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A Review of the Relationship Between Socioeconomic Position and the Early-Life Predictors of Obesity

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Abstract A range of important early-life predictors of later obesity have been identified. Children of lower socioeconomic position (SEP) have a steeper weight gain trajectory from birth with a strong socioeconomic gradient in child and adult obesity prevalence. An assessment of the association between SEP and the early-life predictors of obesity has been lacking. The review involved a two-stage process: Part 1, using previously published systematic reviews, we developed a list of the potentially modifiable determinants of obesity observable in the pre-natal, peri-natal or post-natal (pre-school) periods; and part 2, conducting a literature review of evidence for socioeconomic patterning in the determinants identified in part 1. Strong evidence was found for an inverse relationship between SEP and (1) pre-natal risk factors (pre-pregnancy maternal body mass index (BMI), diabetes and pre-pregnancy diet), (2) antenatal/peri natal risk factors (smoking during pregnancy and low birth weight) and (3) early-life nutrition (including breastfeeding initiation and duration, early introduction of solids, maternal and infant diet quality, and some aspects of the home food environment), and television viewing in young children. Less strong evidence (because of a lack of studies for some factors) was found for paternal BMI, maternal weight gain during pregnancy, child sleep duration, high birth weight and lack of physical activity in young children. A strong socioeconomic gradient exists for the majority of the early-life predictors of obesity suggesting that the die is cast very early in life (even pre-conception). Lifestyle interventions targeting disadvantaged women at or before childbearing age may therefore be particularly important in reducing inequality. Given the likely challenges of reaching this target population, it may be that during pregnancy and their child's early years are more feasible windows for engagement.

Keywords Infant · Socioeconomic position · Physical activity · Nutrition

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Introduction

Socioeconomic position (SEP) has a significant influence on body weight in children, with recent reviews finding an inverse association (the higher the level of advantage, the lower the prevalence of obesity) to be typical (though not universal) in resource-rich settings [1–3]. In contrast, a direct relationship is typical in very resource-poor settings [4].

An inverse relationship is not typically observed at birth, however, where low rather than high birth weight (amongst other adverse birth outcomes) is more frequently seen among disadvantaged populations [5–8]. It is the pre-school years when the direction of the relationship switches, with a 2003 German study suggesting that the inverse SEP and body weight gradient begins to appear between the ages of 2 and

6 years [9]. A more recent Dutch study has refined this estimate, with an inverse association between SEP and body weight appearing between 3 and 4.5 years of age [10••]. Although this inverse association does not appear until 3 years or older, the fact that the direction of the relationship switches between birth and 3 years tells us that the body weight trajectory is steeper among disadvantaged children from birth.

Consistent with the observation that the socioeconomic gradient in obesity begins early in life is the substantial evidence now supporting an early-life origin for later obesity [11]. Pre-natal factors (for example, gestational weight gain, pre-pregnancy weight), peri-natal factors (birth weight) and post-natal factors (early-life nutrition, sedentary and activity-related behaviours) as well as external factors that operate from birth (maternal employment, parental feeding practices, parental body weight) are all predictors of weight later in childhood [12, 13] and into adulthood [11, 14]. Importantly, most of these factors are potentially modifiable and therefore important targets for obesity prevention efforts.

A dedicated assessment of the socioeconomic gradient in these early-life predictors of later overweight and obesity has been lacking. Insight into the socioeconomic patterning of early-life determinants of child obesity could help to better understand the genesis of the socioeconomic gradient in obesity and ultimately develop more timely and appropriately targeted infant obesity prevention efforts. Therefore, the aim of the review was to assess the evidence relating to socioeconomic patterning of the pre-natal, infant and early childhood determinants of later obesity.

Methods

For the purposes of this review, infancy is defined as birth to 12 months, and early childhood is defined as 1–5 years or "preschool" age. The review involved a two-stage process: part 1, using previously published systematic reviews to arrive at a list of the potentially modifiable factors observable in infancy (or prior to birth) that are associated with later obesity (either later in childhood, or in adulthood); and part 2, the literature was searched for evidence of socioeconomic patterning in the behaviours/environments/factors identified in stage 1. As the purpose of this review was to provide practical information on targeting obesity prevention efforts, non-modifiable determinants such as ethnicity and genetics were not considered in this review.

