Teachable moments in the promotion of healthy eating habits, during pregnancy and early childhood

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Abstract

Nutritional exposures during pregnancy, infancy and early childhood can impact on both the short-term and long-term health outcomes of children. Pregnancy has often been described as a 'teachable moment', where women may have increased motivation to change their dietary and other health behaviours. Other teachable moments exist whenever families make choices around nutrition, such as breast or formula feeding, the introduction of solid foods and what to eat at home or at school. This thesis considers whether the promotion of healthy eating habits and adherence to dietary guidelines during these teachable moments, have the potential to improve the health outcomes of women and children.

The eight papers included in the thesis represent an original contribution to knowledge. The two papers which explored women's feelings about their weight, diet, nutrition, and physical activity (PA) during pregnancy, found that weight and lifestyle factors were often problematised without offering constructive solutions. Offering personalised advice, re-framed positively to focus on nutrients for maternal and foetal health, may help to address this. A service evaluation of a pregnancy weight management intervention found that where interventions are tailored and delivered by trusted health professionals, success can be achieved.

Two systematic reviews found some limited evidence that very early introduction of solid foods ($\leq$ 4 months) and high intakes of protein in infancy may contribute to overweight and obesity risk later in childhood. This suggests there is a need for continued promotion and support for families to meet recommendations to breastfeed and introduce solids from 6 months of age. Two further papers explored baby-led weaning (BLW) and found understanding of and adherence to the characteristics of BLW varied considerably amongst parents reporting using the method. Younger (6-8 months) infants following BLW had lower intakes of key nutrients, but differences disappeared by 9-12 months. Milk feeding may play a role in observed differences. A final paper explored why some families choose not to take universal infant free school meals. This appeared to be because the child rejected the food or due to concerns over what/how much the child ate and the quality of the meals provided.

Health promotion activity should focus on the long-term healthy eating habits of women as the gatekeepers of the family diet, whilst recognising the challenges that women face during and following pregnancy.

Acknowledgements

Foremost, I'd like to thank my PhD advisor, Simon Langley-Evans. For encouraging me to apply for the PhD by published works, and for advising my PhD, even after I left the University of Nottingham. This was above and beyond, and I couldn't have done it without your support and encouragement.

I would also like to thank my former colleagues at the University of Nottingham, including the MAGIC study team and particularly Judy Swift, who also encouraged me to apply for the PhD and advised me during the writing of the universal infant free school meal paper. Thank you also, to the Bumps and Beyond team for the opportunity to complete the service evaluation and Leicester City Catering for supporting the universal infant free school meal project.

I would like to acknowledge all the study participants; pregnant mums, mums of small babies and the mums, dads, and carers of the children in reception, year 1 and year 2. Thank you for saying yes to taking part in our studies and for contributing your valuable time and responses.

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List of Abbreviations

ALSPAC – Avon Longitudinal Study of Parents and Children

AMSTAR - A MeaSurement Tool to Assess systematic Reviews

BLW – Baby-led weaning

BMI – Body mass index

CI – Confidence interval

CVD – Cardiovascular disease

DINE – Dietary Instrument for Nutrition Education

DNSIYC – Diet and Nutrition Survey of Infants and Young Children

FFQ – Food frequency questionnaire

GDM – Gestational diabetes mellitus

GWG – Gestational weight gain

IPAQ – International Physical Activity Questionnaire

LGA – Large for gestational age

LIMIT – Australian antenatal lifestyle advice for women who are overweight or obese (randomised controlled trial)

