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The role of energy balance related behaviors in socioeconomic inequalities in childhood body mass index: A comparative analysis of Germany, the Netherlands, the United Kingdom, and the United States

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ABSTRACT

Socioeconomic inequalities in childhood Body Mass Index (BMI) are becoming increasingly more pronounced across the world. Although countries differ in the direction and strength of these inequalities, cross-national comparative research on this topic is rare. This paper draws on harmonized longitudinal cohort data from four wealthy countries—Germany, the Netherlands, the United Kingdom (UK), and the United States (US)—to 1) map cross-country differences in the magnitude of socioeconomic inequalities in childhood BMI, and 2) to examine cross-country differences in the role of three energy-balance-related behaviors—physical activity, screen time, and breakfast consumption—in explaining these inequalities. Children were aged 5–7 at our first timepoint and were followed up at age 8–11. We used data from the German National Educational Panel Study, the Dutch Generation R study, the UK Millennium Cohort Study and the US Early Childhood Longitudinal-Kindergarten Study. All countries revealed significant inequalities in childhood BMI. The US stood out in having the largest inequalities. Overall, inequalities between children with low versus medium educated parents were smaller than those between children with high versus medium educated parents. The role of energy-balance-related behaviors in explaining inequalities in BMI was surprisingly consistent. Across countries, physical activity did not, while screen time and breakfast consumption did play a role. The only exception was that breakfast consumption did not play a role in the US. Cross-country differences emerged in the relative contribution of each behavior in explaining inequalities in BMI: Breakfast consumption was most important in the UK, screen time explained most in Germany and the US, and breakfast consumption and screen time were equally important in the Netherlands. Our findings suggest that what constitutes the most effective policy intervention differs across countries and that these should target both children from medium as well as low educated families.

Childhood overweight and obesity pose a worldwide public health concern (Swinburn et al., 2011). Prevalence rates in developed countries are high, with 21% of 5-to-19-year-old boys and 18% of 5-to-19-year-old girls being overweight or obese in 2016 (González-Álvarez et al., 2020). Childhood overweight tracks into adulthood (Singh et al., 2008), increases the risk of poor mental well-being and life satisfaction (Reilly and Kelly, 2010), and premature morbidity (Horesh et al., 2021). Preventing overweight and obesity in children is therefore an important

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health policy priority (Swinburn et al., 2011).

Although many developed countries have been successful in lowering overall rates of overweight and obesity among children (Ogden et al., 2016; Schönbeck et al., 2011), at the same time more pronounced socioeconomic inequalities in childhood overweight and obesity (Sigmund et al., 2020) as well as in Body Mass Index (BMI) (White et al., 2016) are emerging in many countries. In England, for example, overweight and obesity prevalence among 5-to-10-year-old children levelled off from 2002 to 2006, while between 1997 and 2006 socioeconomic inequalities in child weight status increased (Stamatakis et al., 2009). Considering the evident health concerns, it is understandable that many studies have focused on distinguishing overweight or obese children from normal weight children. That said, researchers have voiced concerns regarding the examination of inequalities only at the clinical thresholds of overweight and obesity (White et al., 2016). White and colleagues argue that this may lead to an underestimation of inequalities in childhood BMI, as the authors also identified substantial increases in inequalities between the 50th to 85th percentile, i.e., below the threshold for overweight. Moreover, evidence indicates that child BMI is independently related to complications of overweight and obesity, such as musculoskeletal pain, obstructive sleep apnea symptoms, headaches, depression, anxiety, and bullying (Bell et al., 2007). Additionally, higher BMI in 4-to-5-year-old children was found to positively relate to poorer peer relationships and teacher-reported emotional problems (Sawyer et al., 2011). An elevated BMI in childhood and adolescence — one that is well within the range that is considered normal — constitutes a substantial risk for obesity-related diseases in adulthood, such as coronary heart disease (Baker et al., 2007; Tirosh et al., 2011). It is for these reasons that the current study focuses on changes across the entire range of BMI. In our review of the literature, we also reference studies that analyzed weight status (and not continuous BMI), to provide a more complete picture of the current understanding of childhood weight inequalities.

The link between socioeconomic status (SES) and BMI, as well as health in general, has long been the focus of scholars and policy makers, and interest in health inequalities has increased markedly over the past decades (Diez Roux, 2012; Wilkinson and Marmot, 2003). In the current study we draw on Link & Phelan's Fundamental Cause Model (FCM; Link and Phelan, 1995; Phelan et al., 2010) and the pathways model (Diez Roux, 2012) to explain socioeconomic inequalities in childhood BMI. The FCM argues that people of higher SES possess a wider range of flexible resources, including knowledge, money, prestige, power, and social networks. These ensure that people of higher SES know about, have access to, can afford, and are motivated to engage in a broad range of health-enhancing activities, including behaviors and treatments and living in environments that contribute to good health (Phelan et al., 2010). The FCM emphasizes the meta mechanisms by which socioeconomic factors contribute to health inequalities. In contrast, the pathways model emphasizes the mediating mechanisms by which SES relates to health indicators, linking the meta factors such as knowledge, access, and motivation, to health. Often studied pathways involve behavioral factors, such as dietary and physical activity patterns (Diez Roux, 2012). As a full understanding of health inequalities requires consideration of distal causes (FCM), as well as mechanisms or proximal causes (the pathways model), we use both models in the current study.

Recent comparative studies found marked differences between developed countries in the strength of the relationship between parental SES and children's weight status (Barriuso et al., 2016; Buoncristiano et al., 2021). This cross-country variation suggests that country context likely affects the magnitude of child weight status inequalities. Cross-national comparisons of inequalities in childhood weight status—and particularly BMI—are very scarce, yet these studies can aid in identifying promising policy contexts that might decrease these inequalities. Single country studies cannot inform us on the extent to which found patterns are common or context specific. This information is important for understanding the role of the macro-level environment, including national public policy choices, in shaping health inequalities.

In the current study we therefore assess differences in inequalities in childhood BMI in four wealthy countries: Germany, the Netherlands, the United Kingdom (UK), and the United States (US). These countries are similar in that they are all highly developed industrialized democracies but differ in important ways in their approaches to the provision of welfare, family services, and education, and their overall levels of income inequality (Olczyk et al., 2021). Single country studies in the four countries have reported significant inequalities in child weight status (UK: Goisis et al., 2016; GE: Langnäse et al., 2002; NL: Veldhuis et al., 2013) and BMI (US: Hanson and Chen, 2007). However, as these single country studies differ in their operationalization of variables, choice of covariates, and model specifications, it is not possible to infer whether there are statistically significant differences in the magnitude of inequalities in childhood BMI across countries. Harmonized comparative studies are needed to identify cross-country differences reliably.

To our knowledge, there is only one study that included the same countries as those under scrutiny in the current study. Due and colleagues document the largest weight status inequalities in 13–15-year-old children in the US, followed by Germany, England, and the Netherlands (Due et al., 2009). The current study builds on this work by examining inequalities in continuous BMI using longitudinal data on younger children. Although inequalities in weight status (Goisis et al., 2016; Jansen et al., 2013) and BMI (Jansen et al., 2013) have been shown to grow steeper during the primary school years, we know surprisingly little about cross-country differences in inequalities in BMI during this developmental stage.

Among the preventable causes of elevated BMI are three important energy balance-related behaviors (EBRBs): physical activity, sedentary behaviors, and diet (te Velde et al., 2012). Most studies that tried to explain BMI and increases therein have focused on these EBRBs. This is because they are not only the most proximal factors related to elevated BMI and overweight/obesity (WHO, 2013), but they are also more susceptible to policy changes in comparison to, amongst others, genetic risk factors for overweight.

