1 y
Bonuck[23]	2015	UK	Avon longitudinal study of parents and children (*n* = 1899)	18	1991–1992	4.75 y	10.25 y
Bolijn[24]	2015	Netherland	KOALA study (*n* = 1658)	16	2000*,[b]	2 y	7 y
Zhou[25]	2015	Singapore	Growing up in Singapore towards healthy outcomes (GUSTO) birth cohort (*n* = 799)	16	2009–2011	0.25 y (3 mo)	1.75 y (21 mo)
Küpers[26]	2015	Netherland	GECKO Drenthe birth cohort (*n* = 2475)	14	2006–2007	0.33 y (4 mo)	1.67 y (20 mo)

TABLE 1 (Continued)

Author	Year Published	Country	Cohort	Quality Score	Recruit-ment Year(s)	Age at Baseline Sleep Measure-Ment(s)	Duration of Follow-up
Butte[27]	2016	USA	Pre-school age cohort (*n* = 111)	17	2010–2012	Mean (SD): 4.6 (0.9) y	1 y
Halal[28]	2016	Brazil	2004 Pelotas birth cohort (N = 4231)	16	2004	1 y	3 y
Baird[29]	2016	UK	Children of the women included in the Southampton Womens survey (SWS) (*n* = 587)	15	1998–2002 (of mothers)	3 y	1 y
Wang[30]	2016	China	Jiaxing birth cohort (*n* = 16 028)	16	1999–2009	3 y	2 y
Derks[31]	2017	Netherlands	Embedded in generation R (*n* = 5161)	14	2002–2006	2–6 mo	5–6 y
Collings[32]	2017	UK	(*n* = 1338)	19		12 mo	2 y
Taylor[33]	2018	New Zealand	Datas from prevention of overweight in infancy (POI) trial	15	2009–2010	1 y	4 y
Wang[34]	2018	Netherlands	BeeBOFT study (*n* = 2308)	15	2009–2010	6 mo	30 mo
Derks[35]	2019	Australia	PEAS study (*n* = 336)	16	1998–2000	2 mo	46 mo
Tuohino[36]	2019	Finland	CHILD_SLEEP birth cohort (*n* = 889)	13	2011–2017	3 mo	24 mo

Note. Description of the 24 studies included in the meta-analyses for (i) overweight/obesity, (ii) BMI Z-score, and (iii) BMI.

[a]Not mentioned in paper. From 'Maternal Age and Other Predictors of Newborn Blood Pressure' by Gillman et al. http://www.ncbi.nlm.nih.gov/pubmed/14760269.

[b]Not mentioned in paper. From 'Etiology of Atopy in Infancy: The KOALA Birth Cohort Study' by Kummeling et al. http://www.ncbi.nlm.nih.gov/pubmed/16343090.

TABLE 1 Continued

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Agras[9]	Sleep duration (average of sleep time at age 3 and 4, not reported if it includes naps)	SS: ≤11.25 hr RS: >11.25 Continuous (h)	Parental report (unreported)	**Analysed as OW/OB:** OW: BMI > 85th percentile for age and sex. Ref: (charts unreported) **Analysed for BMI:** Changes in BMI kg/m2 at end of follow-up	Height and weight measured by researchers	No adjustments mentioned in correspondence
Reilly[10]	Sleep duration (not reported if it includes naps**)**	SS: Lowest quarter; <10.5 (*n* = 1831) RS: Highest quarter; >12 h	Parental report (questionnaire)	**Analysed as OW/OB:** BMI ≥ 95th centile Ref: UK population 1990	Height and weight measured by researchers	Maternal education, energy intake at age 3 y (food groups), sex
Snell[11] (Young)	Nighttime sleep duration (weighted average of week and weekend)	Continuous (h)	Mixed- child and parent reported sleep duration (time diary)	**Analysed for BMI Z-score:** Changes in BMI z-score standardized for age and sex at end of follow-up Ref: CDC OW: Age and gender specific IOTF cut-offs, similar to adult ≥ 25.	Height and weight measured by researchers	Family income, parent education, child race, child age at time 1, child age at time 2, sex, **BMI at time 1**
Taveras[12]	Weighted average of sleep duration (weekend + week) from 6 mo to 2 y (including naps)	SS: <12 hr (*n* = 329) RS: ≥12 h Continuous (h)	Parental report (questionnaire)	**Analysed as OW/OB:** OW: BMI ≥ 95^{th} percentile or greater for age and sex, **analysed as OB:** Ref: CDC **Analysed for BMI Z-score**: Difference in BMI z-scores at end of follow-up	Height and weight measured by researchers	Maternal education, income, pre-pregnancy BMI, marital status, prenatal smoking history, breastfeeding duration, childs race/ethnicity, childs birth weight and 6-mo weight for length z-score, daily television viewing, daily active play

TABLE 1 (Continued)

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Touchette[13]	Nighttime sleep duration (on average) Based on sleep duration on age 2.5, 3.5, 4 and 5	SS: Short persistent (<10) RS: 11-h persistent	Maternal report (questionnaire)	**Analysed as OW/OB:** Overweight or obesity Ref: Age and sex specific cut-offs from IOTF	Height and weight measured by researchers	Birth weight, prematurity, low birth weight, sex of child, maternal smoking during pregnancy, weight at 5 mo, low parental education, modified family structure, late cereal introduction, not breast-fed, immigrant mother, naptime at 2.5 y, watching TV at 6 y, doing physical activities, overeating at 6 y, snacking at 6 y, eating sweets at 6 y, snoring at 6 y, low income status at 6 y
Bell[14]	Duration of nighttime sleep (average of one weekend and one week day)	SS: Low nighttime sleep at baseline (age specific sleep score below the 25^{th} percentile for sleep for age) RS: Age specific sleep score above the 25^{th} percentile for sleep for age	Parental report (time diaries of a week and weekend day)	**Analysed as OW/OB:** OW: BMI > 85th to <95th percentile for age and sex Ref: CDC	Parental report of height and weight	Age, sex, birth weight, father present, hours per day of television viewing, birth order and urban residence, race/ethnicity, family income, maternal education, parents BMI. For older cohort additionally adjusted for child BMI z-score at baseline and physical activity.
Carter[15]	Sleep duration (average of week and weekend sleep, average over age 3, 4 and 5)	Continuous (h)	Accelerometry & parental sleep logs of week and weekend days	**Analysed as OW/OB:** OW: ≥85th age and sex specific percentile Ref: CDC **Analysed for BMI:** Changes in BMI kg/m^2 at end of follow-up	Height and weight measured by researchers	BMI at age 3, sex, maternal education, maternal BMI, income, ethnicity, birth weight, smoking during pregnancy, physical activity, TV viewing, fruit-vegetable intake, non-core foods intake

