Effects of Breastfeeding on Trajectories of Body Fat and BMI throughout Childhood

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Objective: To investigate the effect of breastfeeding in healthy boys and girls on their trajectories of percent body fat (%BF) and BMI standard deviation scores (BMI–SDS) throughout childhood.
Methods and Procedures: Analyses of the DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study included data from 219 male and 215 female term participants, born between 1984 and 1999, with repeated anthropometric measurements between 0.5 and 7 years and prospective data on duration of breastfeeding.
Results: Among boys with an overweight mother (OW-M), analyses adjusted for potential confounders revealed that not or shortly breastfed (≤17 weeks) boys did not experience the age-dependent decrease in %BF seen in all children with normal weight mothers (NW-Ms). In contrast, boys fully breastfed for >17 weeks were protected against the adverse effect of maternal overweight (effect of long breastfeeding vs. no/short breastfeeding among boys with OW-Ms: −0.46%/year; s.e. 0.18; $P = 0.01$). There was also a suggestion of an interaction between maternal overweight and breastfeeding for the BMI–SDS trajectory (−0.08 SDS/year; s.e. 0.04; $P = 0.07$). Among boys with NW-Ms mothers and the corresponding subgroups of girls, breastfeeding had little effect on the development of %BF or BMI–SDS throughout childhood.
Discussion: Our study suggests that breastfeeding could offset a potential programming effect for childhood adiposity among boys with OW-Ms, to whom advice to breast-feed should thus be specifically targeted.

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INTRODUCTION

It is increasingly acknowledged that breastfeeding reduces the risk for subsequent overweight. Systematic reviews have revealed small, but consistently protective effects against overweight in childhood (1) and later life (2), independent of potential confounding factors such as parental obesity, parental smoking, socioeconomic status, or birth weight. The causality of the association is supported by a dose-dependent association between longer duration of breastfeeding and decrease in risk of overweight (3). However, most reports are based solely on single measurements of BMI, while the evidence from the few studies assessing the effect of breastfeeding on more accurate measures of body fat is less conclusive (4–10). Therefore, more information, preferably in the form of prospective data on percent body fat (%BF), is needed since it is the effect on excess fat mass and not BMI *per se* that is considered most relevant for the development of later major health comorbidities (11).

The availability of prospective data may also contribute to understanding the reasons for differences in body composition between breastfed and non-breastfed children. Although some authors suggest that this effect may largely reflect differences in parental overweight, socioeconomic status, or learned self-regulation of energy intake, others have argued that breastfeeding exerts its effect via metabolic imprinting (12). Should the latter be of physiological importance, differences between breastfed and non-breastfed children may even amplify with age, as proposed by Singhal *et al.* (13). Longitudinal analyses from German and New Zealander children have suggested a progressively increasing protective effect of breastfeeding against overweight throughout childhood (10,14); however, a longitudinal study of an Australian birth cohort study did not find a persisting or increasing effect of breastfeeding on BMI until 8 years of age (15).

Moreover, breastfeeding may differentially affect susceptible subgroups: on the one hand a recent report suggests that the combination of maternal prepregnancy obesity and lack of breastfeeding may be associated with a greater risk of childhood overweight, on the other hand breastfeeding may differentially affect the growth trajectories of boys and girls given the sustained sex-differences, not only in the levels of hormones potentially involved in the

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metabolic imprinting effects of breastfeeding (16), but also in the nutritional behavior throughout childhood (17). Using data from the DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study, we therefore investigated the effect of breastfeeding in healthy children on their trajectories of BMI and %BF throughout childhood (ages 0.5–7 years), hypothesizing that the breastfeeding effect could be modified by the presence of maternal overweight and/or the offspring's sex.

METHODS AND PROCEDURES

Design and sample

The DONALD Study is an ongoing, open cohort study conducted by the Research Institute of Child Nutrition in Dortmund, Germany. This study has been previously described in detail (18). Briefly, since recruitment began in 1985, detailed information concerning diet, growth, development, and metabolism between infancy and adulthood has been collected for >1,200 children. Every year, an average of 40–50 infants are newly recruited and first examined at the ages of 3 or 6 months. Each child returns for three more visits in the first year, two in the second, and then once annually until early adulthood. The study was approved by the Scientific Committee of the Research Institute of Child Nutrition and the Ethics Committee of the University of Bonn, and all examinations are performed with parental consent.