Previous studies have revealed large cross-country variation in SES inequalities in these EBRBs (Fismen et al., 2021; Mantziki et al., 2015), which is a first indication that mechanisms underlying inequalities in childhood BMI might also differ across countries. For example, if physical activity is an important predictor of childhood BMI, and differences by SES groups in physical activity are larger in Country A than Country B then—ceteris paribus—we would expect larger inequalities in childhood BMI in Country A than in Country B. However, surprisingly few studies have addressed the question of whether there are cross-national differences in the relative contribution of factors explaining inequalities in child weight status or BMI (Font et al., 2010). Such insights are important, as country-specific context may strongly shape the patterns found.

Another indication for the expectation that there are cross-national differences in the relative contribution of factors that explain inequalities in childhood BMI is that there is some inconsistency in the findings of single-country studies on the importance of specific EBRBs. A study conducted in the UK showed that SES-related disparities in physical activity explain inequalities in child weight status (Goisis et al., 2016), whereas others—based in the US (Hanson and Chen, 2007), the Netherlands (Bouthoorn et al., 2014), and Germany (Seum et al., 2022)—reported no significant role of physical activity in explaining inequalities in child BMI. Socioeconomic inequalities in sedentary behaviours—such as screen time—and certain dietary factors (e.g., breakfast consumption) quite consistently explain inequalities in BMI and weight status across studies. Studies conducted in the US, the UK, and the Netherlands have reported screen time to partly explain the association between parental SES and child weight status (UK: Goisis et al., 2016; NL: Veldhuis et al., 2013) and BMI (US: Hanson and Chen, 2007). A German based study reported that six-year-old children from high SES families spent less time watching TV than their low SES counterparts, and that watching TV significantly predicted children's weight status (Langnäse et al., 2002). The authors did not test whether TV time could account for inequalities in child weight status, however. Regarding breakfast consumption, a Netherlands based study showed that socioeconomic inequalities in overweight/obesity were already present at elementary school entry, and that the children's breakfast consumption contributed to these inequalities (Veldhuis et al., 2013). A study amongst German children also showed that a lower level of parental education was linked to skipping breakfast, and that breakfast consumption partially mediated the association between parental education and BMI (Seum et al., 2022). UK (Libuy et al., 2021) and US (Miech et al., 2006) based studies showed socioeconomic inequalities in breakfast consumption and BMI and weight status. However, these studies did not test the role of breakfast consumption in explaining inequalities in BMI and weight status. Although these studies provide speculative evidence about cross-country differences and similarities in the mechanisms underlying inequalities in childhood BMI it is impossible to ascertain if differences found between studies are due to differences in country context or if varying results are an artifact of methodological differences in the samples, measures, or statistical analyses employed. In the current study we aim to provide insight into cross-country differences in the magnitude of inequalities in BMI and in the relative contribution of EBRBs to these inequalities amongst children aged 5–11. To investigate inequalities, we include parental education as our indicator of parental SES. As argued by Mirowsky and Ross (2005), education is of particular importance for health as it precedes other achieved SES indicators and influences them, including occupational status, income and wealth, and with that freedom from economic hardship. The authors argue that education generates beneficial outcomes as it trains people to acquire, evaluate and use health related information, such as knowledge of the importance of physical activity and a healthy diet (Mirowsky and Ross, 2005). Moreover, education is increasingly the fundamental element of socioeconomic status linking it to health, and weight status and BMI more specifically, more so than income and occupational status (Mirowsky and Ross, 2005; Vazquez and Cubbin, 2020). In line with the FCM and pathway models, Mirowsky and Ross ague that education increases health because it enhances effective agency, which in turn builds a sense of personal control that encourages and enables a healthy lifestyle (Ross and Mirowsky, 2011). More specifically, parents' education is associated—to a larger extent than is either occupation or income—with a series of healthy lifestyles that influence children's BMI (Barriuso et al., 2016; Gebremariam et al., 2017).

Against this background, the current study is guided by two main research questions: 1) to what extent does BMI vary by parental education at age 5–7 (T1) and at age 8–11 (T2), and how does this vary across the four countries? and 2) what is the relative contribution of EBRBs measured at T1 to explaining BMI trajectories between the pre-/early and the late primary school periods, and how does this vary across these four countries?

1. Data and methods

1.1. Data and sample

This paper draws on longitudinal cohort data harmonized and analyzed in the project Development of Inequalities in Child Educational Achievement (DICE). Japan and France are also included in the DICE project. Unfortunately, however, as longitudinal data on BMI was not available for these two countries for the specific developmental period that is the focus of the current study, we could not include these countries. Table 1 provides a brief outline of the data. The German, UK, and US samples are representative of the respective country populations. For the Netherlands, the sample is representative of Rotterdam only, which is the second largest city in this country (for further details see (DICE technical appendix, 2022)). Response rates for the surveys are reported in Appendix A.

Socio-demographic characteristics of participants are presented in Table 2. At both T1 and T2, children are youngest in Germany, followed by the Netherlands, the US, and the UK. Children of high educated parents are overrepresented in the Dutch sample. Substantial differences can be observed in mother's age at giving birth between the countries. Teen mothers are much more common in the US than the other three

Table 2
Socio-demographic characteristics of participants (weighted proportions and *means/SDs*).

Child characteristics	Germany	The Netherlands	The United Kingdom	The United States
Sex				
Girls (in %)	51.5	49.2	48.9	48.6
Age				
Mean age in years at T1 (SD)	5.2 (0.4)	6.1 (0.4)	7.2 (0.2)	7.1 (0.4)
Mean age in years at T2 (SD)	8.9 (0.6)	9.8 (0.3)	11.2 (0.3)	11.1 (0.4)
Family characteristics				
Highest education level (in %)				
High	31.9	66.6	32.1	39.2
Medium	54.2	25.7	27.5	33.9
Low	14.0	7.7	40.3	26.9
Single parent household (in %)	11.1	14.3	21.2	19.0
Mother characteristics				
Foreign born (in %)	23.1	39.1	15.9	24.7
Age at birth of the child (in %)				
<20	1.0	1.8	8.4	29.2
20-24	10.5	9.5	17.3	22.6
25-29	23.2	24.9	28.8	26.8
30-34	35.8	41.4	29.0	15.5
35+	29.6	22.4	16.5	5.9
N Total	1275	4007	11285	6740
High Educated	492	2817	3989	3080
Medium Educated	668	936	3189	1990
Low Educated	115	254	4107	1670

Note. Sample sizes for US are rounded to nearest 10, as required by the National Center for Education Statistics.

Table 1
Data sources.

	Germany	The Netherlands	The United Kingdom	The United States
Survey	National Educational Panel Study (NEPS)	Generation-R (Gen-R)	Millennium Cohort Study (MCS)	Early Childhood Longitudinal Study- Kindergarten Class of 2010–11 (ECLS-K:2011)
Cohort birth dates	2005–2006	2002–2006	2000–2002	2003–2006
Sample at baseline	2349	9749	18552	18170
Analysis sample	1275	4007	11285	6740
Study information	(LIfBi, 2020)	(Kooijman et al., 2016)	(Hansen K. Johnson J., 2014)	(Tourangeau et al., 2019)

countries.