Part 1: Developing a List of Potentially Modifiable Factors Associated with Obesity

Recent reviews to have evaluated the early-life predictors of obesity include the following: two 2012 reviews of the early markers of obesity by Brisbois et al. [11] and Weng et al. [12]; a 2006 review of risk factors for overweight in preschool children by Hawkins and Law [15]; a 2012 review by Robinson and Fall [16] and a 2009 review by Lourenço and Cardoso [17] both examining infant nutrition and later health; a 2013 review by Pearce and Langley-Evans of the types of food introduced during complementary feeding and risk of childhood obesity [18], and a 2010 review of systematic reviews on the early-life determinants of overweight and obesity by Monasta et al. [14]. Between these six review papers and one "review of reviews", the following list of early-life determinants was considered to be important or potentially important (i.e. the evidence is suggestive but insufficient evidence exists to form confident conclusions) in shaping future weight.

1. Maternal pre-pregnancy body mass index (BMI) [11, 14, 15] and maternal pre-pregnancy overweight [12]
2. Maternal smoking during pregnancy [11, 12, 14, 15]
3. Maternal weight gain in pregnancy [11]
4. Maternal pre-gestational and gestational diabetes [14]
5. Maternal diet—although no reviews identified maternal diet as a direct risk factor, diets during and after pregnancy have a strong influence on infant diets [19] via feeding practices, role modelling and food provision, as well as pre-pregnancy BMI and weight gain during pregnancy. Nutrition of the mother can also influence developmental programming [20] and is considered important in the theory of the Developmental Origins of Adult Health and Disease [21].
6. Paternal BMI [11, 14]
7. Infant birth weight (small or large) [11, 12] and restricted or excessive intra-uterine growth [14]
8. Breastfeeding initiation and duration [12, 14, 15, 22]
9. Rapid infant growth and early adiposity rebound (the adiposity rebound is the second rise in BMI that usually occurs between 3 and 7 years) [11, 12, 14]
10. Weaning/early-life diet—given early-life diets directly influence energy balance, and food preferences begin to be shaped very early in life [23], infant diets were included here despite the minimal direct evidence for their influence on weight gain and later obesity [18, 24].
11. Home food environment—although this was not an early-life factor considered in any of the included reviews, strong evidence exists linking the family food environment (food availability, parental modelling, parenting practices, feeding style and parenting style) with eating behaviours and weight across childhood [25–31].
12. Child short sleep duration [14]
13. Lack of child physical activity [14, 15]
14. Television viewing in child (including video and computer games) [14, 15]

Part 2: Identifying Evidence of Socioeconomic Patterning

A number of indicators can be used to measure SEP, including income, education, occupation and material possessions [32]. Composite measures are a particularly useful but rarely used method [33]. Among women of child-bearing age, income and occupation are less useful measures due to the absence from paid work of many women. For this review, we incorporated evidence using any available indicator but preferred education where multiple indicators were used due to its particular relevance to mothers of young children.

As the literature on socioeconomic patterning of behaviours, factors or environments is often not the primary focus of papers reporting this information, a systematic review using search terms in the title/abstract would not in itself be sufficient to identify relevant literature. Our systematic search strategy used PubMed and Google Scholar databases with all-field searches using the terms "socioeconomic" OR "education" and terms relating to each of the 14 identified early-life determinants of obesity. In addition, we also (1) searched the reference lists of identified relevant papers ("snowball searching") to identify older related work and (2) performed citation searches on older relevant papers in order to identify recent related work (this was done using Google Scholar which identifies all papers citing each work). An initial search for published reviews on each topic was conducted (using the "Reviews" filter in PubMed; and identifying recent reviews based on citation searches of highly relevant individual studies identified) in order to identify published summaries of available research. If comprehensive reviews were not available, a search for individual studies examining socioeconomic patterning of risk factors was conducted. An assessment of the direction of the association between each factor and SEP (inverse or direct) and an estimate of the strength of this evidence (weak, moderate or strong) were made by the authors. Given the different type and quantity of evidence considered for each factor, it was not possible to more precisely define these categories.