The ages of the children who were initially recruited onto the DONALD Study were quite variable i.e., information on the first few years of life was not always available. In addition, many children have not yet reached 7 years of age. Therefore:

- the total number of children for whom at least one set of anthropometric measurements within the first 2 years of life and at 7 years of age as well as prospective information on breastfeeding duration were available were 465
- this number was reduced to those with complete information on maternal overweight, smoking status, and birth variables ($n = 455$)
- finally, all children had to be term (37–42 weeks gestation) singletons with a birth weight >2,500 g

The sub-cohort analyzed here therefore included 434 term singletons.

Anthropometry

At each visit anthropometric measurements were performed by trained nurses and regularly monitored according to standard procedures (19) with the children dressed in underwear and barefoot. Recumbent length was measured in children <2 years of age to the nearest 0.1 cm using a Harpenden (United Kingdom) stadiometer. From the age of 2 onward, standing height was measured to the nearest 0.1 cm using a digital stadiometer. Weight was measured to the nearest 0.1 kg using an electronic scale. Skinfold thicknesses were measured from the age of 6 months onward on the right side of the body at the biceps, triceps, subscapular, and suprailiac sites to the nearest 0.1 mm using a Holtain caliper.

Parents were interviewed and their anthropometric measurements were obtained by the study nurses on their child's admission to the study. Information on birth weight and length, as well as gestational age and maternal weight gain during pregnancy were abstracted from the "Mutterpass," a standardized document given to all pregnant women in Germany.

Sex- and age-independent standard deviation scores (SDS) were calculated using the German reference curve for BMI (BMI–SDS) (20). To remove general deviations of our sample from the reference data, BMI–SDS data were then internally standardized (mean = 0, s.d. = 1). %BF was calculated using the equation of Deurenberg (21). We chose 7 years of age as our endpoint because it is an age at which BMI in childhood correlates well with BMI in adulthood (22). Excess body fat at age 7 was defined as recently proposed by McCarthy *et al.* using their 85th percentile of %BF in British children as the cutoff (23). Overweight at age 7 was defined according to the International Obesity Task Force BMI cutoffs for children (24).

Breastfeeding

At the initial visit (i.e., age 3 or 6 months) the study pediatrician questioned mothers about how long (in weeks) they had fully breastfed their infant (no solid foods and no liquids daily other than breast milk, tea, or water). If the mother was still fully breastfeeding, this question was repeated at each subsequent visit(s) (e.g., 6, 9, or 12 months) until complementary feeding was initiated. In addition, for 73% of the infants, their mothers had kept weighed 3-day dietary records during the first year of life so that infant feeding could be quantified at 3, 6, 9, or 12 months. The study dietitian also questioned these mothers about when they had first started feeding formula or solid foods. Before analyses, consistency checks comparing data collected by the pediatricians, the recording of breast milk, and information acquired by the dietitians were performed so as to eliminate any potential source of error.

In the present analyses, *long breastfeeding* was defined as full breastfeeding for >17 weeks (e.g., >4 months). This cutoff was used because it was the lower limit of the German recommendation for the introduction of complementary food (25). Infants who were never breastfed, partially breastfed, or fully breastfed until 17 weeks were combined into the category of *never/shortly breastfed* infants. To graphically illustrate the presence of a dose-response effect, we further subdivided the *never/shortly breastfed* category now comparing infants who were *not breastfed* (not, partially or fully breastfed for up to 2 weeks) to those who were *shortly breastfed* (i.e., fully breastfed for >2 weeks up to a maximum of 17 weeks) and those who were *breastfed for a long duration* (i.e., fully breastfed for >17 weeks).

Statistical analysis

All statistical analyses were carried out using SAS version 8.2 (SAS). Since the distribution of most continuous variables was skewed, all unadjusted associations with breastfeeding were tested using Wilcoxon's rank sum test. Differences in proportions were tested with the chi-square test. Multivariate logistic regression was used to calculate odds ratios for the risk of excess body fat and overweight at age seven. Basic models included terms for a sibling in the data set and for birth year.

Longitudinal models of BMI–SDS and %BF trajectories. Linear mixed effects regression models (PROC MIXED in SAS) including both fixed and random effects were used to investigate the effect of breastfeeding both on initial %BF and BMI–SDS at age 0.5 years and on their rate of change over time from 0.5 to 7 years. The following specifications were made for the models.