1.1.1. Weights

All estimates from the US (ECLS-K) and UK (MCS) applied the recommended longitudinal weights and survey design variables to adjust estimates for complex sampling and attrition. For Germany (NEPS) and the Netherlands (Gen-R), longitudinal weights were constructed by the DICE study team to account for attrition. Weighting adjustments were made via the svy command in Stata.

1.2. Measures

1.2.1. Outcomes

Children's height and weight were measured directly by trained staff in all countries but Germany. German parents were asked to report on their children's height and weight. In all countries, Body Mass Index (BMI) was calculated as weight/(height^2) (kg/m^2). All analyses involving BMI as a dependent variable were performed using raw BMI scores. The use of raw BMI scores is recommended when analyzing changes in BMI (Cole et al., 2005), when the within-child variability over time–the focus of our second research question–depends on the child's level of adiposity. For consistency, we also use raw BMI scores for our first research question. As a robustness check, we repeated the analyses employing age- and sex-specific BMI z-scores using the WHO 2007 growth standards (de Onis et al., 2007) for the first research question (results in Appendix B).

Table 3
Weighted raw BMI scores and BMI Z-scores at T1 and T2 overall and by highest parental education.

	Germany	The Netherlands	The United Kingdom	The United States
Weighted Raw BMI scores				
T1				
High Educated	14.97 (1.85)	15.93 (1.52)	16.34 (2.08)	16.46 (2.45)
Medium Educated	15.43 (2.61)	16.30 (1.93)	16.57 (2.20)	17.19 (2.79)
Low Educated	15.34 (2.73)	16.80 (2.20)	16.69 (2.47)	17.52 (3.43)
Overall Mean (SD)	15.27 (2.42)	16.09 (1.71)	16.54 (2.28)	16.99 (2.89)
T2				
High Educated	15.79 (2.22)	17.16 (2.34)	18.71 (3.17)	19.34 (4.11)
Medium Educated	16.62 (3.09)	18.19 (3.02)	19.27 (3.62)	20.85 (4.97)
Low Educated	16.90 (3.19)	19.09 (3.54)	19.53 (3.92)	21.25 (5.62)
Overall Mean (SD)	16.39 (2.88)	17.62 (2.75)	19.19 (3.63)	20.37 (4.92)
Weighted BMI z-scores				
T1				
High Educated	−0.33 (1.32)	0.33 (0.89)	0.36 (1.06)	0.39 (1.16)
Medium Educated	−0.09 (1.60)	0.50 (1.03)	0.48 (1.09)	0.75 (1.21)
Low Educated	−0.16 (1.62)	0.75 (1.09)	0.51 (1.20)	0.81 (1.37)
Overall Mean (SD)	−0.18 (1.52)	0.40 (0.95)	0.45 (1.13)	0.63 (1.25)
T2				
High Educated	−0.36 (1.30)	0.21 (1.01)	0.43 (1.31)	0.56 (1.36)
Medium Educated	0.01 (1.49)	0.60 (1.16)	0.60 (1.22)	0.99 (1.40)
Low Educated	0.19 (1.38)	0.89 (1.23)	0.64 (1.28)	1.01 (1.58)
Overall Mean (SD)	−0.08 (1.43)	0.38 (1.10)	0.56 (1.22)	0.83 (1.45)

Table 4
Descriptive statistics (in %) for energy balance related behaviors at T1.

Energy Balance Related Behaviours	Germany	The Netherlands	The United Kingdom	The United States
Physical Activity				
Never	4.9	14.3	3.7	7.4
1 day a week	9.6	37.9	3.0	2.3
2 days a week	NA[a]	31.5	5.0	7.1
3 days a week	39.4	11.3	5.6	14.2
4 or more days a week	46.1	5.1	82.7	69.0
Screen Time (dummy)				
< 1 hour a day	56.5	25.5	4.0	13.4
1 hour + a day	43.5	74.5	96.0	86.6
Breakfast Consumption (dummy)				
less than 7 days a week (5 days for US)		6.0	6.2	8.8
7 days a week (5 days for US)		94.0	93.8	91.2

Note. [a] Data for three countries allows us to distinguish the precise number of days of physical activity per week, top-coded at 4. In the German data, only a single category ("Several days a week") lies between the categories for one day and four or more days per week. The distribution of PA for Germany is skewed to the left, so to harmonize with the remaining countries we chose to place "Several days a week" with the 3-days rather than 2-days category.

1.2.2. Predictors

All predictors were derived from parent reports at T1. In the Netherlands only, this information stems from a questionnaire administered shortly before the T1 BMI measurements, at a mean age of 6.0 years. In Germany, screen time was measured with a one year delay (see Appendix D). For the other countries all predictors are measured at a single measurement occasion (T1).

1.2.2.1. Highest parental education. Our analyses include parental education as an indicator of SES. We analyze the highest level of education attained by a parent who is co-resident with the child at T1, using coding developed by the DICE team. In Appendix C we provide more detailed and country-specific information regarding the coding of education. High education was defined as a first/bachelor's university degree or higher, requiring 3–4 years of full-time study at the tertiary level. The definition of low education differs between countries with comprehensive systems (i.e., little or no tracking below age 16; the US and the UK) and those with early tracking and a high degree of academic/vocational specificity (Germany and the Netherlands). For the UK and the US, low education was defined as no qualification beyond the expected standard which is the target of the education system for all children in compulsory education. In the US the expected standard is a high school diploma/ GED. In the UK the expected standard is attainment of at least a grade C qualification at the end of compulsory schooling at age 16. For Germany it is a basic school leaving certificate plus vocational training (VET). Persons with such a qualification, persons with a basic or intermediate school leaving certificate without VET, and persons with no qualification at all form the low education group. This equals 12 years of education or less (Pelz and Zielonka, 2017). In the Netherlands compulsory education ends at age 16. The medium education group holds all those who do not fall in either the high or low categories (*DICE Technical Appendix*, 2022).

1.2.2.2. Energy balance-related behaviors (EBRBs). To investigate drivers of BMI inequalities, we focus on three types of parent-reported EBRBs of their children: physical activity, screen time, and breakfast consumption. These measures were chosen based on the literature and can be harmonized across the four countries. As is common in the literature, we use exercise as an indicator of physical activity and screen time (TV and computer use) as an indicator of sedentary behaviors (Gebremariam et al., 2017). Screen time has consistently been shown to explain socioeconomic inequalities in child BMI, and breakfast consumption together with sugar sweetened beverages are the indicators of child diet that most consistently explain inequalities in BMI (Gebremariam et al., 2017). As breakfast consumption was the only diet indicator that could be harmonized across the majority of countries, we include this as an indicator of child diet. Exact questions used and coding conducted in the four countries are reported in Appendix D.

1.2.2.2.1. Physical activity (PA). In all four countries, parents were asked to report on their children's physical activity which resulted in a variable indicating the number of days a week that children play sports or exercise. This PA variable was scored 0 (=never), 1 (=1 day a week), 2 (=2 days a week), 3 (=3 days a week), or 4 (=4 days a week or more). German parents had slightly different answer categories. The answer 'several times a week' was coded as '3 days a week'.

1.2.2.2.2. Screen Time (ST). Parents were also asked to report on their children's sedentary behaviors. Survey questions included time spent by children watching television, videos, or DVDs, and time spent using the computer and playing video games. Parents were asked to answer these questions keeping an average weekday in mind, Germany excepted (parents were asked about the entire week, including weekends). The combined information on TV/video/DVD and computer time resulted in a variable screen time (ST). We were able to harmonize to a dummy variable cross-nationally (0= <1 hour a day; 1= 1 hour + a day). Although finer grained information was available in the original questionnaires, the format of the questions and the distributions of the responses differed across countries (see Appendix D and Table 4 respectively). The simple binary measure was chosen for its transparency and to generate distributions that were as balanced as possible within countries while maintaining comparability of definition.