Results

From the seven review papers assessed, a total of 14 modifiable, early-life determinants of later obesity were identified. Below are brief reviews of the literature on the association between SEP and each of these factors. Table 1 contains a summary of the direction and strength of the association between each of the 14 factors and SEP (with indications of where this differs between high- and low-income settings), as well as an assessment of how strongly each factor predicts later obesity.

Maternal BMI and Maternal Pre-Pregnancy Overweight

The seminal 1989 review by Sobal and Stunkard of the relationship between SEP and obesity among women in high-income countries as well as a 2007 update by McLaren both found a high proportion (~70 %) of studies on this topic to have reported an inverse relationship (higher obesity among lower SEP women) [34, 35]. In contrast, a direct relationship

Table 1 Summary of the relationship between SEP and the early-life predictors of obesity

Risk factor	Relationship with SEP[a]
Maternal BMI/pre-pregnancy overweight	−−−[b]
Maternal smoking during pregnancy	−−−[c]
Maternal weight gain in pregnancy	None/unclear[c]
Maternal pre-gestational and gestational diabetes	−−−[b]
Maternal diet (poor)	−−−[b]
Paternal BMI	−−[b]
Infant birth weight (small or large)/intra-uterine growth	(Low birth weight only)−−−
Low level of breastfeeding initiation and short duration	−−−[b]
Rapid infant growth and early adiposity rebound	−[b]
Poor early feeding practices/dietary patterns	−−−
Poor home food environment	−−[c]
Child short sleep duration	−[c]
Lack of physical activity in child	None[c]
High level of television viewing in child	−−[c]

"−" inverse association, "+" direct association

[a] The number of minuses or pluses indicates the strength of the association based on the authors' assessment of the literature

[b] Evidence that this relationship differs in low and/or low/middle income countries, or other settings

[c] Lack of evidence on the relationship in low and/or low/middle income countries

is frequently observed among women in low-income countries that have not undergone (or are early in the process of) "nutrition transition" [36]. The shift from direct to inverse association is strongly income-related, with inverse associations seen in countries having a gross national income (GNI) per capita >$1000 [4]. In a secondary analysis by McLaren, age was not found to be an effect modifier of the association between SEP and obesity among women in countries ranked high on the U.N. Human Development Index (HDI); however, some evidence was observed (detail not provided) that the association varied modestly by age in women from countries listed as medium on the HDI [35].

We conclude: strong evidence for an inverse relationship between maternal BMI and SEP in women from developed countries. The relationship is dependent on country income level.

Maternal Smoking During Pregnancy

A 2001 review of nine cohort studies found SEP to be an important determinant of maternal smoking and smoking cessation during pregnancy [37]. A number of studies published since have found likewise [38–44].

We conclude: strong evidence for an inverse relationship between maternal smoking during pregnancy and SEP.

High Maternal Weight Gain in Pregnancy

The evidence for an association between excess gestational weight gain and SEP was assessed as part of a 2009 review of pregnancy weight guidelines for the US Institute of Medicine, with the finding that there were few studies on this topic [45]. The single reported study found a trend toward greater weight gain in more educated women [46].

Our review identified several other studies that have reported on this topic, with two US studies finding a positive association (high SEP associated with excessive gestational weight gain) [47, 48]. Studies from Belgium, Canada and Sweden demonstrated an inverse association (but the association only being apparent in those with healthy pre-pregnancy weight in the Swedish study) [49–51], while nine studies from Iran, USA, Australia/New Zealand, Brazil and the Netherlands found no association [52–60]. One study from New York found that the relationship was complex and depended upon area of residence [61].

We conclude: SEP may in some instances be associated with excess gestational weight gain; however, this relationship is inconsistent, may be context dependent, and the direction of the association is unclear.

Maternal Pre-Gestational Diabetes and Gestational Diabetes

With the strong inverse relationship between SEP and obesity (see results for maternal BMI), and with obesity being a major risk factor for type 2 diabetes, it is not surprising that a strong inverse relationship also exists between SEP and type 2 diabetes in high-income countries [62–64]. A direct relationship has been observed in several low-income countries (reviewed in [65]). Given that type 2 diabetes is strongly age-related (uncommon in young people), we were not able to find evidence relating specifically to women of child-bearing age. Dode and dos Santos (2009) and Bouthoorn (2015) have both recently reviewed the relationship between SEP and gestational diabetes [66, 67]. Both reviews cite a number of studies in which low education is related to greater risk of gestational diabetes but also some studies in which no association is observed.