Dependent variables. %BF or BMI–SDS (continuous).

Random statement. Terms for person and family accounted for the nested nature of our data (children within families).

Repeated statement. Defines the ordering of the repeated measurements within each subject and specifies the structure of the within-person error covariance.

Fixed effects. Breastfeeding and time (chronological age and age^2) were the principle independent fixed effects. The fixed covariates that potentially affect the association between breastfeeding and %BF (or BMI–SDS) were maternal overweight (BMI ≥ 25 kg/m^2), high maternal educational status (12 or more years of schooling), maternal age ≥35 years at birth, smoking in the household, and birth year (with 1984 set to zero), BMI–SDS at birth, birth at early (week 37 or 38) or

Table 1 Demographic, socioeconomic, and anthropometric characteristics of 7-year-old children participating in the DOrtmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study, stratified by gender and feeding mode ($n = 434$)

	Boys		Girls	
	Full breastfeeding for		Full breastfeeding for	
	Never/short duration	Long duration	Never/short duration	Long duration
N	126	93	119	96
Full breastfeeding				
Duration (weeks)	6 (0, 15)*	24 (21, 26)	6 (0, 16)*	25 (20, 26)
>2–16 weeks (*n* (%))	72 (57)*	0 (0)	72 (61)*	0 (0)
≥17 weeks (*n* (%))	0 (0)*	93 (100)	0 (0)*	96 (100)
Birth variables				
Birth year	1990 (1987, 1994)*	1993 (1988, 1996)	1990 (1987, 1993)*	1993 (1989, 1996)
Gestational age (weeks)	40 (39, 41)	40 (39, 41)	40 (39, 41)	40 (39, 41)
Maternal weight gain during pregnancy (kg)	13 (11, 16)	12 (10, 15)	13 (11, 16)	12 (10, 15)
Birth weight (g)	3,630 (3,320, 3,950)	3,500 (3,230, 3,820)	3,410 (3,150, 3,740)	3,345 (3,055, 3,650)
Birth length (cm)	53 (51, 54)	52 (51, 54)	51 (50, 53)	51 (50, 53)
BMI at birth (kg/m^{2}[a])	13.0 (12.2, 14.0)	12.9 (12.2, 13.7)	13.1 (12.4, 13.7)*	12.6 (12.0, 13.3)
BMI–SDS at birth	0.27 (−0.39, 1.02)	0.21 (−0.39, 0.79)	0.43 (−0.18, 0.87)*	0.00 (−0.46, 0.58)
Socioeconomic variables				
Overweight mother[a] (*n* (%))	32 (25)	24 (26)	41 (34)*	20 (21)
High maternal educational status[b] (*n* (%))	70 (56)*	67 (72)	62 (52)	61 (64)
Maternal age at birth ≥35 years (*n* (%))	20 (16)	13 (14)	14 (12)	14 (15)
Smoking in the household (*n* (%))	41 (33)*	17 (18)	38 (32)*	24 (25)
Firstborn child (*n* (%))	77 (62)	53 (57)	69 (58)	56 (59)
Anthropometry at age 7				
Body weight (kg)	25.7 (23.5, 28.3)*	24.4 (22.8, 26.9)	24.8 (22.0, 28.0)	24.4 (22.6, 26.2)
Height (cm)	127 (123, 130)	126 (123, 129)	125 (122, 129)	124 (122, 127)
BMI (kg/m^2)	16.0 (14.8, 17.3)	15.6 (14.9, 16.4)	15.7 (14.7, 17.3)	15.4 (15.0, 16.9)
BMI–SDS	0.19 (−0.51, 0.81)	−0.03 (−0.47, 0.41)	0.03 (−0.54, 0.79)	−0.11 (−0.38, 0.62)
Body fat[c] (%)	15.5 (13.6,18.2)*	14.1 (12.9, 16.6)	18.8 (16.0, 23.2)	18.8 (16.3, 21.8)

Data are medians (25th, 75th percentile) or frequencies.
SDS, standard deviation scores.
[a]Maternal overweight was defined as BMI ≥25 kg/m^2. [b]≥12 years of schooling. [c]Percent body fat (%BF) was calculated according to the equations of Deurenberg *et al.* (21).
*Significantly different form children breastfed for a long duration within each gender, $P < 0.05$.