1.2.2.2.3. Breakfast consumption (BC). Information was available on breakfast consumption in all countries, except Germany. Parents were instructed to keep an average week in mind and report how many days a week their child ate breakfast. US parents were additionally asked to report on their child's breakfast consumption at school, reflective of the existence of school-breakfast programs in that country (see Appendix D for exact question wordings). This resulted in a variable breakfast consumption (BC), which was highly negatively skewed in all countries (see Table 4). Therefore, we used a dummy variable that distinguished the maximum possible response (5 days in the US as parents were asked to report exclusively on weekdays, 7 days elsewhere; coded as 1) from all lower categories (coded as 0).

1.3. Analyses

To answer our first research question—examining cross-country variation in the magnitude of inequalities in childhood BMI in the four countries—we ran two sets of linear regression models predicting raw BMI scores. BMI scores, first at age 5–7 (T1), then three to four years later at age 8–11 (T2), were regressed onto highest parental education (T1). In our results section we refer to three types of socioeconomic inequalities in child BMI. The overall high-low gaps (H/L gaps) indicate differences in BMI scores between children with high versus low educated parents (1). These H/L gaps can be broken down into the high-medium gaps (H/M gaps), capturing the difference in BMI scores between children with high versus medium educated parents (2), and the low-medium gaps (L/M gaps), representing the differences in BMI scores between children with low versus medium educated parents (3). The H/M and L/M gaps are the coefficients for respectively high and low educated families (medium educated families form the omitted reference category) from the regression models predicting children's BMI (at T1 and T2), while controlling for the main covariates. The overall H/L gaps are simply the combination of the two component gaps (H/M minus L/M), with standard errors derived via the delta method. A growing body of literature suggests that the SES–BMI association is complex and varies by several demographic factors, including the age of the child (Jansen et al., 2013), gender of the child (Shrewsbury and Wardle, 2008), ethnicity, maternal age (Gnavi et al., 2000), and single parent household status (Huffman et al., 2010). In line with the literature and based on harmonized data availability, the following covariates were added to both sets of regression models: child sex (girl=1), child age in months (at T1 and T2), mother foreign born (1=foreign born mother), maternal age at the birth of the child (1=<20; 2=20–24; 3=25–29; 4=30–34; 5=35+), and a single parent household indicator (1=single parent).

To answer the second research question—regarding cross-country variation in the relative contribution of EBRBs to socioeconomic inequalities in child BMI in the four countries—we started with the second set of regression models as described above, in which we regressed BMI at T2 onto highest parental education and the main covariates at T1 (M1). In addition, we controlled for prior BMI as measured at age 5–7 (T1) in Model 2 (M2). This implies that we examine cross-country differences in the relative contributions of EBRBs to changes in BMI inequalities between the pre-/early and the late primary school periods. This approach will lead to conservative estimates of the role of EBRBs in accounting for BMI inequalities at T2, as any contemporaneous effects that are manifest in BMI inequalities by T1 will be controlled away by the lagged dependent variable. Its inclusion, however, helps to rule out bias from reverse causation, whereby children's BMI at T1 might affect certain EBRB's (e.g., heavier children might encounter more substantial barriers to physical activity). In a next step we added each of the three EBRBs (PA, ST, and BC) individually to this baseline model (M3; M4; M5). Our final model included all variables (M6). In Table 5 we summarize the regression results for our basic model, controlling for prior BMI (M2), and our final model including all three EBRBs (M6). In Table 5 we also present H/L gaps for Models 2 and 6 with corresponding standard errors, again calculated via the delta method.

Contributions of the EBRBs to BMI inequalities are represented by the (percentage) change in the association between highest parental education and child BMI due to the addition of the EBRBs to the model (M2). The contribution of PA is thus captured in the changes in the education coefficients from M2 to M3, the contribution of ST is captured in the changes in the education coefficients between M2 to M4, and the contribution of BC in the changes in the education coefficients between M2 and M5. Finally, the contribution of all EBRBs taken together can be read from the changes in the education coefficients between M2 and M6. Absolute changes were calculated as $\Delta = \beta2-\beta1$. In line with Omorou et al. (2020), percentage change was calculated as: $\%\Delta = (\beta2-\beta1)/\beta1*100$. Delta ($\%\Delta$) is the respective effect size of PA, ST, and/or BC. The regression coefficients of the associations between child BMI and highest parental education before and after adjustment for the EBRBs are indicated by β_1 and β_2 respectively. All analyses were conducted in Stata (Stata Corp, 2015). Between country differences in regression coefficients were tested using pairwise Z-tests.

1.4. Results

1.4.1. Descriptive statistics

The descriptive statistics for BMI raw scores as well as BMI z-scores by highest parental education are presented in Table 3. Children in the UK and the US are slightly older and have higher BMIs compared to Dutch and German children. In all four countries, children from higher educated families have lower BMIs than their lower educated counterparts. The negative z-scores for Germany indicate that German children on average have lower BMIs than the overall mean of the WHO 2007 reference data (de Onis et al., 2007).

Descriptive statistics for EBRBs are presented in Table 4 (with a breakdown by parental education in Appendix E). Overall, children are most physically active at T1 in the UK, followed by the US, Germany and finally, the Netherlands. Regarding ST, most children in the German sample spend one hour or less behind their screens, whereas for the other three countries most children were in the one hour or more a day category. For BC we have information for the Netherlands, UK, and US.

Table 5
Regression coefficients and standard errors - BMI at T2 predicted by highest parental education and EBRBS (T1).

	Germany		The Netherlands		The United Kingdom		The United States	
	M2	M6	M2	M6	M2	M6	M2	M6
High Educated	−0.64*** (0.21)	−0.53*** (0.20)	−0.51*** (0.07)	−0.48*** (0.07)	−0.28*** (0.06)	−0.26*** (0.06)	−0.43*** (0.12)	−0.40*** (0.12)
Low Educated	0.60* (0.35)	0.54 (0.35)	0.24* (0.14)	0.21 (0.14)	0.10 (0.06)	0.09 (0.06)	−0.08 (0.14)	−0.08 (0.14)
H/L gap (calculated)	−1.25*** (0.35)	−1.06** (0.35)	−0.75*** (0.13)	−0.69*** (0.13)	−0.38*** (0.06)	−0.35*** (0.06)	−0.35* (0.15)	−0.32 * (0.15)
H/L Δ	–	0.18 [14.5%]	–	0.06 [7.6%]	–	0.03 [8.4%]	–	0.03 [8.6%]
Prior BMI (T1)	0.54*** (0.08)	0.54*** (0.08)	1.25*** (0.02)	1.24*** (0.02)	1.26*** (0.02)	1.25*** (0.02)	1.40*** (0.03)	1.40*** (0.03)
Days of physical activity per week	–	−0.09 (0.15)	–	−0.02 (0.03)	–	−0.02 (0.03)	–	0.02 (0.04)
Screen time 1 h + per day	–	0.41* (0.22)	–	0.19*** (0.06)	–	0.29*** (0.10)	–	0.27* (0.14)
Breakfast every day	–	N.A.	–	0.26* (0.14)	–	0.40*** (0.13)	–	0.06 (0.16)
N	1275	1275	4007	4007	11285	11285	6740	6740
R^2	0.248	0.254	0.690	0.691	0.635	0.636	0.690	0.691

Note. *$p < .05$; **$p < .01$, ***$p < .001$. Sample sizes for US rounded to nearest 10, as required by the National Center for Education Statistics. The H/L gaps are the combination of the two component gaps (H/M minus L/M), with standard errors derived via the delta method. These coefficients stem from the regression models predicting T2 BMI by highest parental education, while controlling for prior BMI (T1) and the main covariates (child sex, child age, mother foreign born, maternal age at the birth of the child, and single parent household). H/L Δ is the change in this H/L gap between Models 2 and 6.