TABLE 1 (Continued)

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Hiscock[16]	Sleep duration (average of 1 week and one weekend day), including daytime naps	Continuous (minutes), converted to hours	Parental report (time diary of a week and weekend day)	**Analysed for BMI Z-score:** Changes in BMI z-scores at end of follow-up Ref: CDC	Height and weight measured by researchers	Wave 1 sex and BMI (or weight-for-age adjusted for birth length for infants)
Diethelm[17]	Usual daily sleep duration (day and nighttime sleep)	SS: Consistent short sleep duration: <13 h at 1.5 and 2 y (*n* = 122). RS: Consistent long sleep duration: >13 h at 1.5 and 2 y	Parental report (interview)	**Analysed as OW/OB:** OW: IOTF BMI cut-offs for children.	Height and weight measured by researchers	Sex, gestational age, birth year, birth weight, fully breastfeeding, rapid weight gain, SES family, maternal education status, maternal overweight, smoking in the household. Maternal age at birth of child, birth order of participating child.
Klingenberg[18]	Total sleep duration (nighttime sleep + daytime napping)	Continuous (h)	Parental report (TSD-Q questionnaire)	**Analysed for BMI Z-score:** Changes in sex and age adjusted BMI z-score at end of follow-up Ref: WHO standard	Height and weight measured by researchers	Birth weight, gestational age, duration of breast feeding, maternal smoking during pregnancy, maternal BMI at 9 mo, household income, highest education level of both parents
Miller[19]	Nightly sleep duration (average of week and weekend days)	Continuous (h)	Parental report (interview)	**Analysed for BMI Z-score:** Change in age and sex specific BMI z-score over 1 y Ref: CDC	Height and weight measured by researchers	Baseline BMI z-score, SDB, soda consumption, home chaos
Magee[20]	Sleep duration (including napping, weighted average of week and weekend sleep)	Continuous (h)	Parental report (time use diary)	**Analysed for BMI:** Changes in BMI kg/m^2 at end of follow-up	Height and weight measured by researchers	Child gender, child sleep problems, household income, maternal education and maternal weight status

TABLE 1 (Continued)

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Speirs[21]	Night-time sleep duration (average over the past week)	Continuous (h)	Mothers/parental report (questionnaire)	**Analysed for BMI:** Changes in BMI kg/m^2 at end of follow-up Ref: CDC	Height and weight measured by researchers	Gender of child, child age, maternal BMI, maternal age, maternal education, marital status, annual household income, maternal race/ethnicity, maternal employment Additional data from author
Scharf[22]	Usual nighttime sleep duration	SS:<9.48 h RS: ≥9.48 h Continuous (h)	Parental report (computer assisted interview administered by assessors)	**Analysed as OW/OB:** OW ≥ 85th–95th percentile for age and sex OB ≥ 95th percentile for age and sex Ref: CDC **Analysed for BMI Z-score:** Changes in age and gender specific BMI z-score over 1 y	Height and weight measured by researchers	Sex, race/ethnicity, SES, television viewing
Bonuck[23]	Weekday nighttime sleep duration	SS ≤ 10.5 h RS > 10.5 to <12.08 h	Parental report (typical weekday bed and wake times)	**Analysed as OW/OB:** OB: BMI > 95th percentile for age and sex Ref: IOTF	Weight and height measured by researchers	Childs sex, age at BMI/height assessment and birth weight, childs estimated weight and height at 6 mo, maternal education, age, parity and pre-pregnancy BMI, T&A, SDB cluster

TABLE 1 (Continued)

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Bolijn[24]	Night-time sleep duration	Continuous (h)	Parental report (questionnaire)	**Analysed as OW/OB:** OW: >85th percentile BMI z-score Ref: (Charts not mentioned) **Analysed for BMI Z-score:** Changes in BMI Z-score at age 5 through 9	Parental report	Daytime sleep duration, recruitment group, pre-pregnancy BMI, maternal smoking during pregnancy, pregnancy weight gain, maternal age at birth, country of birth, educational level, hours/week of paid work by mother, age of child at BMI measurement, child gender, time at kindergarten, tv time, computer time, time playing outside
Zhou[25]	Total daily sleep duration on average (sum of nighttime sleep and daytime sleep)	Continuous (h)	Parental report (brief infant sleep questionnaire)	**Analysed for BMI:** Changes in BMI kg/m^2 over 21 mo	Height and weight measured by researchers	Ethnicity, maternal education, household income, maternal height and BMI at 26 weeks of gestation, age, sex, gestational age, birth weight and length, pregnancy smoking status, maternal gestational diabetes, breast-feeding duration, total media use and outdoor physical activity at 24 mo

TABLE 1 (Continued)