Table 2 Odds ratios for having excess body fat[a] or being overweight[a] at 7 years of age in children never/shortly breastfed compared with children breastfed for a long duration, stratified by gender

	Boys				Girls			
	Full breastfeeding for				Full breastfeeding for			
	Never/short duration	Long duration			Never/short duration	Long duration		
Excess body fat[a]								
Rates *n* (%)	35 (28)		17 (18)		24 (20)		17 (18)	
Odds ratios[d]		OR	95% CI	*P*		OR	95% CI	*P*
Basic model[e]	1	0.52	0.26, 1.03	0.06	1	1.04	0.50, 2.14	0.9
Socioeconomic status model[d]	1	0.52	0.25, 1.09	0.08	1	1.14	0.54, 2.38	0.7
Socioeconomic status and birth variables model[5e]	1	0.49	0.23, 1.02	0.06	1	1.13	0.53, 2.39	0.7
Overweight[a]								
Rates *n* (%)	18 (14)		11 (12)		24 (20)		15 (16)	
Odds ratios[b]		OR	95% CI	*P*		OR	95% CI	*P*
Basic model[c]	1	0.67	0.29, 1.57	0.3	1	0.86	0.41, 1.78	0.7
Socioeconomic status model[d]	1	0.74	0.30, 1.82	0.5	1	1.00	0.47, 2.13	1.0
Socioeconomic status and birth variables model[d]	1	0.70	0.27, 1.74	0.5	1	1.11	0.50, 2.44	0.8

CI, confidence interval; OR, odds ratio. [a]Excess body fat defined as body fat ≥85th age- and gender-specific percentile for body fat in British children (23), overweight according to the International Obesity Task Force (IOTF) age- and gender-specific BMI cutoffs (24). [b]Reference category: never/shortly breastfed children (i.e., never fully breastfed or fully breastfed ≤17 weeks). [c]Basic model includes sibling in data set and birth year. [d]Socioeconomic status model includes sibling in data set, birth year, maternal overweight, high maternal educational status, and smoking in the household. [e]Socioeconomic status and birth variable model includes sibling in data set, birth year, maternal overweight, high maternal educational status, smoking in the household, BMI–SDS at birth, and gestational age.

late (week 41 or 42) gestation, pregnancy weight gain of ≥12 kg, and whether the infant was a first born child.

Interactions. The interaction between time and other variables in the model was used to interpret whether a particular variable had a significant effect on the change in %BF or BMI–SDS over time. A three-way interaction between time, breastfeeding, and maternal overweight was also included to consider differential effects of breastfeeding on the BMI–SDS or %BF trajectories between children with or without an overweight mother (OW-M). When the three-way

Table 3 Mixed models of the association between breastfeeding and percent body fat (%BF) and BMI standard deviation scores (BMI–SDS): association with values at age 0.5 years and rate of change between 0.5 and 7 years of age in *n* = 219 boys

	%BF[a]		BMI–SDS[b]	
	Estimate ± s.e.[c]	*P* value	Estimate ± s.e.[c]	*P* value
Initial status at age 0.5 years				
Initial %BF or BMI–SDS (= intercept[d])	20.1 (0.2)	<0.0001	0.02 (0.11)	0.8
Breastfeeding (long duration = 1, never/shortly = 2)	−0.70 (0.33)	0.04	−0.17 (0.15)	0.2
Maternal overweight (yes = 1, no = 2)	−0.98 (0.43)	0.02	0.04 (0.20)	0.8
Maternal overweight × full breastfeeding	0.88 (0.65)	0.2	0.01 (0.29)	1.0
Smoking in the household (yes = 1, no = 2)			0.23 (0.14)	0.1
BMI at birth (SDS)			0.17 (0.05)	0.002
Rate of change between 0.5 and 7 years				
Time in years (= linear slope[d])	−1.41 (0.10)	<0.0001	−0.07 (0.02)	0.001
Time × time	0.11 (0.01)	<0.0001		
Time × breastfeeding	0.04 (0.09)	0.6	0.02 (0.02)	0.3
Time × maternal overweight	0.53 (0.12)	<0.0001	0.11 (0.03)	<0.0001
Time × maternal overweight × breastfeeding	−0.46 (0.18)	0.01	−0.08 (0.04)	0.07
Time × BMI at birth (SDS)	0.04 (0.04)	0.2		
Time × birth year (1984 = 0)			0.005 (0.002)	0.01