In the former two countries six percent of the children in the sample did not eat breakfast all days of the week. In the US this was slightly higher with nine percent of children not eating breakfast every day.

1.5. *Regression results*

1.5.1. *Socioeconomic inequalities in childhood BMI across the four countries*

The first research question involved mapping socioeconomic

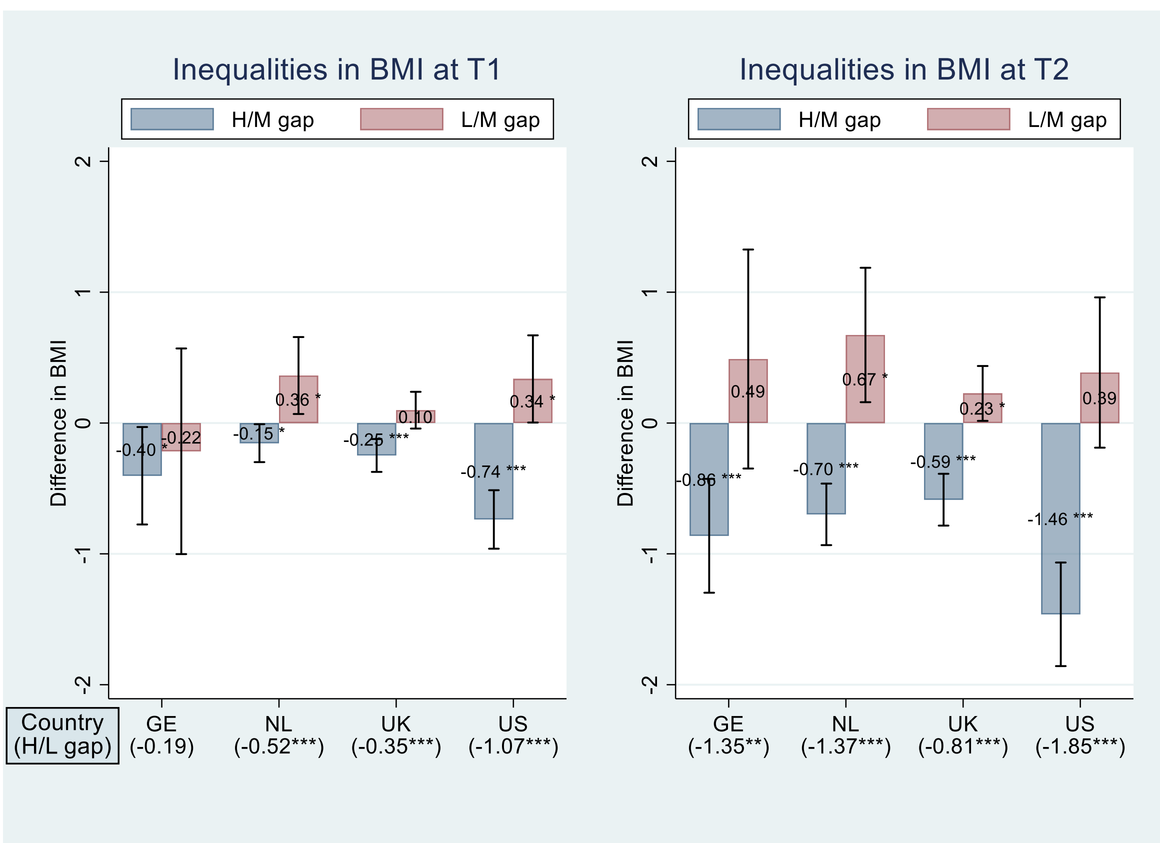

Fig. 1. Socioeconomic inequalities in child BMI at T1 and T2. *Note.* Country abbreviations: GE=Germany; NL=Netherlands; UK=United Kingdom, US=United States. Socioeconomic inequalities in child BMI are expressed in three gaps: H/L gaps (1) reported on the x-axis below country abbreviations. H/L gaps indicate differences in BMI scores between children with high versus low educated parents. These H/L gaps can be broken down into the high-medium gaps (H/M gaps), capturing the difference in BMI scores between children with high versus medium educated parents (2), and the low-medium gaps (L/M gaps), representing the differences in BMI scores between children with low versus medium educated parents (3). The H/M and L/M gaps are the education coefficients for respectively high and low educated families (medium educated families form the omitted reference category) from the regression models predicting children's BMI (at T1 and T2), while controlling for the main covariates (child sex, child age, mother foreign born, maternal age at the birth of the child, and single parent household). The H/L gaps are the combination of the two component gaps (H/M minus L/M), with standard errors derived via the delta method. ***p < .001, **p < .01, *p < .05.

inequalities in BMI at age 5–7 (T1) and at age 8–11 (T2) and examining how these varied across the countries. In all four countries there were clear inequalities in BMI already visible at age 5–7, controlling for the main covariates (see Fig. 1, left panel). The regression models on which Fig. 1 is based are included in Appendix F. The overall high-low gaps (H/L gaps) indicate differences in BMI scores between children with high educated parents and children of low educated parents and are reported on the x-axis of Fig. 1 below the country abbreviations. H/L gaps at T1 were significant for all countries except Germany, indicating that children of high educated parents had significantly lower BMIs compared to children of low educated parents. H/L gaps were largest in the US, followed by the Netherlands, the UK, and smallest in Germany. The H/L gap in the US was significantly larger ($p < .05$) than in each of the other three countries; no other pairwise comparisons were significant (see Appendix G). Gaps expressed in effect sizes are reported in Appendix H to aid the interpretation of the size of BMI inequalities in the four countries. For example, the German H/L gap at T1 is 0.08 of an SD, respectively .37 SD for the US. Hence the US H/L gap and its difference to the German H/L gap are non-trivial.

Breaking down the H/L gaps at T1, disparities between children of high- and medium-educated parents (the H/M gaps) were negative and significant in all four countries. Here again, the US gap was significantly larger ($p < .05$) than in each of the other three countries. Gaps between children of low- and medium-educated parents (the L/M gaps) were positive and significant only in the Netherlands and the US. Apart from the Netherlands, the L/M gaps were smaller in magnitude than the H/M gaps in each country and there were no significant differences in the L/M gaps between any pair of countries (see Appendix G).

The right panel of Fig. 1 shows socioeconomic inequalities in child BMI at T2. Gaps appear to have increased in all countries, particularly in Germany. The H/L gap in the UK was significantly smaller ($p < .05$) than in the US and the Netherlands; no other pairwise comparisons were significant. The US H/L gap remains the largest among the four countries and the US continues to stand out because of the large magnitude of disparities between children of the high- and medium-educated; the US H/M gap was significantly larger than in any of the European countries. As was the case at T1, there were no significant differences between any pair of countries in the size of the L/M gaps.