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Küpers[26]	Total sleep duration (including naps)	Continuous (h)	Parental report (questionnaire)	**Analysed for BMI:** Changes in BMI kg/m^2 from 6 to 24 mo. **Analysed for BMI Z-score:** Changes in age and gender specific BMI z-scores from 6 to 24 mo Ref: Dutch growth references from 1997	Height and weight measured by researchers	Gestational age, birth weight, gender, paternal BMI, maternal pre-pregnancy BMI, gestational weight gain mother, smoking during pregnancy, maternal age at date of birth, maternal diabetes, maternal hypertension, Dutch ethnicity, type of feeding at 3 mo, complementary feeding at 4 mo, family screen time at 6 mo, time of possible unrestricted moving at 9 mo, multiparity, maternal education level, household income, one-parent family, childcare by family or friends at 3 mo, mother working at 3 mo after delivery Additional data provided by author
Butte[27]	Total sleep duration (Nighttime sleep and nap time)	Continuous (min/day), converted to per hour	Accelerometry for seven consecutive days	**Analysed for BMI:** Annual changes in BMI kg/m^2 Annual weight gain (kg)	Height and weight measured by researchers	Age, sex, race/ethnicity, daycare hours, household size, household income, mothers age, BMI and education
Halal[28]	Usual nighttime sleep duration	SS: <10 h in at least one of the follow-up visits (at ages 1, 2, 3, and 4) RS: ≥10 h in each of the follow-up visits.	Annual parental report (interview)	**Analysed as OW/OB:** OW (BMI Z-scores between 2–2.99 SDs) or OB: (BMI Z-scores ≥3 SDs) Ref: WHO charts	Height and weight measured by researchers	Mothers skin colour and schooling, sleep characteristics measured at 1 y of age (sleep latency, number of night awakenings, duration of daytime naps)

TABLE 1 (Continued)

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Baird[29]	Usual nighttime sleep duration	Continuous (h)	Maternal report (interview)	**Analysed for BMI:** Changes in BMI at end of follow-up	Height and weight measured by researchers	Age at DXA measurement, gestational age at birth, sex, maternal pre-pregnancy BMI, maternal educational attainment and smoking during pregnancy, age last breastfed, childs television watching and level of activity, dietary quality, highest social class of parents
Wang[30]	Average sleep duration during a 'typical' week.	Categorized ≤10 h, 11–12 h and ≥13 h	Parental report (questionnaire)	**Analysed as OW/OB:** Overweight and obesity were defined by age and gender-specific cut-off points according to the latest Chinese criteria (overweight:, 16.5, and 16.6 for 5-y old boys, and 5-y old girls; Obesity: 17.9, and 18.2 for 5-y old boys, and 5-y old girls.	Height and weight measured by trained nurses.	Age, gender, birth weight, breastfeeding status, appetite, physical activity, maternal age at delivery, maternal body mass index, education and occupation.
Derks[31]	Usual bedtimes and wake times, Daytime sleep (naps) assessed.	Continuous (h)	Parental report (questionnaire)	**Analysed for BMI Z-score:** BMI (kg/m^2) standard deviation (SD) scores calculated by adjusting BMI for age and sex using Dutch reference growth curves.	Height and weight measured by trained staff.	Ethnicity, birth weight, duration of television watching, duration of breastfeeding, maternal education level, maternal BMI, maternal psychopathology symptoms, baseline BMI SD score.

TABLE 1 (Continued)

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Collings[32]	Child sleep duration in hours per day		Parental report	**Analysed for BMI:** Changes in BMI kg/m^2 over 24 mo	Body weight and BMI, Measured by researchers	Gender, gestational age, birth weight, birth season, maternal smoking in pregnancy, maternal follow-up BMI, TV viewing duration, unhealthy snacking, fruit and vegetable intake.
Taylor[33]	Sleep duration in hours per day and included naps where relevant.	Continuous	Accelerometers	**Analysed for BMI Z-score:** Determined using WHO growth standards.	Body weight and BMI, Measured by trained researchers	Adjusted for concurrent BMI z-score, randomised group, sex primiparous, maternal education, household deprivation, ethnicity and maternal BMI..
Wang[34]	Total sleep time between 6:00 pm and 8:00 am and 8:00 am and 6:00 pm	Continuous	Parental report (questionnaire)	**Analysed for BMI Z-score:** Calculated using WHO growth standard.	Height and weight measured by trained staff.	Adjusted for exact age of child at sleep measurement and exact age of child at BMI measurement, maternal age, maternal education level, maternal pre-pregnancy BMI, and parity, child gender, child ethnic background, child birth weight, gestational age, duration of breastfeeding, and child screen time at baseline and intervention groups and baseline BMI z-scores/sleep duration.
Derks[35]	Infant sleep duration in hours per day	Continuous	Parental report (sleep diary)	**Analysed for BMI:** Changes in BMI kg/m^2 over 46 mo	Height and weight measured by trained staff.	Age at outcome visit, ethnicity BMI at birth, gestational age, maternal education, maternal BMI, neighbourhood socioeconomic status

TABLE 1 (Continued)

Author	Sleep Exposure	Sleep Exposure Categories Short Sleep (SS) Reference (RS)	Exposure Assessment	Outcome	Outcome Assessment	Adjusted Variables
Tuohino[36]	Infant sleep duration in hours per day	Continuous	Parental report (brief infant sleep questionnaire)	**Analysed as OW/OB:** High increase in weight-for-length/height z-score between 3 and 24 mo	Height and weight measured by trained staff at health clinics.	Adjusted for age, birth weight, sex, maternal early pregnancy BMI, parental education level, maternal smoking during pregnancy, and breastfeeding at age 3 mo.

Note. Description of the 24 studies included in the meta-analyses for (i) overweight/obesity, (ii) BMI Z-score, and (iii) BMI.
[a]Not mentioned in paper. From 'Maternal Age and Other Predictors of Newborn Blood Pressure' by Gillman et al. http://www.ncbi.nlm.nih.gov/pubmed/14760269.
[b]Not mentioned in paper. From 'Etiology of Atopy in Infancy: The KOALA Birth Cohort Study' by Kummeling et al. http://www.ncbi.nlm.nih.gov/pubmed/16343090.