[a]Model contains a random statement for the individual (allowing variation in intercept, time, and time[2] with an unstructured covariance between the effects) and a repeated statement (with an autoregressive heterogenous covariance (arh(1)). [b]Model contains one random statement for the individual (allowing variation in intercept and time with an unstructured covariance un(2) between the effects), one random statement for family (allowing variation only in intercept), and one repeated statement (with an autoregressive heterogenous covariance (arh(1)). [c]s.e. [d]The multilevel models have two intercepts, one for baseline % body fat (%BF) (or BMI–SDS) at age 0.5 years and another for subsequent linear change in %BF (or BMI–SDS) over time. Each represents the mean value of the dependent variable at the baseline time, when all other predictors are 0.

interaction was significant we kept it, as well as all lower order two-way interactions and main effects, in the model.

Tests for interactions initially performed in unadjusted models with the whole cohort suggested that the effect of breastfeeding on the trajectories of %BF was modified by maternal overweight (time × breastfeeding × maternal overweight, $P = 0.11$), but not by the offspring's sex (time × breastfeeding × sex, $P = 0.5$). Descriptive plots nonetheless indicated differences between boys and girls. We thus also tested whether the effect modification by maternal overweight differed between boys and girls. Since this four-way interaction was suggestive of a sex-difference (time × breastfeeding × maternal overweight × sex: $P = 0.11$), all subsequent analyses were performed separately for boys and girls.

RESULTS

Overall, 42% ($n = 93/219$) of the boys and 45% ($n = 96/215$) of the girls were fully breastfed for >4 months (**Table 1**). Children *breastfed for a long duration* were born later than *never/shortly breastfed* children, but were otherwise comparable in their birth variables, except for the fact that girls *breastfed for a long duration* had a lower BMI at birth. As compared to their *never/shortly breastfed* counterparts, children *breastfed for a long duration* were less likely to live in a smoker household and boys *breastfed for a long duration* had mothers with a higher educational status while girls *breastfed for a long duration* were less likely to have an OW-M. At 7 years of age, children *breastfed for a long duration* tended to be lighter, with a lower BMI–SDS and %BF than *never/shortly breastfed* children, but differences were only significant for body weight and %BF in boys.

Influence of full breastfeeding on risk for excess body fat or overweight

Next we investigated whether *breastfeeding for a long duration* protected against the risk of excess body fat or overweight at age 7 once other influences had been adjusted for (**Table 2**). Among boys, there was a tendency toward a protective effect of *breastfeeding for a long duration* against having excess body fat at age 7, but not against overweight. The odds ratios were only marginally affected by adjustment for potential confounders. Among girls, *breastfeeding for a long duration* did not confer any protection against overweight or excess body fat.

Influence of full breastfeeding on %BF and BMI–SDS trajectories in boys

Multilevel models for %BF revealed a significant physiological decrease of %BF between age 0.5 and 7 years (β for time: −1.41 (0.10)%/year, $P < 0.0001$) (**Table 3**), and a strong effect of maternal overweight on the development of %BF (β for time × maternal overweight: 0.53 (0.12)%/year, $P < 0.0001$). Interestingly, *breastfeeding for a long duration* did not affect the overall development of %BF from 0.5 to 7 years (β for time × breastfeeding: 0.04 (0.09), $P = 0.6$), but the effect differed significantly between boys with an OW-M and those with a normal weight mother (NW-M), with a significant protective effect among boys with an OW-M (β for time × maternal overweight × breastfeeding: −0.46 (0.18)%/year, $P = 0.01$ for boys *breastfed for a long duration* with an OW-M as compared to *never/shortly breastfed* boys with an OW-M). A potential dose-response effect is illustrated in **Figure 1a**: boys with an OW-M who were *not fully breastfed* (filled circles) did not experience the physiologic decrease in %BF seen in all other groups. A slight increase in %BF after 5 years of age was also seen among boys with an OW-M who were *fully breastfed for a short duration* (filled triangles). It is noteworthy that in both boys with an OW-M and a NW-M, full breastfeeding affected the development of %BF in a dose-dependent manner.