We conclude: strong evidence exists for an inverse relationship between SEP and type 2 diabetes in high-income countries. The evidence is moderate for a corresponding association between SEP and gestational diabetes mellitus.

Maternal Diet

Darmon and Drewnowski (2008) reviewed the evidence for an association between food and nutrient consumption and SEP [68]. Using data from European, North American and Australian datasets, they conclude that "higher-quality diets are, in general, consumed by better educated and more affluent people". Conversely, lower quality diets tended to be consumed by groups of lower SEP and more limited economic means. These findings relate to the broader population, although other studies have reported similar findings in samples of mothers with young children [69–71].

Following on from Darmon and Drewnowski, Mayén et al. recently conducted a similar review of studies from low- and middle-income countries. Although their conclusion was that (as for high-income countries) higher SEP individuals had higher quality diets overall, this was a reflection of the superior micronutrient content and diversity of their diets, even though they simultaneously consumed more energy, cholesterol, and saturated fats and fewer fibres [72]. The stage of transition to a more "Western" diet pattern had an important influence on diet composition relative to SEP.

We conclude: a large volume of consistent evidence exists for an inverse association between low dietary quality and SEP in high-income countries (some specific to mothers). The relationship exists but is different, complex and dependent on the stage of nutrition transition in low and middle income countries.

Paternal BMI

The relationship between body weight and SEP is stronger in women than in men [35]. In the 2007 McLaren review [35], the majority of the 564 associations in high-income countries used education (45 %) or occupation (22 %) as measures of SEP. Among these, the most common finding was either an inverse relationship (46 %) or no relationship (48 % either non-significant or curvilinear) between SEP and BMI in men. Five per cent of studies reported a direct association. Studies using income more frequently reported direct associations (n=20 or 29 %) than negative associations (n=14 or 17 %). In countries classified as "medium development index", a similar pattern was seen (n=128 studies); however, in the few studies from "low human development index" countries, only direct associations between SEP and BMI were observed (n=3 studies). Age was not found to be an effect modifier of the association between SEP and obesity among men from countries ranked either high or low on the HDI [35].

We conclude: moderate evidence for an inverse relationship between paternal BMI and SEP in medium and highly developed countries.

Infant Birth Weight (Low or High) and Restricted or Excessive Intra-Uterine Growth

Low birth weight (defined by the World Health Organization as <2500 g) can result from being born too soon (preterm), or too small for gestational age, or both, and usually results from slower than normal rate of foetal growth [73]. The major causes of pre-term birth do not appear to vary much between low-, middle- and high-income countries [74]. The causes of being born small for gestational age do however vary both between countries and within regions. Kramer has comprehensively reviewed the determinants of low birth weight, finding that smoking during pregnancy (which is strongly socio-economically patterned [75]) is the major determinant of low-birth weight in countries where a sizeable proportion of pregnant women smoke [74]. In low-income countries where smoking rates are low, low SEP impacts the incidence of low birth weight via inadequate maternal nutrition (pre-pregnancy BMI, gestational weight gain, short stature) [76]. The conclusions of Kramer, that there is a strong and consistent association between low maternal education and low birth weight, have been confirmed in a review by Jansen et al. of European studies of the association between SEP and low birth-weight [7], and a more recent meta-analysis of 12 European cohort studies [77]. In addition, Jansen et al. also confirmed that the strongest mediator of this association was maternal cigarette smoking [7]. A recent meta-analysis found a 33 % protective effect of high maternal education against low birth weight, although heterogeneity of results was considered moderate [78]. Comparatively little literature exists regarding the association between high birth weight (defined as >4000 g by the US Centers for Disease Control and Prevention: http://www.cdc.gov/pednss/what_is/pednss_health_indicators.htm) and SEP. One Canadian study found the association to vary geographically, with women of higher SEP having greater odds of delivering a baby >4000 g in Quebec, but this being true for lower SEP women in British Columbia [79]. A recent modelling paper confirms that there is little literature in this area, with conceptual models providing evidence to suggest that higher SEP improves positive health outcomes and thereby reduces the risk of high birth weight [80]. With evidence that high SEP reduces the risk of both high and low birth weight, it is clear that the relationship between SEP and birth weight is non-linear.