LRNI – Lower reference nutrient intake

MAGIC – The MAnaging weiGht In pregnanCy (MAGIC) cohort study

MPR – Multi-pass 24 recall

NDNS – National Diet & Nutrition Survey

NHANES – National Health And Nutrition Examination Study

NHLBI – National Heart, Lung, Blood Institute

NIHR – National Institute for Health Research

OR – Odds Ratio

PA – Physical activity

PROSPERO - International Prospective Register of Systematic Reviews

RCT – Randomised controlled trial

RNI – Reference nutrient intake

RR – Relative risk

SACN – Scientific Advisory Committee on Nutrition

TW – Traditional weaning

UoN – University of Nottingham

UPBEAT - UK Pregnancy Better Eating and Activity Trial

USDA – United States Department for Agriculture

WHO – World Health Organisation

WMD - Weighted mean difference

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1.0 Introduction

1.1 The PhD by published works route

~~(Powell, 2004)~~The University of Nottingham (UoN) offers the PhD by published works route to staff who hold an undergraduate or postgraduate degree and have worked at the university for a minimum of 4 years, at the start of their PhD (University of Nottingham, 2016). Publications should have been completed whilst employed by UoN and the thesis should be submitted within 4 years of a PhD application being approved by the Quality and Standards Committee (a sub-committee of the teaching and learning board). PhD by published works candidates usually have one advisor who provides guidance on the selection, coherence and quality of the published works and advice on the structure of the thesis. There is no minimum or maximum number of articles or book chapters to include, although the final thesis should be the same length as a traditional PhD (70,000 – 100,000 words) including the 'published works' along with a critical narrative of the subject area and the included works. The included publications should adhere to a theme which connects the included research together (Chong, 2022).

My journey to the published works route began after I completed my MSc in Public Health Nutrition at the London School of Hygiene and Tropical Medicine. I did not want to do another degree, I was adamant that I wanted to work in public health. Part of my first role as a community nutritionist at SureStart, however, was supporting a study which evaluated the impact of Healthy Start vouchers on diet in low-income pregnant women in Sheffield (Ford et al., 2008). I spent one day a week visiting and completing food frequency questionnaires (FFQs) with women recruited from ante-natal clinics. Surprisingly, this soon became one of the most enjoyable parts of my job and was not at all like the contrived research projects I had done at university. When I spotted a research assistant post at the School Food Trust, a non-departmental public body, based in Sheffield, I applied. I worked there for 6 years, contributing to cross-sectional studies which monitored the provision and consumption of school food across England and interventions which explored the impact of dining room modifications on children's nutritional intake and behaviour in school (Golley et al., 2010; Golley et al., 2011; Pearce et al., 2011; Pearce et al., 2013a; Pearce et al., 2013b; Pearce et al., 2013c; Storey et al., 2011). I found a lot of satisfaction in the research process.

When the organisation's government funding ended, I secured another research assistant post at UoN, followed by a lecturing role. Because I had never planned for a career in research and

teaching, I found myself in the position of being a lecturer without a PhD, and I began looking into options for completing my Doctorate. I could have opted for a traditional PhD but given the amount of research that I had already completed, my previous engagement in all the stages of research projects, management of research projects and the academic skills I had developed, I thought I could use this experience to complete a PhD by the published works route. A PhD should demonstrate that a candidate has autonomy, independence, interpersonal and group interaction skills, motivation, tenacity, time management and working to deadlines (Shaw and Green, 2002). Badley (2009) added analysis, creativity, discrimination, evaluation, research management and synthesis to the list. The major criteria of any PhD are appropriate methods, coherence, contribution of knowledge, critical appreciation, independence, and intellectual merit. Taken altogether they 'represent a formidable level of doctorateness' (Badley, 2009)

Not all the work I completed at UoN fitted into the theme, but the eight papers included here support the theme of 'Teachable moments in the promotion of health eating habits, during pregnancy and early childhood'. The theme represents my favourite research interests, which are complementary feeding and school food. The theme also covers maternal nutrition and weight-related issues experienced by pregnant women, which I became involved in thanks to the opportunity from and encouragement by my former colleagues at UoN. A timeline for the research is available (Figure 2, section 5.2).

1.2 The theme

Early-life nutrition plays a significant role in the future health of an individual. The first 1000 days, from conception until a child is 2 years of age, is seen as a critical window for both short- and long-term health outcomes (Barlow, 2019; Cusick and Georgieff, 2016; Linnér and Almgren, 2020; Mameli et al., 2016). Nutritional exposures during pregnancy and the early postnatal developmental window affect brain development, development of the immune system, metabolism, development of the microbiome and can directly affect adult non-communicable disease risk (Cusick and Georgieff, 2016; Langley-Evans, 2015; Mameli et al., 2016; Prescott, 2016). This 'window' is, therefore, a target for strategies aimed at improving health (Martinon-Torres et al., 2021). This thesis explores opportunities for health promotion during this critical window and during early childhood, where children's growing autonomy present further opportunities to influence health.