TABLE 2 Intervention studies

Study	Year	Country	Subject Age	Interventions	Outcome Measures	Main Outcomes
Paul[37]	2011	USA	0–12 mo (n = 110)	1 of 4 treatment groups to receive both, one or no interventions delivered at 2 nurse home visits. Interventions were either soothe/sleep or introduction to solids. Control—No intervention	Weight for length percentile at age 1 y. Sleep duration—Parent reported	Infants who received both interventions had lower weight for length percentiles (p = 0.009). No significant difference between single intervention group and control. Breastfed infants in the sleep/sooth group showed significantly more sleep than the control group (p = 0.04).
Haines[38]	2013	USA	2 to 5 y (n = 121) 6-mofollow-up	Interventions: Promotion of 4 family routines: (1) family meals, (2) adequate sleeping, (3) limiting TV time, (4) removing the TV from the childs bedroom. Delivery by motivational coaching at home and by phone, mailed educational materials, text messages. Control—Mailed materials on child development Included TV watching	Secondary outcome: Body mass index. Primary outcome: Child sleep duration (parent reported).	Compared with control subjects, intervention participants had increased sleep duration (0.75 h/day; 95% CI, 0.06 to 1.44; p = 0.03), greater decreases in TV viewing on weekend days (−1.06 h/day; 95% CI, −1.97 to −0.15; p = 0.02), and decreased body mass index (−0.40; 95% CI, −0.79 to 0.00; p = .05). No significant intervention effect was found for the presence of a TV in the room where the child slept or family meal frequency.
Walton[39]	2015	Canada	3 to 5 y (n = 48) 9-mofollow-up	Family-based obesity prevention intervention, parent and tots together (PTT). Intervention—Focused on lifestyle behaviours Active control—Focused on home safety. 9-mo follow-up.	Body mass index. Sleep duration (parent reported).	High retention rates: Intervention (93%) and control (84%). 87% of parents reported that they would highly recommend PTT to a friend. Intervention parents lower parenting stress (P = 0.02) and greater self-efficacy in managing their childs behaviour (P = 0.05) v controls. No significant change in child BMI or sleep between intervention and control.
Woo Baidal[40]	2017	USA	2 to 4 y (n = 1461)	Intervention—Special supplemental nutrition program for women, infants and children (WIC) in 2 communities. Staff working in these communities received additional training around obesity risk factors including sleep routines; participant centred interviewing techniques and additional resource materials. Control—1 control community. All 3 sites received WIC usual care which is in person visits at least three but typically 4 times a year. Included TV watching	Body mass index, BMI z-scores. Sleep duration (parent reported).	WIC in both intervention sites had improved sleep duration compared to control. Study reported small improvement in BMI z-scores in 1 of the 2 intervention communities when children of Asian origin were excluded (P = 0.01). In non-Asian group: Test for overall effect for both sites p = 0.01

(Continues)

TABLE 2 (Continued)

Study	Year	Country	Subject Age	Interventions	Outcome Measures	Main Outcomes
Taylor[41]	2018	New Zealand	1 to 5 y (n = 380)	Intervention—FAB (food, activity and breastfeeding), sleep or combination of both interventions. Include only the sleep v control arm for this analysis (sleep n = 131, control n = 142).	Body mass index, BMI z-scores. Obesity as defined as BMI ≥ 95th percentile. Sleep duration measured by 24-h accelerometry data	Significant intervention effect was observed for BMI at 5 y Significant intervention effect for BMI z-score at 5 y Protective effect for obesity among those receiving the 'sleep intervention' v control: Relative risk, 0.82 (95% CI, 0.36-1.84) at 5 y.

Note. Description of interventions studies that included a sleep component and obesity-related outcomes.

Review Manager software version 5 was used for additional statistical analyses. A two-sided $p < 0.05$ was considered statistically significant. The systematic reviews and the meta-analyses were carried in accordance with PRISMA guidelines for non-randomised studies, nonrelevant items were excluded, as appropriate.[7]

3 | RESULTS

3.1 | Characteristics of study cohorts

After exclusion of ineligible studies (Table S1 for details of the studies and the reason for exclusion), we identified a total of 1719 studies from the searches (Figure 1. Twenty-eight studies (32 cohorts) met the inclusion criteria for the qualitative synthesis and had data suitable for the different sets of analyses. Where studies reported data, for different age groups or for different nationalities, we treated them as separate cohorts. At the start of the studies, mean age ranged from 0 to <5 years (Table 1). There were 13 studies for obesity (42 878 participants from nine countries),[9,10,12–15,17,22–24,28,30,36] 11 studies for BMI z-score (12 cohorts; 29 553 participants from five countries)[11,12,16,18,19,22,24,26,31,33,34] and 10 studies for BMI (13 cohorts; 9035 participants from six countries).[9,15,20,21,25–27,29,32,35]

3.2 | Incidence of overweight and/or obesity in short sleepers

The relationship between sleep and preschool children who were overweight and/or obesity is shown in Figure 2A. Short sleep was associated with an increased risk of overweight or obesity (RR: 1.54 [95% CI, 1.33 to 1.77]; $p < 0.001$). There was significant heterogeneity between studies ($I^2 = 68\%$, $p = 0.002$) with no evidence of publication bias (Egger's test $p = 0.699$).

3.3 | Short sleep and BMI Z-score

We observed a significant negative relationship between sleep duration and BMI z-score (RR: −0.02 [−0.03 to −0.01]; $p < 0.001$). For every hour increase in sleep, BMI z-score significantly decreased (Figure 2B).

There was significant heterogeneity between studies ([$I^2 = 49\%$, $p = 0.03$] and evidence of publication bias [Eggers test $p = 0.039$]), possibly resulting from two missing studies with larger positive mean as indicated by the Trim and fill (Figure 1).