We conclude: a strong and consistent association exists between lower SEP and low birth weight, mediated primarily by smoking rates (and poor maternal nutrition in low income countries). Few studies have reported the association between SEP and high birth weight, with no clear trends apparent.

Breastfeeding Initiation/Duration

Reviews in 1999, 2002 and 2009 of the association between SEP and breastfeeding initiation and duration in women from high-income countries all concluded that a strong and positive association exists [81–83]. The authors of an Australian study of the determinants of breastfeeding initiation that failed to detect any association with SEP suggested that in populations with an almost universal level of breastfeeding initiation, no gradient in initiation is possible [84]. A Danish study of breastfeeding duration concluded that the absence of a socio-economic gradient in their study was due to an overwhelming influence of day-care initiation on breastfeeding duration in that population [85].

The level of economic development in a country is likely to modify the relationship between SEP and breastfeeding duration and initiation, with studies from low-income countries frequently observing an inverse association [86–89].

We conclude: a strong and consistent inverse association between SEP and reduced breastfeeding duration and initiation exists in high-income countries although, in some areas, this may be moderated by local cultural practices regarding mothers returning to work and childcare initiation. The level of economic development is a key modifier of this relationship, with high SEP found to be associated with reduced duration and initiation in several studies from low-income countries.

Weaning/Early-Life Diet

We are not aware of any reviews of the association between early-life diet and SEP, with the majority of the literature on the topic being published in the past 2–3 years. A review of papers from the Avon Longitudinal Study of Parents and Children (ALSPAC) on the topic concluded that "Maternal education was a strong determinant of … not following feeding guidelines" [90]. Similar findings of the influence of maternal education or SEP were observed in studies assessing both meeting feeding guidelines (e.g. appropriate age of solids introduction) and child dietary patterns from the USA [91–93], Canada [94, 95], UK [96, 97], France [98], Australia [99], Brazil [100] and Peru [101]. A 2009 review of the determinants of early weaning and the introduction of cow's milk in infants found strong evidence for a relationship with low levels of both maternal education and SEP [102].

We conclude: strong and consistent evidence was found for a direct relationship between SEP and more appropriate child feeding practices and dietary patterns in infancy and early childhood.

Rapid Infant Growth and Early Adiposity Rebound

No reviews on the association between infant growth trajectory, rapid infant growth or early adiposity rebound and SEP were found. In our search, we found only one UK study that assessed early adiposity rebound, finding no association with SEP [103]. A greater number of studies assessed infant growth (weight and/or height) trajectories and SEP; however, it is worth noting that several examined overall infant growth in the population [104–107], rather than rapid infant growth [108–110]. Studies from the Netherlands, Australia and the UK found no association between infant growth and SEP [104, 105, 108] (with the Australian study assessing rapid infant weight gain), with four European studies from the UK, Netherlands and Sweden finding an inverse association [106, 107, 109, 110] (Wiljaars finding an association with rapid weight gain and Svensson finding an association with overall weight gain but not rapid weight gain). Only two studies were conducted in low- or middle-income countries, with a positive association observed in infants from both Belarus [111] and Chile (noting that the Chilean sample excluded babies <3 kg at birth) [112].

We conclude: moderate evidence exists for an inverse association between SEP and infant growth trajectories with roughly half of all studies from high-income countries reporting this finding. The remainder found no association. A direct association was observed in the only two studies from low- or middle-income countries. Less evidence is available regarding rapid weight gain specifically.

Home Food Environment

The home food environment is multi-component and can include home food availability and accessibility, parental modelling, meal context and feeding behaviours (which are influenced by parenting styles). The type of variables used to quantify the home food environment and their measurement properties often vary between studies, making robust conclusions difficult. Given the broad scope of elements which can be included in the home food environment, we are not able to present a detailed review of each element and associations with SEP, and thus a selection of the most relevant evidence available is included. We are not aware of any reviews assessing the association between home food environment and SEP in pre-school children and infants. Rosenkranz and Dzewaltowski, in their review of home food environments and childhood obesity (not restricted to pre-school children), did evaluate the influence of SEP, noting that "The potential influence of socioeconomic status on the home food environment is pervasive enough that nutrition-related studies usually measure and account for its contribution or confounding potential in relationships between other observed variables" [113].