Similarly, *breastfeeding for a long duration* tended to have a protective effect on the development of BMI–SDS primarily among breastfed boys with an OW-M (β for time × maternal overweight × breastfeeding −0.08 (0.04) SDS/year, $P = 0.07$). **Figure 1b** suggests that in boys with an OW-M *full breastfeeding for a short or long duration* provided some protection in a dose-dependent manner against the increase in

BMI–SDS experienced by boys with OW-Ms who were *not fully breastfed* (filled circles). Conversely, breastfeeding or its duration made little difference to the growth trajectories of boys with NW-Ms (dotted lines).

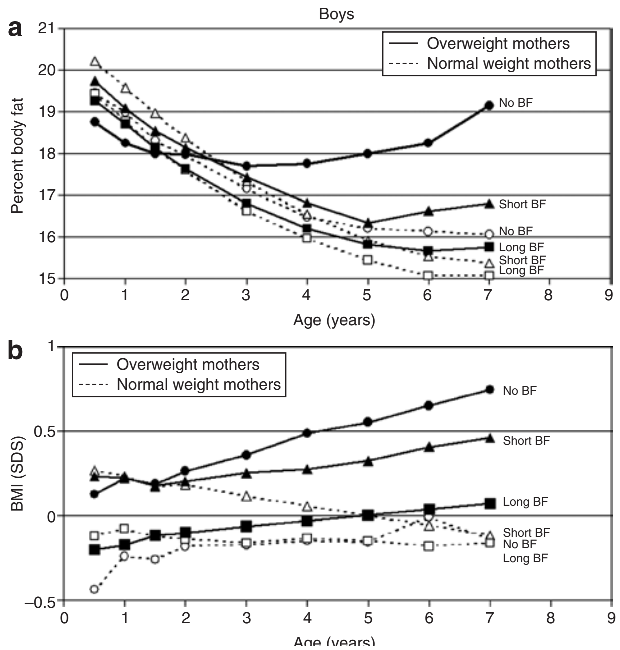

Figure 1 (**a**) Predicted mean %BF trajectory and (**b**) mean BMI–SDS trajectory by strata of full breastfeeding and maternal overweight status in 219 boys. Model analogous to **Table 3**. N-numbers: overweight mothers: no full breastfeeding ($n = 19$), short ($n = 13$), or long breastfeeding ($n = 24$); normal weight mothers: $n = 35$, 59, and 69, respectively.

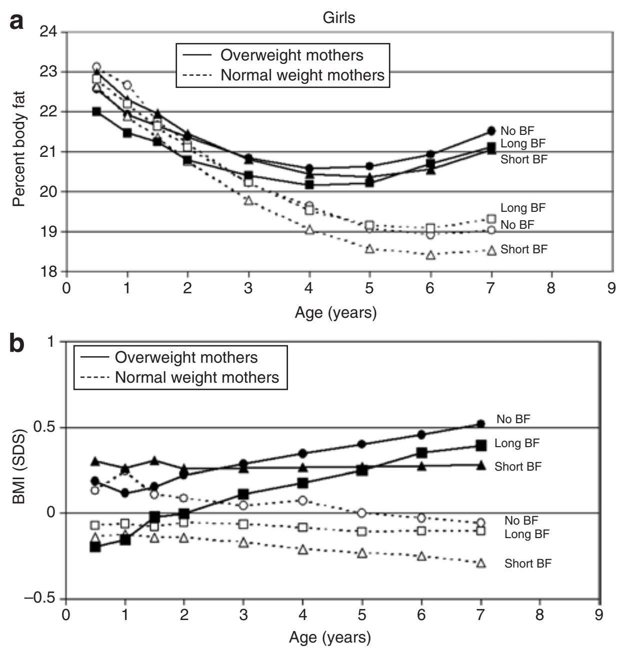

Figure 2 (a) Predicted mean %BF trajectory and (**b**) mean BMI–SDS trajectory by strata of full breastfeeding and maternal overweight status in 215 girls. Model analogous to **Table 4.** N-numbers: overweight mothers: no full breastfeeding ($n = 20$), short ($n = 21$), or long breastfeeding ($n = 20$); normal weight mothers: $n = 27$, 51, and 76, respectively.