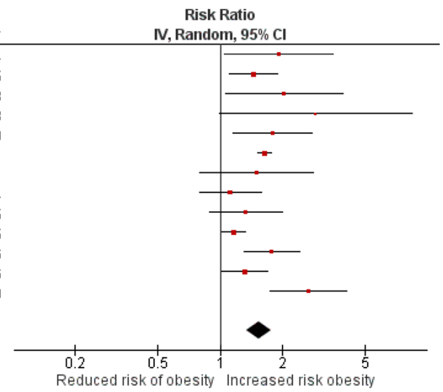
3.4 | Short sleep and BMI

Similarly, we observed a significant negative relationship between BMI and sleep duration, with BMI decreasing (RR: −0.03 [−0.04 to −0.01; $p = 0.001$]) for every extra hour of sleep (Figure 2C). There was significant heterogeneity between studies ($I^2 = 82\%$, $p < 0.001$)

(a)

Study or Subgroup	log[Risk Ratio]	SE	Participants Total	Total	Weight	Risk Ratio IV, Random, 95% CI	Year
Agras (USA)	0.6539	0.3092	0	150	4.1%	1.92 [1.05, 3.53]	2004
Reilly (UK)	0.3716	0.1381	0	5493	10.0%	1.45 [1.11, 1.90]	2005
Taveras (USA)	0.7129	0.3306	0	915	3.7%	2.04 [1.07, 3.90]	2008
Touchette (Canada)	1.0647	0.5459	0	1138	1.6%	2.90 [0.99, 8.45]	2008
Bell 0-4y (USA)	0.5878	0.2248	0	822	6.3%	1.80 [1.16, 2.80]	2010
Carter (New Zealand)	0.4943	0.0376	0	224	15.1%	1.64 [1.52, 1.76]	2011
Diethelm (Germany)	0.4055	0.3196	0	481	3.9%	1.50 [0.80, 2.81]	2011
Scharf (USA)	0.1133	0.1768	0	8950	8.1%	1.12 [0.79, 1.58]	2014
Bonuck (UK)	0.2852	0.205	0	1899	7.0%	1.33 [0.89, 1.99]	2015
Bolijn (The Netherlands)	0.1508	0.0631	0	1658	14.1%	1.16 [1.03, 1.32]	2015
Wang (China)	0.571	0.1575	0	16028	9.0%	1.77 [1.30, 2.41]	2016
Halal (Brazil)	0.2776	0.1278	0	4231	10.6%	1.32 [1.03, 1.70]	2016
Tuohino (Finland)	0.9821	0.2155	0	889	6.6%	2.67 [1.75, 4.07]	2019
Total (95% CI)			**0**	**42878**	**100.0%**	**1.54 [1.33, 1.77]**	

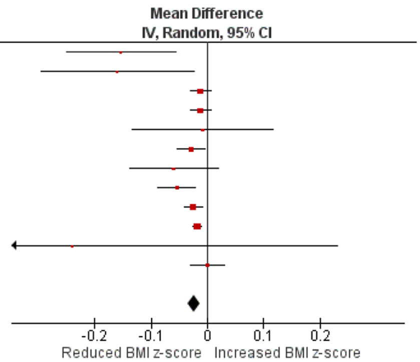
Heterogeneity: Tau² = 0.03; Chi² = 37.85, df = 12 (P = 0.0002); I² = 68%
Test for overall effect: Z = 5.94 (P < 0.00001)



(b)

Study or Subgroup	Mean Difference	SE	Participants Total	Control Total	Weight	Mean Difference IV, Random, 95% CI	Year
Snell-younger (USA)	-0.153	0.05	0	720	1.2%	-0.15 [-0.25, -0.06]	2007
Taveras (USA)	-0.16	0.069	0	915	0.7%	-0.16 [-0.30, -0.02]	2008
Hiscock 4-5y (Australia)	-0.012	0.0092	0	3857	14.9%	-0.01 [-0.03, 0.01]	2011
Hiscock 0-1y (Australia)	-0.012	0.0092	0	3844	14.9%	-0.01 [-0.03, 0.01]	2011
Klingenberg (Denmark)	-0.008	0.0638	0	211	0.8%	-0.01 [-0.13, 0.12]	2012
Scharf (USA)	-0.0287	0.0127	0	8950	11.0%	-0.03 [-0.05, -0.00]	2014
Miller (USA)	-0.06	0.04	0	273	1.9%	-0.06 [-0.14, 0.02]	2014
Bolijn (The Netherlands)	-0.054	0.017	0	1658	7.7%	-0.05 [-0.09, -0.02]	2015
Kupers (The Netherlands)	-0.025	0.008	0	2475	16.4%	-0.03 [-0.04, -0.01]	2015
Derks a (The Netherlands)	-0.018	0.0041	0	5161	21.6%	-0.02 [-0.03, -0.01]	2017
Taylor b (New Zealand)	-0.24	0.24	0	292	0.1%	-0.24 [-0.71, 0.23]	2018
Wang (The Netherlands)	0	0.015	0	1197	9.0%	0.00 [-0.03, 0.03]	2019
Total (95% CI)			**0**	**29553**	**100.0%**	**-0.02 [-0.03, -0.01]**	

Heterogeneity: Tau² = 0.00; Chi² = 21.44, df = 11 (P = 0.03); I² = 49%
Test for overall effect: Z = 4.06 (P < 0.0001)



(c)

Study or Subgroup	Mean Difference	SE	Participants Total	Total	Weight	Mean Difference IV, Random, 95% CI	Year
Agras (USA)	-0.706	0.237	0	150	0.1%	-0.71 [-1.17, -0.24]	2004
Carter (New Zealand)	-0.39	0.1684	0	244	0.2%	-0.39 [-0.72, -0.06]	2011
Speirs (USA)	-0.401	0.134	0	247	0.4%	-0.40 [-0.66, -0.14]	2014
Magee BMI (Australia)	-0.07	0.035	0	2984	4.4%	-0.07 [-0.14, -0.00]	2014
Kupers (The Netherlands)	-0.033	0.011	0	2475	15.3%	-0.03 [-0.05, -0.01]	2015
Zhou - Malay (Singapore)	-0.042	0.0163	0	237	11.5%	-0.04 [-0.07, -0.01]	2015
Zhou - Indian (Singapore)	0.002	0.0012	0	155	21.0%	0.00 [-0.00, 0.00]	2015
Zhou - Chinese (Singapore)	-0.006	0.0036	0	507	20.3%	-0.01 [-0.01, 0.00]	2015
Baird (UK)	-0.234	0.0707	0	587	1.3%	-0.23 [-0.37, -0.10]	2016
Butte (USA)	-0.24	0.12	0	111	0.5%	-0.24 [-0.48, -0.00]	2016
Collings - S Asian (UK)	-0.03	0.0158	0	776	11.8%	-0.03 [-0.06, 0.00]	2017
Collings - White (UK)	-0.0047	0.019	0	562	9.9%	-0.00 [-0.04, 0.03]	2017
Derks b (The Netherlands)	-0.04	0.0408	0	314	3.4%	-0.04 [-0.12, 0.04]	2019
Total (95% CI)			**0**	**9349**	**100.0%**	**-0.03 [-0.04, -0.01]**	