One review of associations between predictors of children's diets and SEP in 9–13-year olds identified that several home environment factors were consistently associated with SEP (such as home food availability and accessibility and parent modelling), whereas associations with child feeding practices were less consistent [114]. In a review of correlates of child feeding practices (child age 2–6 years), associations with SEP were reported, but again, these were inconsistent with associations differing for different feeding practices [115].

Behaviours related to mealtimes are infrequently studied in early childhood. In an Australian study of children aged 0–6 years, higher SEP was associated with more optimal eating locations for meals and less television viewing during meals [116]. However, studies of family meal frequency have shown inconsistent associations. For example, in Australian 5–6-year olds, higher education has been associated with less frequent family meals [117], while in US adolescents, family meal frequency has been positively associated not only with SEP but also with maternal unemployment [118].

Associations between parental modelling of healthy eating and SEP (better modelling in higher SEP groups) have also been reported in parents of infants [119] and children aged 2–7 years [71]. The vast majority of the literature around the determinants of eating behaviours in infants and pre-school children is from high-income countries [115, 120].

We conclude: moderate to strong evidence exists from high-income countries for a direct association between SEP and some aspects of the home food environment, including parental modelling, while few studies and less consistent findings related to feeding practices and meal time behaviours are reported.

Short Sleep Duration

While SEP is positively correlated with sleep duration in adults [121, 122], less information is available about this relationship for children under 5. In a 2011 review of the role of SEP, race and ethnicity in children's sleep, the vast majority of evidence cited was from school-aged children, with mixed findings regarding the link between SEP and sleep duration [123]. The only cited study conducted in pre-school children was a US study which did find a socioeconomic gradient in "sleep behaviour scores" in 2 to 7-year-old children, with children from lower SEP homes having more impaired scores. This study measured SEP at the area level as median income per zip code and therefore could not be considered strong evidence linking SEP and sleep duration [124]. Likewise, in a review of risk factors for early-childhood dyssomnias, Touchette reports no association between parental education level and sleep consolidation [125]. A more recent study of >7000 children's sleep from 6 months to 11 years in the Avon Longitudinal Study of Parents and Children (ALSPAC) also found no association between sleep duration and maternal education in younger children [126]. In this study, even though children from lower income households went to bed later, they also woke later. An analysis of the GEMI NI twin cohort, however, found maternal education to be inversely associated with short sleep in infants (14–27 months), independent of a range of other predictors [127]. Another US study from Massachusetts also found in bivariate analysis that low maternal education was associated with shorter sleep duration at 6 months, 1 year and 2 years of age (multivariable analysis not conducted) [128]. A US study of bedtime routines, while not assessing sleep duration per se, did find an inverse association between maternal education and both time to bed and presence of bedtime routines [129]. Many of the studies cited above found racial and cultural differences to be strong influences on sleep duration, independent of SEP.

We conclude: few studies have reported the association between SEP and sleep duration in pre-school children, with no studies outside Europe and North America. Although some studies report no association, one large UK cohort study did report a strong and independent inverse association.

Lack of Physical Activity

A 2012 review of the determinants of pre-school children's energy balance-related behaviours found that none of the nine examined studies reported an association between SEP and total physical activity in 4–6-year-old children. Similar results were observed when the level of moderate to vigorous physical activity was assessed [130]. Very little evidence is available for younger children although recently, Hesketh et al. have found an association between maternal education and infant time spent outdoors and time spent free to move around (proxies for physical activity) [131].

We conclude: very little to no evidence exists for an association between SEP and level of pre-school physical activity.