Influence of full breastfeeding on %BF and BMI–SDS trajectories in girls

Among girls, *breastfeeding for a long duration* neither had any effect on the trajectories of %BF or BMI–SDS, nor did we observe any interaction between breastfeeding and maternal overweight in their association with the trajectories of %BF and BMI–SDS. As also illustrated in **Figure 2a,b** and **Table 4** the trajectories of BMI–SDS and %BF differed only between girls with a normal and those with an OW-M, irrespective of breastfeeding or its duration.

DISCUSSION

To our knowledge, this is the first study to suggest that the strong adverse influence of maternal overweight on her offspring's body fat development throughout childhood may be offset by breastfeeding, at least among boys.

Our finding of a beneficial breastfeeding effect only among those with an OW-M is in line with previous findings of an additive interaction of maternal prepregnancy BMI and breastfeeding on childhood overweight (26). However, unexpectedly our results suggest that the protective effect of breastfeeding is of particular relevance for the trajectories of %BF only for the subgroup of male infants with OW-Ms. Since BMI does not differentiate between lean and fat mass (27) it is not surprising that the beneficial effect of breastfeeding on adiposity development among boys with OW-Ms was best discernible for the trajectory of %BF. Nonetheless, five other studies did not find an association of breastfeeding with adiposity, assessed only once at different ages ranging from 3 months to 18 years (4–7,9). Our results do however confirm the findings of another longitudinal study of a beneficial effect of breastfeeding on the development of triceps or subscapular skinfold thickness from ages 6 months to 6 years (10). In our study, as in the study by Bergmann *et al.* (10), %BF was estimated from skinfold measurements, which are known to be more susceptible to measurement error than specialized research-based techniques such as total body water, dual energy X-ray absorptiometry, or underwater weighing (28) and may underestimate body fatness (29). However, intra- and inter-observer variability is notably reduced when measurements are conducted by trained personnel (30), as was the case in both our (18) and the study by Bergmann *et al.* (10). Furthermore, use of skinfolds to estimate %BF has been reported as a useful feasible alternative to laboratory-based methods in childhood (29). Overall, the repeated assessment of skinfold thickness, and the fact that our findings were significant even after adjustment for known confounders, support a causal relationship between breastfeeding and the development of adiposity throughout childhood, at least among boys with OW-Ms.

We do not believe that our results reflect residual confounding by behavioral or socioeconomic attributes, first because the DONALD Study participants are from a relatively homogenous socioeconomic background and the effect of breastfeeding was

Table 4 Mixed models of the association between breastfeeding and percent body fat (%BF) and BMI standard deviation scores (BMI–SDS): association with values at age 0.5 years and rate of change between 0.5 and 7 years of age in *n* = 215 girls

	%BF[a]		BMI–SDS[b]	
	Estimate ± s.e.[c]	*P* value	Estimate ± s.e.[c]	*P* value
Initial status at age 0.5 years				
Initial % body fat or BMI–SDS (= intercept[d])	23.8 (0.39)	<0.0001	0.006 (0.11)	1.0
Breastfeeding (long duration = 1, never/shortly = 2)	0.20 (0.36)	0.6	−0.02 (0.14)	0.9
Maternal overweight (yes = 1, no = 2)	−0.38 (0.38)	0.3	0.05 (0.16)	0.7
Birth year (1984 = 0)	−0.13 (0.04)	0.002		
BMI at birth (SDS)			0.26 (0.06)	<0.0001
Rate of change between 0.5 and 7 years				
Time in years (= linear slope[d])	−1.55 (0.15)	<0.0001	−0.04 (0.01)	0.004
Time × time	0.14 (0.02)	<0.0001		
Time × full breastfeeding	0.12 (0.09)	0.2	0.03 (0.02)	0.1
Time × maternal overweight	0.38 (0.10)	0.0001	0.06 (0.02)	0.001
Time × birth year (1984 = 0)	−0.01 (0.01)	0.4		
Time × BMI at birth (SDS)	0.07 (0.04)	0.1		
Time × smoking in the household (yes = 1, no = 2)	0.16 (0.09)	0.08	0.03 (0.02)	0.06