Significant H/M gaps were found in all four countries at both time points, indicating that regardless of context, children in high educated families have lower BMI than children in medium educated families. The gradient at the lower end of the socioeconomic hierarchy, however, was less clear-cut. At both time points the L/M gap in Germany was non-significant and this was also the case in the UK at T1 and the US at T2. The reverse was true in the Netherlands at both time points and in the US at T1 and the UK at T2. The extent to which medium SES children are differentiated from low SES children in terms of BMI, therefore, appears to be context specific.

1.5.2. The relative contribution of EBRBs to socioeconomic inequalities in childhood BMI

The second research question considered the relative contribution of EBRBs to inequalities in BMI at age 8–11 (T2), and cross-country variation in the importance of these explaining mechanisms. For the EBRBs to contribute to inequalities in BMI, we should see differences in the EBRBs by parental education. Significant socioeconomic inequalities were indeed observed in all three EBRBs in all countries (Appendix I). Table 5 summarizes the regression results for our basic model, controlling for prior BMI (M2), and our final model including all three EBRBs (M6). A longer version of Table 5—showing results for all models (M2-M6), including covariates—is included in Appendix J. Table 6 shows the contributions of each of the EBRBs to inequalities in BMI at T2 by specifying the absolute change and the percentage change in the socioeconomic inequalities in BMI (H/L, H/M, and L/M gaps respectively) after adding the EBRBs stepwise to the basic regression model (M2). Boldness indicates whether differences between the three educational categories remain significant after adding the EBRBs.

Table 6
Changes in Socioeconomic Inequalities in BMI by adding Energy Balance Related Behaviors (EBRBs).

	Germany	The Netherlands	The United Kingdom	The United States
Model 3 PA (T1)				
H/L gaps	**0.04 [3.1%]**	**0.01 [<1%]**	**0.00 [1.0]**	**+0.01 [+1.7%]**
H/M gaps	**0.03 [4.2%]**	**0.01 [<1%]**	**0.00 [<1%]**	**0.00 [+0.2%]**
L/M gaps	**0.01 [2.0%]**	**0.00 [<1%]**	0.00 [2.0%]	0.01 [8.4%]
Model 4 ST (T1)				
H/L gaps	**0.15 [11.9%]**	**0.04 [4.7%]**	**0.01 [1.3%]**	**0.03 [8.4%]**
H/M gaps	**0.09 [14.2%]**	**0.02 [4.3%]**	**0.01 [2.9%]**	**0.03 [6.0%]**
L/M gaps	0.06 [9.6%]	**0.01 [5.4%]**	**+0.00 [+2.9%]**	+0.00 [+3.6%]
Model 5 BC (T1)				
H/L gaps	–	**0.03 [3.6%]**	**0.02 [6.4%]**	**0.00 [0.6%]**
H/M gaps	–	**0.01 [2.0%]**	**0.01 [4.0%]**	**0.00 [0.7%]**
L/M gaps	–	**0.02 [7.0%]**	0.01 [12.8%]	0.00 [1.2%]
Model 6 All EBRBs (T1)				
H/L gaps	**0.18 [14.5%]**	**0.06 [8.5%]**	**0.03 [8.4%]**	**0.03 [7.2%]**
H/M gaps	**0.11 [17.6%]**	**0.03 [6.7%]**	**0.02 [7.3%]**	**0.03 [7.0%]**
L/M gaps	0.07 [11.3%]	0.03 [12.4%]	0.01 [11.5%]	0.01 [6.0%]

Note. PA=Physical Activity; ST=Screen time; BC=Breakfast Consumption. Numbers show the change in the estimated parental education gaps (expressed in percentage terms in the square brackets) when EBRB variables are added to the baseline Model 2 shown in Table 5. Results adjusted for child sex and age; time difference between T1 and T2 surveys; foreign born mother; maternal age; and single parent household. Boldness indicates whether differences between the three educational categories remain significant after adding the EBRBs. BC information not available for Germany.

When children's BMI at T1 is controlled for, regression results indicate that physical activity (PA) at T1 did not significantly predict children's BMI at T2 in any of the four countries (See Table 5, 6th row). In line with these non-significant coefficients for PA, the results in Table 6—showing the change in gaps when EBRBs are added to the model—indicate that the contribution of PA to inequalities in BMI was negligible in all countries (see Table 6; M3).

In contrast, screen time (ST) —taken as a proxy for sedentary behaviors—was a significant predictor of children's T2 BMI in all countries (Table 5, 7th row). Screen time of one hour a day or more was associated with a higher BMI in children compared to the reference category (< one hour a day). The association was strongest in Germany, followed by the UK, the US, and the Netherlands, although between-country differences were non-significant (see Appendix G; Table G.3). ST explained quite a large part of the H/L gap in Germany, less in the other two countries, and very little in the UK. Breakfast consumption (BC) significantly predicted children's BMI in the Netherlands and the UK, but not in the US. Results (Table 5, 8th row) indicated that children in the Netherlands and the UK who ate breakfast daily had lower BMI's than children who did not eat breakfast every day. The association was strongest in the UK although pairwise between-country differences were non-significant (see Appendix G; Table G.3). BC explained most in the Netherlands, mainly driven by its contribution to the L/M gap. BC did not account for inequalities in childhood BMI in the US.

As visible in Table 6 (M6), all EBRBs together explained relatively large parts of the H/L gaps in Germany, but less in the other three countries. As shown in Appendix G (Table G.4), there were significant differences between counties in M2, and most of these remained significant in M6. Differences in EBRBs are therefore not able to fully account for why countries differ in the degree of socioeconomic inequality in BMI: influences other than EBRBs differ significantly at the country level. All EBRBs together explained more of the H/M gaps than of the L/M gaps in Germany, the UK, and the US. In contrast, in the Netherlands, more of the L/M gaps was explained in Model 6. In fact, the L/M gap was no longer significant for the Netherlands in the final model, indicating that differences in BMI change between the medium- and low-educated groups in that country could be entirely accounted for by the measured EBRBs. The EBRBs—mostly driven by screen time—explained more of the socioeconomic inequalities in Germany compared to the other three countries.

2. Discussion

Our first research aim involved mapping socioeconomic inequalities in BMI at age 5–7 (T1) and age 8–11 (T2) and examining how these inequalities vary across Germany, the Netherlands, the UK, and the US. Except for Germany at the first time point, all countries revealed statistically significant H/L gaps in BMI, indicating that children of high educated parents had significantly lower BMIs compared to children of low educated parents. This is in line with the Fundamental Cause model, which argues that people of higher SES possess a wide range of flexible resources, such as knowledge, money, and networks, which ensure that people of higher SES know about, have access to, can afford, and are motivated to engage in a broad range of health-enhancing activities (Phelan et al., 2010). Our findings are also in line with previous single-country studies based in the UK (Goisis et al., 2016), the US (Hanson and Chen, 2007), and the Netherlands (Veldhuis et al., 2013), however not with a German based study (Langnäse et al., 2002). Langnäse and colleagues reported significant differences in BMI in children from high versus lower educated families, using the same dominance approach to parental education as used in the current study. The study by Langnäse and colleagues used objectively measured height and weight and the sample included slightly older children (mean age 6.3 years in the Langnäse study versus mean age 5.2 years in our study), which might explain why their study yielded different results. The largest gradient was observed in the US at both time points, which is in line with findings of Due and colleagues (Due et al., 2009). Inequalities in BMI in the Netherlands are relatively larger than would be expected based on findings of Due and colleagues. This discrepancy might be related to the fact that for the Netherlands only, we could not rely on nationally representative data.