Television Viewing (Including Video and Computer Games)

Several reviews of the correlates of television viewing in pre-school children have been conducted, all since 2010. A 2013 review by Duch et al. reported that 5 of the 12 included studies (58 %) of children <3 years old found television viewing time to be lower in high SEP households [132]. The other seven studies found no association. Similarly, Hoyos-Cillero and Jago reported that in 11/16 studies of <7-year olds, a negative association was observed when using mothers' education as the SEP marker. A greater proportion of studies reported a negative association when fathers' education was used (7/8 studies) [133]. Two of the five studies included in the Hinkley review found a negative association between SEP and television viewing [134], while 6/13 studies included in the review of De Craemer et al. reported a negative association [130].

We conclude: moderate to strong evidence exists to support an inverse relationship between parental education and the television viewing time of pre-school children.

Discussion

This review provides a summary of the literature linking SEP and the key early-life predictors of obesity in children. Our findings suggest that there is strong evidence for an inverse relationship between SEP and (1) pre-conception risk factors including pre-pregnancy maternal BMI, diabetes and pre-pregnancy diet, (2) antenatal/peri-natal risk factors—predominantly smoking during pregnancy and low birth weight—and (3) early-life nutrition (including breastfeeding initiation and duration, early introduction of solids, maternal and infant diet quality and some aspects of the home food environment), and television viewing in young children. There was less strong evidence of socioeconomic patterning of other risk factors including paternal BMI, maternal weight gain during pregnancy, child sleep duration, high birth weight and lack of physical activity in young children. For some of these factors (including early adiposity rebound, sleep duration, high birth weight and rapid weight gain in infancy), a lack of evidence limited our ability to make strong conclusions regarding the presence or absence of an association. Future investigations of the link between SEP and both high birth weight and rapid weight gain in the first year of life may be particularly important, with these having been found to be powerful determinants of obesity later in life [135]. Importantly, for the majority of predictors, while an inverse association with SEP was observed in high-income populations, this was not the case for low-income populations. In low-income settings, direct associations were common and in many cases, a lack of data proved to be a significant limitation. The findings of this review help to highlight which potentially modifiable risk factors to target to reduce the socioeconomic gradient in obesity in young children. The importance of targeting inequality early in life is clear, with a socioeconomic gradient in obesity continuing into adulthood.

Early-life SEP is a powerful predictor of adult health, being causally linked to a range of morbidity and mortality outcomes [136]. A socioeconomic gradient in a wide range of exposures has been implicated, including demonstrably poorer physical and psychosocial environments [137•]. Here, we have added to the literature in this area by demonstrating that a strong socioeconomic gradient exists in relation to many of the pre-natal, peri-natal and early-life determinants of childhood overweight and obesity. Understanding exactly how these SEP gradients arise is likely to be complex given the number of factors considered, the multiple mechanisms that potentially impact each and the difficulty in identifying the relative importance of the pre- and post-natal periods (and any genetic influences [138]). It is clear that while a socioeconomic gradient exists for many of the early-life predictors of obesity, this gradient is also present in adolescence and adulthood for many factors associated with obesity. Knowing whether SEP is most powerfully linked to obesity at a particular life stage or whether accumulation of exposure to a low SEP environment over time (or change in exposure) is important are challenges for future research in this area [136]. A fuller knowledge of the mechanisms linking SEP and obesity will help to put the findings of this review in perspective. With many (most) of the risk factors examined here being transmitted between mother and child via biological or behavioural means, it is clear that inter-generational studies linking the SEP of parents with health outcomes in their children are likely to be of particular importance.

Although almost all of the factors studied here were maternal characteristics linked with child obesity, paternal factors (other than paternal BMI) were not included largely due to lack of evidence. The literature linking fathers' diets and behaviours with infant obesity is extremely limited, with early evidence pointing to fathers having an independent effect on the obesity-related behaviours of their children [139]. How important paternal SEP is in relation to the risk factors studied here is unknown, with the majority of studies reporting on associations with maternal SEP. This is an important area for future research.

While we investigated a range of risk factors linked to child obesity, some key factors can be identified. Maternal smoking, maternal diet and breastfeeding initiation and duration appear to be core influences on the demonstrated association between SEP and infant growth and obesity. The link between maternal smoking and obesity is biological and could relate to both epigenetic insults and the impact on infant growth. The recent reduction in smoking prevalence in developed countries may help to reduce associated inequality in birth outcomes [140]. The massive expansion in tobacco use in developing countries will ensure however that smoking-related inequality in birth outcomes will only increase, even if the differences are primarily between rather than within countries and hence less obvious [140]. Maternal diet is likewise linked to child obesity and later health via biological mechanisms but can also influence obesity risk post-partum via modelling and the influence of the home food environment. We have shown here that both are strongly associated with infant diet quality and SEP.