Heterogeneity: Tau² = 0.00; Chi² = 67.93, df = 12 (P < 0.00001); I² = 82%
Test for overall effect: Z = 3.22 (P = 0.001)

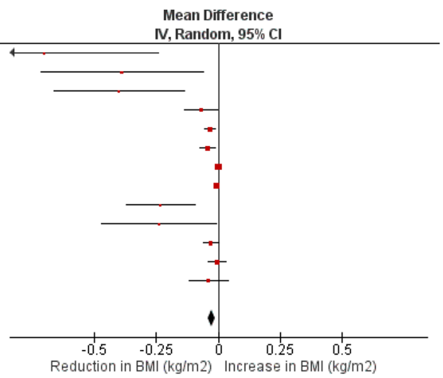


FIGURE 2 Forest plots of meta-analysis of results from prospective studies looking at sleep and measures of overweight or obesity. Forest plot of prospective observational studies on the effect of short sleep duration on the incidence of overweight and/or obesity in preschool children. Results are relative risks (and 95% CI). Forest plot of prospective observational studies on the effect of sleep duration on the change in BMI z-score over time in preschool children. Results are mean BMI z-score difference per an additional hour of sleep (and 95% CI). Forest plot of prospective observational studies on the effect of sleep duration on the change in BMI (kg/m^2) over time in pre-school children. Results are mean BMI difference per an additional hour of sleep (and 95% CI)

and evidence of publication bias (Eggers test $p < 0.001$) with six possible missing studies identified by 'trim and fill'.

3.5 | Subgroup analysis by continent

3.5.1 | Short sleepers with overweight and/or obesity

Subgroup analysis by continent yielded risk ratios ranging from 1.50 to 1.77 across the four subgroups, each with statistically significant results. Heterogeneity ranged from 30% to 73% (Table S2A).

3.5.2 | Short sleepers and BMI Z-score

Subgroup analysis by continent yielded risk ratios ranging from −0.01 to −0.087 across three subgroups with the exception of the Australia and Oceanic group, each with statistically significant results. Heterogeneity ranged from 0% to 67% (Table S2B).

3.5.3 | Short sleepers and BMI

Subgroup analysis by continent yields risk ratios ranging from −0.03 to −0.39 across three subgroups, which apart from both the Australia and Oceania and East Asian groups were statistically significant. Heterogeneity estimates ranged from 38% to 83% (Table S2C).

3.6 | Sensitivity analysis

3.6.1 | Short sleepers with overweight and/or obesity

For the sensitivity analysis, we deleted one study at a time. The heterogeneity was reduced to 33% ($p = 0.12$) by the removal of the study of Bolijn et al.[24] The removal of this study yielded risk ratios that were still statistically significant (1.59 [1.42 to 1.79], $n = 41{,}220$; $p < 0.001$).

3.6.2 | Short sleep and BMI Z-score

The removal of Snell (younger)[11] reduced the heterogeneity to 32% ($p = 0.16$) with the effect being highly significant ($p < 0.001$). The removal of Bolijn, Snell (younger) and Taveras[11,12,24] reduced the heterogeneity to zero ($p = 0.68$) with a highly significant overall effect ($p < 0.001$).

3.7 | Intervention study analysis

Five intervention studies with different strategies to improve sleep duration and quality and the effect on weight-related prospective outcomes were published between 2011 and 2018. All contained boys and girls. Three were from the United States and one each from Canada and New Zealand with sample sizes ranging from 48 to 1461 (see Table 2). The individual results and meta-analyses are shown in Figure 3. The first study by Paul et al[37] is a 2 × 2 factorial RCT of intervention with both soothe and sleep and introduction to solids group ($n = 22$), or just solids ($n = 29$) or just sooth/sleep (n = 29) compared to a control group ($n = 30$). The follow-up was of 1 year. It shows that the sooth/sleep intervention when combined with the solids intervention had a improved effect on BMI. These infants had lower weight for length percentiles ($p = 0.009$), and breastfed infants in the soothe/sleep group showed more sleep than the control group ($p = 0.040$).[37] However, these interventions were not effective on their own (Figure 3A). There was no evidence of publication bias.

The second panel shows the results from the three studies[38,39,41] which looked at change in BMI following interventions that aimed to improve sleep. There was a significant overall effect of −0.27 (−0.50 to −0.03), $p = 0.03$, with no evidence of heterogeneity between studies or publication bias (Figure 3B).

In the two intervention studies (three cohorts)[40,41] reporting changes in BMI z-scores, there was a favourable effect of the interventions of −0.14 (−0.36 to 0.08), $p = 0.006$, with no evidence of heterogeneity (Figure 3C) or publication bias.

In the study by Taylor et al,[37] when looking at the effect of sleep compared to control on overweight or obesity outcomes, a favourable outcome was observed (Figure 3D).

4 | DISCUSSION

In this comprehensive systematic review of the literature, quantitative estimates of the longitudinal associations between short sleep and overweight or obesity have been provided for preschool children. The pooled effect was strong for sleep and overweight or obesity. Significant relationships between hours of sleep and changes in both BMI z-scores and BMI were also observed. Data from intervention studies are limited but increasing sleep duration was associated with beneficial effects on BMI and the prevalence of obesity in some of the studies.