By using objectively measured BMI for most of our countries and harmonized education coding across all countries, we were able to draw reliable conclusions concerning differences between countries in socioeconomic inequalities in childhood BMI. Significant H/M gaps were found in all four countries at both time points, indicating that regardless of context, children in high educated families have lower BMI than children in medium educated families. The gradient at the lower end of the socioeconomic hierarchy, however, was less clear-cut. At both time points the L/M gap in Germany was non-significant and this was also the case in the UK at T1 and the US at T2. In these cases, therefore, a 'threshold' specification of the social gradient (high educated families versus the rest) is a better model fit than a 'staircase' specification in which each step up the socioeconomic hierarchy is associated with a significant reduction in BMI. The reverse was true in the Netherlands at both time points and in the US at T1 and the UK at T2. The extent to which medium SES children are differentiated from low SES children in terms of BMI, therefore, appears to be context specific.

Furthermore, H/M gaps were larger in the US than in the other three countries, pointing to greater relative differences in the environments and experiences of children of high- and medium-educated parents in the US versus the European countries. As there are many macro-level differences across the four countries—such as degrees of income and wealth inequality (Alvaredo et al., 2013), differences in taxation, and other political processes (Kenworthy and Pontusson, 2015)—which are not included in our analyses, it is difficult to speculate about the origins of the larger gaps found in the US. However, one possible explanation might relate to the highly targeted, social welfare system in the US. Only very low-income families (who are overall also lower educated) receive benefits such as health care insurance (i.e., Medicaid) and free early childhood education and care (e.g., Head Start) or cash assistance, whereas middle-income families are not provided with these social securities (Bradbury et al., 2012). State-provided resources in the US, therefore, might be expected to primarily attenuate the L/M gap but have little effect on the H/M gap. This contrasts with a country such as the UK where middle- and even higher-income families receive benefits such as universal preschool, national health insurance, and child benefits, such that the equalizing effect of state resources will be felt further up the socioeconomic hierarchy. That said, however, future research is needed to identify possible reasons for the larger H/M gaps in the US versus the three European countries. Our findings indicate that the existence of early inequalities in BMI, and their degree of national variation, may be driven more by the extent of protective factors among the most advantaged than by the extent of risk factors among the least advantaged.

Finally, in all countries, BMI increased over the course of primary school, which is in line with previous research (Datar et al., 2011). In addition to an overall increase in BMI across the primary school period, our study shows increasing socioeconomic inequalities in BMI during this developmental period. The increase in weight inequalities during early to middle childhood is also in line with the literature (Goisis et al., 2016; Jansen et al., 2013) and these are likely to transpire into adolescence and adulthood. Given the plethora of negative health consequences of elevated childhood BMI, such as poorer peer relationships and emotional problems (Sawyer et al., 2011) and greater risk of coronary heart disease in adulthood (Bell et al., 2007), we would expect inequalities in mental and physical health in child- and adulthood to increase as well. Our findings thus emphasize the need for policy interventions to attenuate inequalities in BMI during the primary school years across the four countries.

Our second research aim considered the role of EBRBs in explaining childhood BMI inequalities across our four countries. Considering socioeconomic inequalities in EBRBs, we found significant inequalities in all countries, in line with findings from a systematic review (Atkin et al., 2014). Second, the role of two EBRBs in predicting changes in BMI over the course of primary school was the same in all four countries: Physical activity did not predict changes in children's BMI over the course of primary school, and screen time did. Our findings on physical activity are in line with some previous literature, such as the systematic review of Must and Tybor (2005) that found no consistent significant relationship between physical activity and children's weight gain in children aged nine or younger. There is evidence, however, that this finding may reflect limitations in the way that physical activity is measured; we return to this issue below. Our findings regarding screen time are in line with findings from a recent meta-analysis, reporting that screen time was positively associated with elevated BMI among children and adolescents (Tripathi and Mishra, 2020). For breakfast consumption, we saw that in the UK and the Netherlands, it did predict changes in children's BMI over the course of primary school, but this wasn't the case in the US. Our Dutch and UK results for breakfast consumption are in line with previous research: a review reported a protective role for breakfast consumption in preventing increases in BMI during childhood and adolescence (Blondin and Anzman-Frasca, 2016). Rerunning our US analyses with a breakfast variable including only breakfast at home (not in school) showed that BC at home significantly predicted changes in BMI over the primary school period in the US (see Appendix K; Table K.1). One possible explanation for why BC at home has more explanatory power for children's BMI, is that it is a stronger indicator of overall attention to healthy lifestyles of parents, and thus reflects—more strongly than home and school breakfasts combined—the general healthy upbringing of the child. Interestingly, our study showed that which EBRBs contributed to changes in BMI inequalities over the course of primary school was consistent across the four countries. First, in all four countries, socioeconomic inequalities in physical activity did not contribute to the increase in BMI inequalities over time. This finding is in line with some (Côté-Lussier et al., 2015; Dollman et al., 2007), but not other studies (Goisis et al., 2016). A recent systematic review concluded there is no consistent association between physical activity and a broad class of measures of adiposity among children aged 0 to 4, but also noted that the quality of the evidence base on this link is "low" or "very low" (Carson et al., 2017, p.55). A key limitation of our measure of physical activity that it captures only frequency of activity, with no measure of intensity. Other studies that share this limitation have also found null results (Côté-Lussier et al., 2015). In contrast, a recent large-scale study that used uniaxial accelerometry found significant protective effects of moderate-to-vigorous physical activity on child weight trajectories (Sprengeler et al., 2021). Hence, survey-reported measures that do not distinguish between light, moderate and vigorous activity – as used in this study – may miss the weight-reducing benefits of certain types of activity. This highlights the need for more sophisticated measures of PA to be available for future cross-national research on the factors that underlie variation in BMI inequalities. Second, across the four countries, socioeconomic inequalities in screen time explained increases in BMI inequalities in a similar way. Our results show the specific importance of sedentary behaviors— occurring when body movement is minimal—regardless of physical activity, in explaining socioeconomic inequalities in childhood BMI (Veldhuis et al., 2013). Even though sedentary behaviors and physical activity might appear to be on opposite ends of the same movement-spectrum, our results suggest that they might differently impact BMI and may thus operate in different ways to influence BMI. This underscores the need to control and distinguish ST from PA, and vice-versa, which has also been suggested by previous work (e.g., Eisenmann et al., 2008). Third, for two of the three countries for which information on breakfast consumption was available—the Netherlands and the UK—socioeconomic inequalities in BC explained the increase in BMI inequalities in a similar way. This is in line with the literature (Gebremariam et al., 2017). In the US however, BC did not account for inequalities in BMI. This might be due to school breakfast programs in the US that offer children from low-income families free or reduced-price breakfast in school. Rerunning our analyses with a breakfast variable including only breakfast at home (not in school) showed larger inequalities in BC in the US (see Appendix K; Figure K.1).

Our study also identified differences in the relative importance of particular EBRBs for childhood BMI inequalities. Breakfast consumption was the most important explaining mechanism in the UK and screen time explained most of the BMI inequalities in Germany (although breakfast consumption information was not available for this country) and the US. In the Netherlands, screen time and breakfast consumption were equally important in explaining childhood BMI inequalities. Finally, our results showed that, in Germany, the UK, and the US, the contribution of EBRBs to changes in BMI inequalities during primary school were mostly explained by the disproportionately protective behaviors of children of the highest-educated parents. EBRBs, as well as levels of BMI, were generally less differentiated between children of medium- and low-educated parents and in many cases differences between these groups were not statistically significant. This finding suggests that policy efforts that aim to mitigate childhood BMI inequalities via decreasing screen time and increasing breakfast consumption should be directed towards children from medium as well as low educated parents.