The antenatal period represents a unique opportunity for health promotion, as women are more susceptible to health messages and have an increased motivation to change their diet and health behaviours (Phelan, 2010). One of the aims of the published works which comprise this thesis was to explore these susceptibilities and how women may be targeted by health promotion techniques to improve both their health outcomes and those of their offspring. The included publications have shown that targeting weight management interventions at severely obese pregnant women can produce significant reductions in pregnancy-related hypertensive disorders (McGiveron et al., 2015). Women require unprejudiced, tailored advice about weight-related pregnancy behaviours (Swift et al., 2016) and women would like more discussion and engagement by health professionals on the issue of weight management during pregnancy (Swift et al., 2017). At the time of writing, these provided an original contribution to knowledge as women's feelings about diet, nutrition, and physical activity (PA) in pregnancy are often not addressed and a one-size-fits-all approach to diet and exercise advice during pregnancy, or a failure of health professionals to engage women on the topic is lacking. The lack of discussion arises possibly because there is a fear that women may be embarrassed or stigmatised by discussions around gestational weight gain (GWG) (Swift et al., 2017).

Appropriate complementary feeding, when an infant is 6-24 months, prevents malnutrition, including overweight and obesity (Michaelsen et al., 2017). Early eating habits are known to track into childhood, adolescence and adulthood and have a profound impact on long-term health outcomes (Birch and Fisher, 1998; Birch and Fisher, 2000; Fisher et al., 2000; Savage et al., 2007). Two systematic reviews included as part of this thesis look for an association

between the timing of the introduction of solid foods (complementary feeding) and types of food given to children during the complementary feeding period and childhood obesity (Pearce and Langley-Evans, 2013; Pearce, Taylor et al., 2013). Findings indicate that very early introduction of solid foods and high intakes of protein in infancy may contribute to overweight and obesity in children (Pearce and Langley-Evans, 2013; Pearce et al., 2013).

The way in which solid foods are introduced to a baby may also impact on nutritional intake and future health outcomes. Baby-led weaning describes an approach to weaning which hands some control of feeding over to the baby (Rapley, 2015). This thesis includes papers which explore the differences in nutritional intake between babies following baby-led and traditional weaning (Pearce and Langley-Evans, 2021), what baby-led weaning means to parents (Pearce and Rundle, n.d) and the extent to which parents adhere to characteristics of baby-led weaning (Pearce and Langley-Evans, 2021). Parents are increasingly using online forums such as Instagram®, Netmums® and Facebook® to obtain, share and comment on information regarding diet in their children. Parents are also turning to the internet to source information about GWG, dietary intake and PA during pregnancy as well as for information on complementary feeding (Swift et al., 2017). More recently, digital spaces have been used by health providers to educate and support behaviour change, particularly around exercise, diet and weight management (Fox and Duggan, 2012).

Finally, another publication has explored the factors which shape the parental decision for children to receive universal infant free school meals (UIFSM) at primary and infant schools (Goodchild et al., 2017). Children must make their own food choices, from what is on offer, when they start school. This represents a further teachable moment, where children should have an opportunity to eat healthy food alongside their peers. All children in years Reception- Y2 (ages 4-7) are eligible for UIFSM but take up of the offer remains at between 84 and 87% (Holford and Rabe, 2020; Sellen et al., 2018). The paper explored why parents chose not to allow their children take the meals and found that a need for control over their children's dietary intake was prevalent amongst those parents whose children did not take a meal.

The PhD by publication presents a selection of papers that demonstrate a range of research skills. The accompanying commentary will outline the philosophical position underpinning the portfolio of research presented, covering epistemological, ontological, and methodological issues.

1.3 Table 1. Papers put forward

Paper	Study design/Aim	Data reported	Contribution
Pearce J, Langley-Evans SC. (2013) The types of food introduced during complementary feeding and risk of childhood obesity: a systematic review. *International Journal of Obesity*, 37(4): 477-485	Systematic review exploring the association between the types of food provided during the complementary feeding period and risk of overweight or obesity in childhood (4-12 years).	Data from 10 studies were reported. There was no association between the type of food provided during complementary feeding and childhood obesity but higher energy intake during complementary feeding was associated with a higher childhood BMI and high protein intake at 2-12 months showed some association with higher BMI/body fatness in childhood.	90% JP conducted the review and wrote the draft paper. SCLE acted as second reviewer and commented on the draft paper.
Pearce J, Taylor M, Langley-Evans, SC. (2013) Timing of the introduction of complementary feeding and risk of childhood obesity: a systematic review. *International Journal of Obesity*, 37(10): 1295-1306	Systematic review exploring the association between the timing of the introduction of solid food to infants and risk of overweight or obesity in childhood (4-12 years).	Data from 21 studies were reported. There was no clear association between the timing of the introduction of solid food and risk of childhood obesity, but there was some evidence, from 5 studies, that very early introduction of solid food (at or before 4 months) may increase obesity risk.	90% JP conducted the review and wrote the draft paper. SCLE acted as second reviewer and both SCLE and MT commented on the draft paper.
McGiveron A, Foster S, **Pearce J,** Taylor MA, McMullen S, Langley-Evans SC. (2015) Limiting antenatal weight gain improves maternal health outcomes in severely obese pregnant women: findings of a pragmatic evaluation of a midwife-led intervention. *Journal Human Nutrition and Dietetics*, 28(Suppl. 1):29-37	Service evaluation of the Bumps and Beyond antenatal weight management intervention.	Mean weight gain in intervention compared to control group. Impact of the intervention on pregnancy and labour complications. Pregnancy complications by quartile of weight gain. Breastfeeding rates between control and intervention groups at discharge, n=188.	20% JP coded, entered, and cleaned data, assisted with analysis, wrote the methodology section and commented on the draft paper.