In relation to breastfeeding initiation and duration, research into the reasons behind poorer practices among low SEP women has identified lack of family support and ability to seek help with breastfeeding problems, the need to return to work and greater concerns about breastfeeding in public as important explanations [141]. Moreover, low SEP women are more likely to interact socially with women who cease breastfeeding prematurely, with our own research showing that women in social groups with lower rates of breastfeeding were less likely to continue breastfeeding [142]. This suggests that low SEP mothers are in greater need of support for initiation and maintenance of breastfeeding. With the SEP gradient in breastfeeding duration and initiation seen mostly in high-income countries, it is important to note that these comments are only likely to apply in that setting.

An important consideration in choosing which risk factors to target to reduce the socioeconomic gradient in childhood obesity is the degree to which these risk factors are modifiable in low SEP families. A thorough critique of interventions targeting maternal nutrition, breastfeeding initiation and duration, and smoking is beyond the scope of this paper; however, we briefly evaluate some recent papers of interest. Our own systematic review on this topic found that few of the obesity-prevention interventions targeting pre-school children from low SEP environments were high quality. Those conducted in children from 0 to 2 had a positive impact on diet quality, but few reported later impacts on weight change, while interventions in 3–5-year old children had mixed results, with the successful interventions being more intensive [143]. That review also suggested that for breastfeeding outcomes and the timing of the introduction of solid food, anticipatory guidance approaches (proactively supporting and advising parents about issues and how to manage them before they occur) show particular promise in low SEP families [143]. Such interventions should commence in the antenatal period to effectively influence breastfeeding outcomes. Anderson reviews the range of interventions targeted toward low-income women in the UK and USA, noting that the effectiveness of many otherwise good policy interventions is not often evaluated [144]. Similarly, in our own assessment of the moderation effect of an obesity prevention intervention by SEP, we noted that the majority of interventions do not report such moderation effects [145]. This should be an important consideration when planning and analysing future studies given the importance of SEP to the early-life determinants of obesity. An assessment of the strength of the association between each determinant and future obesity would clearly add to our assessment of their links to SEP. Unfortunately, previous reviews were not able to make such an assessment.

While the inclusion of a comprehensive range of determinants of infant obesity is a strength of this review and enhances its value to policy makers, this approach necessarily introduces some limitations. For instance, because of its scope, we were unable to fully investigate the nuances of the findings in relation to important study characteristics such as study design, control of confounding factors, sample size and the validity of outcome and exposure measures. The non-systematic nature of the review could also be considered a limitation; however, our search strategies that included both backward and forward snowball searching of citations are likely to have captured a substantial proportion of relevant material. Restricting our results to English language publications is an additional limitation, which may be of particular importance due to the frequent finding of limited research from low-income countries and contexts. Understanding the differences in the way that SEP relates to predictors of obesity between low- and high-income countries would be a good topic for future reviews. Exploration of the SEP link to behavioural differences in relation to smoking, breastfeeding and nutrition and how this changes as GDP increases would be of particular interest.

Conclusion

This review represents a summary of the link between socioeconomic inequality and obesity in the early-life period. We expect that this will be of particular relevance to policy makers wishing to focus obesity-prevention efforts on factors that will reduce inequality in health outcomes over time. A strong socioeconomic gradient exists for the majority of the early-life predictors of obesity suggesting that the die is cast very early in life (even pre-conception). Lifestyle interventions targeting disadvantaged women at or before child-bearing age may therefore be particularly important in reducing inequality [146]. Given the likely challenges of reaching this target population, it may be that during pregnancy and their child's early years are more feasible windows for engagement.

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Compliance with Ethics Guidelines

Conflict of Interest Adrian Cameron, Alison C. Spence, Rachel Laws, Kylie D. Hesketh, Sandrine Lioret and Karen Campbell declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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