2.1. Limitations

Harmonizing data across countries is challenging. First, varying sample sizes across countries bring differences in precision of the estimates. Sample sizes for all German subgroups and for low educated families in the US were quite small, leading to wider confidence intervals. This affected the power of the analyses to identify differences between parental education groups and likely explains the lack of statistical significance of the H/L gap in Germany at T1. Second, although the datasets used were representative of the national populations of Germany, the UK, and the US, the sample for the Netherlands represents the country's second largest city, whose population is more ethnically diverse, and harbors graver poverty than rural Netherlands (CBS, 2019). This possibly led to overestimating inequalities for the Netherlands. Third, the current study relied on parental self-reports of children's weight and height for Germany. Previous research has shown that parents are more likely to assess their child's weight accurately when their child has a normal weight compared to when their child is overweight (Doolen et al., 2009). In the latter case, parents are more likely to underestimate their child's weight. Given that children of low educated parents are more likely to be overweight than children of higher educated parents, it is possible that German children in the low educated group in particular had higher BMI's than those reported by their parents. Consequently, we might have underestimated BMI inequalities for Germany relative to the other countries. Fourth, self-reports for EBRBs might not yield the most reliable measurements. Although there is accelerometer data available in the UK dataset—which is arguably more reliable than parent-reports of their children's activity levels—those data were not available in the other countries. As some studies show that social desirability bias differs by social strata (Kim and Tamborini, 2014), underreporting of unhealthy behaviours and overreporting of healthy behaviours might have been more severe in the lower educated groups (Nyberg et al., 2016). This possibly biased our results towards underestimating the contribution of PA and ST to BMI inequalities. Additionally, as discussed above, our specific measurement of physical activity is limited in the sense that we could not include intensity of activity. Future data collections should address this limitation to allow for more nuanced understanding of how the links between SES, PA and BMI differ across countries. Finally, we used screen time as our proxy measure for sedentary behaviors. As there are other relevant sedentary behaviors besides screen time, which we unfortunately were not able to harmonize, our measure for sedentary behaviors is relatively narrow. Fifth, our measures of EBRBs show rather unbalanced distributions in the four countries, which begs the question of whether these categorizations yield the most reliable representations of EBRBs. Although the cross-national harmonization procedure did not allow us to categorize in a way that would result in more balanced distributions (in some countries the imbalance was mainly between the bottom versus the other categories, whereas in other countries it was the top versus the other categories, see Table 4), we believe our measures indicate relevant differences in the behaviors of children between the four countries. In previous work examining associations between EBRBs and child weight status and BMI, EBRBs are commonly measured by questionnaires including similar items to the ones employed in the current study (Gebremariam et al., 2017). This is especially the case for screen time and to a lesser extent for physical activity. For example, exercise is often analyzed as an indicator of physical activity. Screen time—also as a dummy variable (Dubois et al., 2008; Musić Milanović et al., 2021) —is often used as a proxy for sedentary behaviors. Sixth, slight differences in question wording between countries may have affected our results. Our screen time measure included general computer use (other than gaming) in all countries, except the US. This might have led to overestimation of gradients for the US, as increased screen time among children from lower SES families was found to be driven by TV- rather than computer time (Mantziki et al., 2015). Finally, although we controlled for children's BMI at baseline to rule out issues of reverse causality, our data do not allow us to interpret our findings in a causal manner.

2.2. Directions for future research

Our study focused on similarities and differences in the mechanisms explaining socioeconomic inequalities in BMI in pre- and primary school aged children across four Western developed countries. Future research should test whether the patterns found in the current study remain consistent when incorporating a wider range of developed countries. Furthermore, the current study investigated whether there were cross-national differences in the role that micro-level mechanisms play in explaining BMI inequalities. Future studies might also examine meso-level mechanisms, such as neighborhood differences in built environments across countries (Gordon-Larsen et al., 2006) and differences in school policies regarding diet and activity. Furthermore, recent studies conducted in Europe (Luiggi et al., 2021) and the US (Kim et al., 2020) have shown interaction effects between meso- and individual/family-level SES and overweight and obesity among children and adolescents. For example, Kim et al. (2020) showed that, in the US, living in a high SES neighborhood is protective against obesity among higher-income children, but not among low-income children. These findings suggest that examining both family and neighborhood level SES indicators can provide a more comprehensive understanding of BMI and overweight/obesity inequalities in children. We therefore recommend researchers to test for these interaction effects in future studies. Finally, future research could explore further why a particular EBRB is more consequential for children's BMI in one country than in another.

2.3. Implications for policy

The observed increase in BMI inequalities during early to middle childhood indicates that there is ample possibility for policy interventions to attenuate BMI inequalities during the primary school years in all four countries. This is particularly salient considering the consequences of elevated BMI in children, for childhood physical health (Bell et al., 2007) and socio-emotional problems (Sawyer et al., 2011), as well as their later health (Baker et al., 2007). In line with findings from a recent systematic review (Gebremariam et al., 2017), our findings suggest that sedentary behaviors and dietary factors are promising mechanisms to target when aiming to reduce BMI inequalities in children. Additionally, our findings suggest that what constitutes as the most effective policy intervention differs across countries. Finally, policy efforts should be directed towards children from medium as well as low educated parents in the primary school years.

Credit author statement

Substantial contributions to conception and design of the work, or acquisition, analysis, or interpretation of data for the work. Liz Washbrook, Jane Waldfogel, Sanneke de la Rie, Renske Keizer, Cesarine Boinet, Valentina Perinetti Casoni, Melanie Olzyck, Jascha Drager, Sarah Jiyoon Kwon; Drafting the article or revising it critically for important intellectual content; All authors final approval of the version to be published; all authors and Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. all authors.

Data availability

The authors do not have permission to share data.

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Germany: This paper uses data from the National Educational Panel Study (NEPS): Starting Cohort 2, https://doi.org/10.5157/NEPS:SC2:9.0.0. From 2008 to 2013, NEPS data was collected as part of the Framework Programme for the Promotion of Empirical Educational Research funded by the German Federal Ministry of Education and Research (BMBF). As of 2014, NEPS is carried out by the Leibniz Institute for Educational Trajectories (LIfBi) at the University of Bamberg in cooperation with a nationwide network.

Syntax files on data preparation and analysis used to produce the German results are available under https://osf.io/439pa/

Netherlands: The Generation R Study is conducted by the Erasmus MC, University Medical Center Rotterdam in close collaboration with the Erasmus University Rotterdam and the city of Rotterdam. We gratefully acknowledge the contribution of children and parents. The general design of Generation R Study is made possible by long-term financial support from Erasmus MC, University Medical Center Rotterdam, Netherlands Organization for Health Research and Development (ZonMw) and the Ministry of Health, Welfare and Sport.

UK: The UK results are based on data from the Millennium Cohort Study (MCS; doi: http://doi.org/10.5255/UKDA-SN-5795-5) conducted by the Centre for Longitudinal Studies. We would like to thank the MCS families for their time and cooperation as well as the MCS team at the Institute of Education, University College London.

US: The US results are based on restricted-use data from the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011). The ECLS-K:2011 data is sponsored by the National Center for Education Statistics (NCES) within the Institute of Education Sciences (IES) of the U.S. Department of Education.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2022.115575.

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