Swift JA, **Pearce** J, Jethwa PH, Taylor MA, Avery A, Ellis S, Langley-Evans, McMullen S. (2016) Antenatal Weight Management: Women's Experiences, Behaviours, and Expectations of Weighing in Early Pregnancy. *Journal of Pregnancy*, pp. 8454759-9	Baseline qualitative and quantitative data reported during the MAGIC cohort study. The aims were to describe the samples experiences, behaviours and expectations of antenatal weight management.	Sociodemographic, physiological, psychological and behavioural measures including age, ethnicity, occupation, height, weight, pre-pregnancy weight, weight monitoring behaviour, shape concern, awareness of guidance around healthy eating and physical activity, n=193.	20% JP recruited the study participants, coded, cleaned, entered and checked data, managed data collection at 32 weeks gestation and 2 weeks, 6 months and 12 months postpartum. Also assisted with data analysis, writing, and editing the draft paper.
Swift JA, Langley-Evans SC, **Pearce J**, Jethwa, P, Taylor MA, Avery A, Ellis S, McMullen S, Elliott-Sale KJ. (2017) Antenatal weight management: Diet, physical activity, and gestational weight gain in early pregnancy. *Midwifery* 49: 40-46	Baseline indicators of dietary behaviours and estimates of physical activity and gestational weight gain in the MAGIC study. Also, women's understanding of dietary and physical activity behaviour during early pregnancy.	Anthropometrics, dietary intake estimated using DINE and physical activity estimated using IPAQ, perceived changes in diet and physical activity and awareness of dietary and physical activity guidelines, n=193.	20% JP recruited most study participants, coded, cleaned, entered, and checked data, managed data collection at 32 weeks gestation and 2 weeks, 6 months and 12 months postpartum. Also assisted with data analysis, writing, and editing the draft paper.
Goodchild GA, Faulks J, Swift JA, Mhesuria J, Jethwa P, **Pearce, J**. (2017) Factors associated with universal infant free school meal take up and refusal in a multicultural urban community. *Journal of Human Nutrition and Dietetics* 30: 417-428	An investigation of the school-based factors, child and socio-demographic characteristics and parental beliefs associated with universal infant free school meal take up and refusal in Leicester, a multicultural urban community.	Ethnicity, social class, number of children and free school meal eligibility, decision-making around taking school meals and reasons for taking or not taking meals, n=676.	80% JP designed the study, recruited schools, coded and cleaned data, analysed the data and wrote the draft paper.

Pearce J, Langley-Evans SC. (2021) Comparison of food and nutrient intake in infants aged 6-12 months, following baby-led or traditional weaning: a cross-sectional study. *Journal Human Nutrition and Dietetics*; 1-15. https://doi.org/10.1111/jhn.12947	An exploration of food exposures and nutrient intakes between infants following baby-led and traditional weaning. Also, self-reported and interviewer-reported adherences to characteristics of baby-led weaning.	Maternal characteristics including age, years in education, ethnicity, social class. Infant characteristics including age, milk feeding history, feeding behaviour, choking, supplement use, use of puree foods and spoon feeding. Exposure of infants to food groups and infant nutrient intake estimated from interviewer administered 24-hour recalls.	95% JP designed study, recruited participants, collected, entered and analysed data and wrote the draft paper. SCLE commented on the draft paper.
Pearce J, Rundle R. (Submitted to Journal of Human Nutrition & Dietetics) Baby-led weaning: A thematic analysis of comments made by parents using online parenting forums.	This study aimed to explore the meaning of baby-led weaning to parents, using qualitative thematic analysis of posts made on UK parenting forums.	Key themes identified: 1)BLW used as an alternative approach; 2) Blurred boundaries; 3) Ethos and experience.	80% JP designed the study, collected and formatted data, analysed data and wrote the draft paper. RR analysed data and drafted the results section.