4.1 | Sleep and measures of obesity in preschool children: Strengths and limitations

The findings from this study are consistent with our previous study in infants, children and adolescents[6] and demonstrate that the effect of sleep duration is large, even when restricted to pre-school children. They confirm that sleep duration is an important predictor of measures of obesity and that the findings are consistent in different populations. The observed significant heterogeneity between studies appeared to be due to only one study.[24] There was no evidence of publication bias. The results from the categorical studies were corroborated by the meta-analysis of regression coefficients looking at both

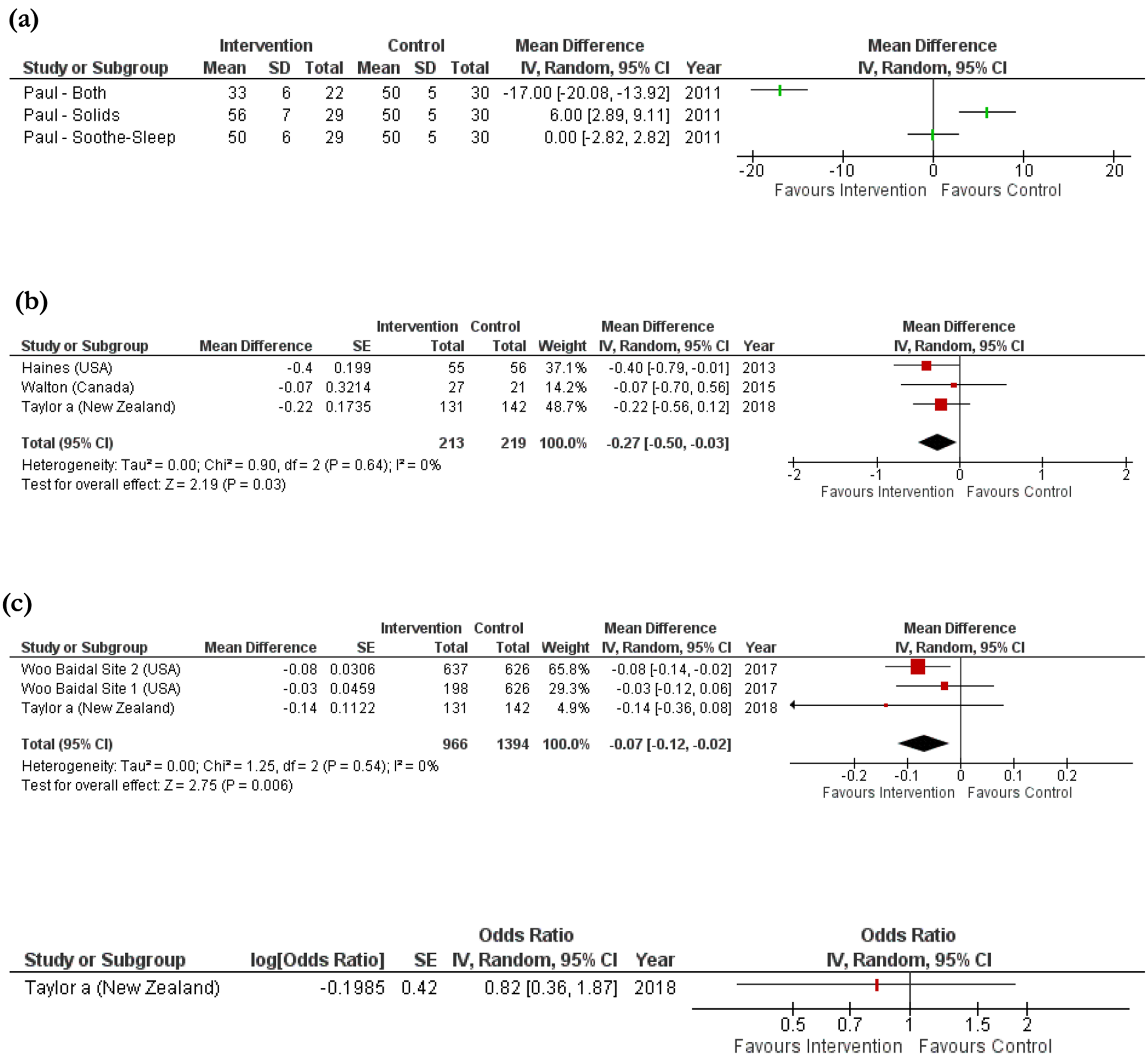


FIGURE 3 Forest plot of the results of five intervention trials of different strategies to improve sleep duration and quality and the effect on weight-related prospective outcomes. This is a 2 × 2 factorial RCT of intervention with both solids and soothe and sleep group (n = 22), or Solids (n = 29) or both approaches together (n = 29) compared to a control group (n = 30). The follow-up was to 1 year with outcome of weight for length percentile. (A) These three intervention trials share the same outcome (change in BMI) at the end of follow-up. Haines used a promotion to promote four family routines (family meals, adequate sleep, limiting TV, and removing TV from the child's bedroom) with 6-month follow-up. Walton used an intervention, which focused on lifestyle behaviours with a 9-month follow-up. Taylor used food, activity and breastfeeding (FAB) and sleep interventions. This analysis compares the sleep intervention vs control group with a 5-year follow-up. These two trials have both looked at change in BMI z-score. Woo Baidal is a pretreatment and posttreatment trial using woman, infants, and children (WIC) nutrition and sleep routines intervention to improve BMI z-score over 2 years. Taylor has looked at sleep intervention vs Control with a 5-year follow-up. The graph below shows the protective effect of sleep compared to control on overweight or obesity outcomes

changes in BMI z-score and BMI. In these, longer sleep duration in children was associated with a reduced age-related weight gain. For short sleep duration and BMI z-scores following removal of three studies,[11,12,24] the overall effect was still significant (p < 0.001), and the heterogeneity was reduced to zero. There was no appreciable effect on the results when studies with quality scores <15 out of a maximum of 20 were removed (Table S3).