[a]Model contains one random statement for the individual (allowing variation in intercept and time with an unstructured covariance between the effects) and a repeated statement (with an autoregressive heterogenous covariance (arh(1)). [b]Model contains one random statement for the individual (allowing variation in the intercept only), one random statement for family (allowing variation in intercept and time with an unstructured covariance), and one repeated statement (with an autoregressive heterogenous covariance (arh(1)). [c]s.e. [d]The multilevel models have two intercepts, one for baseline BMI–SDS (or %BFt) at age 0.5 years and another for subsequent linear change in BMI–SDS (or %BF) over time. Each represents the mean value of the dependent variable at the baseline time, when all other predictors are 0.

maintained after adjustment for socioeconomic status or parental variables; second, the fact that only boys—but not girls—with an OW-M profited in a slowly progressive manner from being breastfed does not support the notion of a general behavioral explanation, but instead suggests an interaction between genetic/intrauterine programming by maternal overweight and postnatal imprinting by breastfeeding in association with the subsequent development of body composition. This is the first study to suggest sex-differences in the interaction of maternal overweight and breastfeeding on the development of childhood body composition. Nonetheless, the fact that the growth trajectories of girls appeared predominantly programmed by maternal overweight with no discernible postnatal imprinting effect by breastfeeding is in line with previous reports that girls are intrinsically more insulin resistant than boys (31) and that they may therefore be less susceptive to intrauterine nutritional stimuli (32). Our findings suggest an extension of this sex difference into the early postnatal period.

One mechanism by which metabolic imprinting owing to infant feeding mode may affect body composition is through protein intake. It has been proposed that higher protein intakes stimulate the secretion of insulin and insulin-like growth factor 1, both of which may accelerate growth velocity and enhance adipogenic activity and adipocyte differentiation (33), potentially followed by increased weight gain (34). In our study, infants who were not or shortly breastfed consumed up to two thirds more protein during their first 6 months of life, since formulas available at the time this sub-cohort went through infancy (1984–1999) were characterized by 1.5- to 2-fold higher protein content than human breast milk (35). Interestingly, those with the highest protein intakes, i.e., those not breastfed or fully breastfed for up to 2 weeks only, were least protected against the adverse effect of maternal overweight, and experienced the earliest adiposity rebound at 3 years of age. Higher protein intakes in early childhood have been proposed to be associated with an earlier adiposity rebound (34), and in the DONALD Study, such a relation was only suggested for boys (36).

The particular strengths of this study lie first in the repeated assessment of anthropometry throughout childhood from as early as 6 months onward, which allowed the analysis of full growth trajectories instead of overweight prevalences at a single point in time used in other studies (1). Second, full breastfeeding was carefully assessed in a prospective manner. Finally, from a methodological point of view, the relative homogeneity of the DONALD cohort considerably reduces the potential bias introduced by differences in the socioeconomic background. Nonetheless, the high educational attainment and socioeconomic status as well as the relatively small size of the DONALD cohort may limit the generalizability of our findings. The homogeneity of the DONALD sample may partly explain why we did not see any remarkable confounding by socioeconomic status or parental characteristics on the association between feeding mode and body composition. On the other hand, the prevalence and duration of breastfeeding in the DONALD cohort was comparable to that observed in a nationwide German study on breastfeeding (1997–1998) (37) and lower than the rates and durations reported in some Scandinavian countries (38). Furthermore, both the magnitude of the risk reduction associated with breastfeeding and the clear dose-dependent associations between the duration of breastfeeding and the development of adiposity among boys with both OW-M and NW-Ms are in line with other studies (1,3), thus further supporting the plausibility and generalizability of our data. Finally, non-representativeness is less relevant for the present longitudinal analyses of physiological processes as well as for their internal validity.

We therefore believe that our results allow us to highlight a specific need to promote breastfeeding among OW-Ms in particular, even more so because they often decide not to breastfeed their infants and are less successful in breastfeeding initiation (39). In fact, OW-Ms may need to be informed that they may actually be harming their infant by not breastfeeding, since it was the growth trajectory of the not fully breastfed boys with OW-Ms in particular that diverged from the growth trajectories of all other boys. Despite our study suggesting a breastfeeding effect only among boys with OW-Ms, breastfeeding should certainly be promoted among all mothers so as to exploit the multiple other benefits of breastfeeding for both mother and child.

In summary, our study suggests that breastfeeding could offset a potential programming effect for childhood adiposity among boys with OW-Ms. It remains to be confirmed by other studies whether girls with OW-Ms do not experience a comparable benefit.

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DISCLOSURE

The authors declared no conflict of interest.

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