The study has some limitations. The results are only representative of included studies. The quality of the data within the study is limited by the quality of the individual studies.

There are inherent limitations associated with the measurement of the variables of interest. Twenty six of the 28 studies used parental report to record the duration of sleep of the children, which does require that the parent has a good understanding of their child's sleep schedule. One study used both parental report and an accelerometer,[15] the other two studies used accelerometers.[27,33]

This review is also limited to sleep duration as very few studies have examined other dimensions of sleep, which include sleep quality, sleep efficiency and bed/wake times in relation to obesity. It is therefore important that future studies include these additional dimensions.[48]

There was variable diagnostic classification of overweight and obesity across studies. A meta-analysis of observational studies cannot directly control for confounding and therefore may be open to biased estimates. Age and sex are used for BMI standardization of BMI z-scores, but some studies still adjusted for age and sex in BMI z-score models. Possible over adjustment is an inextricable problem, as we were unable to derive estimates by excluding age and sex from the BMI z-score models. This however would result in an underestimation of the true effect, hence indicating that the relationship we describe might be conservative.

4.2 | Sleep intervention studies: Strengths and limitations

To our knowledge, this is the first systematic review of sleep interventions in this population. The meta-analyses of the three studies in the BMI and BMI-z-scores are encouraging showing a favourable effect. However, there are major limitations; none of the intervention studies had been specifically designed to look at the effect of sleep extension per se, but all included a sleep element as part of a wider multicomponent behavioural intervention. The number of available studies is undoubtedly small. In addition, the type of interventions involving sleep differ from each other and outcomes too, varied. In one study,[40] the significant effect of sleep duration on BMI was only seen after individuals of Asian and other race had been excluded and, at only one of the two sites. Another study[37] looked at the effect of 'sooth/sleep' which instructed parents how to discriminate between hunger and other forms of infant distress and soothing strategies to prolong sleep duration and 'solids' which taught parents about hunger and satiety cues, timing of food, and so forth. There was no significant effect of 'soothe/sleep' or 'solids' alone, but a significant effect was observed in the combined group. They noted that multiple interventions might be required throughout an infants' development to maintain long-term obesity protection.

Accelerometers were only used in one study[41] with parents' self-reports of their children's sleep duration in the remaining studies. The way in which interventions were conducted varied considerably, some included home visits to the families and one intervention also included a group educational session,[41] others videos,[37] coaching telephone calls, weekly texts and mailed educational materials.[38] The advice given to families as part of the interventions also varied.

One study had a short 6-month follow-up and high attrition rate especially in the combined treatment group and was limited to first-time mothers.[37] Haines et al[38] targeted low income and racial/ethnic minority parents, so their results may not be generalizable to other groups. Likewise, there was only a 24% uptake of this study by eligible families, and it is unclear whether it could be rolled out to a large population.

The results from the study of Taylor et al[41] are interesting as this study had both self-reported and accelerometer data. Furthermore, children who received the sleep intervention have significantly lower measures of obesity at 5 years, those who received the food, activity and breastfeeding (FAB) intervention had significantly higher BMI z-scores.

One of the studies showing significant results found success in using mobile technology to send weekly texts on the desired household routine (e.g., sleep routine).[38] The study also investigated the effect of limiting television watching time and the effect of removing the television from the child's bedroom. Their results suggest that interventions that increase sleep duration and reduce TV viewing may be effective for the reduction of body mass index amongst low income and racial/ethnic minority children. Similarly, Woo Baidal et al[40] found that favourable outcomes on obesity measures were observed when both sleep duration and television screen time were targeted together.

The use of mobile technology is worth considering for future programmes due to its cost-effectiveness and participant acceptance.[49] Also, television screen time needs to be considered in future sleep and obesity interventions.

4.3 | Importance and potential mechanisms

The results are important as they suggest that better well-designed interventions for sleep and other factors, delivered in early years, may have a beneficial effect on measures of obesity.[37–41] This is important because night time sleep duration has been decreasing worldwide[50] with children getting less than the recommended amount of sleep, which in part may be a result of an increase in mobile technology.[51] Later bed-time, at least in adults, is the strongest predictor of short sleep duration,[52] but it remains to seen if this is true for preschool children. The National Sleep Foundation (NSF) in America recommends different sleep durations for different age groups ranging from 14 to 17 h in newborns (0–3 months) to 10–13 h in preschool children (3–5 years).[53] Although it is possible that early-life growth patterns may be associated with childhood and adult obesity, it is not clear whether 'an hour' of sleep reduction or extension effects children from birth to pre-school age in the same way.

There are several plausible mechanisms by which insufficient or poor sleep may lead to obesity in children.[6] These include changes in appetite control and, in particular, the hormones leptin and ghrelin,[54,55] changes in factors which would affect inflammation and metabolism, including the metabolism of insulin, glucose, cortisol, growth hormone and thyroid stimulating hormone.[56–61] Sleeping less would give more time to eat energy dense foods and to engage in other sedentary activities such as increasing their screen time as opposed to undertaking physical activity.[56] In a recent study, in parents and preschool children aged 3–5 years, parental screen time was positively associated with child screen time. Furthermore, after controlling for household income, parental occupation, and parental BMI, greater child screen time on weekends, was associated with higher child BMI percentile.[62]

Given the observed interaction with ethnicity,[40] the effect of ethnicity also needs to be explored in future studies. Insufficient sleep is associated with alterations in mood, attention, impulse control, motivation and judgment; although all of these factors could potentially influence eating behaviours, energy intake and ultimately BMI in children, it is not clear if they would be as important in pre-school children, where a large part of their food intake is being governed by parents and carers.[63,64]

5 | CONCLUSIONS

These two systematic reviews and meta-analyses show that short sleep duration is prospectively associated with measures of obesity and that interventions to improve sleep may lead to a reduced weight gain in preschool children. Further studies are required to determine whether specifically targeting obesity prevention programmes to include sleep interventions may be effective in reducing the incidence of overweight and obesity in preschool children.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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