2.0 Literature Review

2.1 The antenatal period

2.1.1 Maternal overweight and obesity

The World Health Organization (WHO) uses body mass index (BMI), an individual's weight divided by their height squared, as an estimated measure of body fatness (WHO, 2021a). BMI does not measure body fat directly but is quick, inexpensive, simple to measure and correlates well with more direct measures of body fat, allowing BMI to be applied in clinical practice, research and in the development of guidelines (WHO, 2021a). Categories for non-pregnant populations are underweight (<18.5 kg/m^2), normal/recommended weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2), and obese (≥30 kg/m^2). Obesity can be further subdivided into class I (30–34.9 kg/m^2), class II (35–39.9 kg/m^2), class III obesity (≥40 kg/m^2) and extreme obesity (BMI ≥ 50 kg/m^2) (WHO, 2021a). The categories represent cut-offs above which an increased risk in diabetes and cardiovascular disease (CVD) outcomes are observed (WHO, 2021a). Excess body weight is associated with an increased risk of CVD, type 2 diabetes, some cancers, infertility, and psychological disorders such as depression and low self-esteem (WHO, 2021a). Obesity during pregnancy has been further associated with a range of adverse outcomes for both mother and infant, including an increased likelihood of childhood adiposity and obesity (Bider-Canfield et al., 2017; Restall et al., 2014; Slack et al., 2018a).

Worldwide, women are more likely to live with obesity than men, but rates and differences between genders vary by country, dependent on gender inequalities and socioeconomic factors (Wells et al., 2012). The worldwide prevalence of overweight in women is 40% whilst 15% are obese (WHO, 2016). These figures have tripled since 1990 with the greatest prevalence of obesity in women noted in the Pacific island nations (70-80% of adult women), the Caribbean (50-60%) and the Middle East (40-50%) (WHO, 2016). In England, figures for overweight and obesity in women were 31% and 29% respectively in 2019 (NHS Digital, 2019), with the highest rates observed in areas of high deprivation and amongst older women (NHS Digital, 2019). In 2019, 22% of women attending antenatal booking appointments in England were living with obesity (NHS, 2019a) and the trend towards a greater prevalence of women obese in the first trimester appears to be accelerating rather than slowing (Heslehurst et al., 2010). Women in the UK who are South Asian (OR: 2.9, 95% CI, 2.08-2.31) or Black (OR: 1.70, 95% CI, 1.62-1.78) are more likely to live with obesity than white women. The BMI at which the risk of CVD is increased could also be lower in South Asian populations (increased risk above

27.5kg/m2) which would further increase the number of women at risk of serious disease (Heslehurst et al., 2012). The causes of obesity are complex, but an environment of cheap, abundant, and ultra-processed food, aggressive marketing, reduced opportunities for exercise, psychology, and socioeconomic factors all contribute (Butland et al., 2007).

2.1.2 Gestational weight gain

Irrespective of pre-pregnancy weight, pregnancy is a risk factor for the development of obesity. Women gain weight during pregnancy and may fail to lose weight after their baby is born or continue to gain weight whilst they care for an infant (Harris et al., 1999; Linné et al., 2004). Studies exploring gestational weight gain (GWG) and postpartum weight retention 10 or 15 years after pregnancy found that 45.6% of normal weight women who experienced excessive GWG and 43.8% of women who had significant retained weight 12 months after delivery, had shifted from normal to overweight when followed up 15 years later (Linné et al., 2004). Women who returned to their normal weight after delivery gained 2.4kg over the next 10 years, compared to an average weight gain of 8.3kg amongst women who did not (Rooney and Schauberger, 2002).

Women may be classed as obese during pregnancy either because they were obese prior to pregnancy or because they gained weight excessively whilst they were pregnant, moving them into a higher BMI category (Slack et al., 2018a). There are no pregnancy-specific BMI criteria to define maternal obesity (Heslehurst et al., 2012) so maternal obesity is described as having a BMI $\geq$30.0kg/m^2 at the first antenatal consultation, usually prior to 12 weeks gestation (CMACE/RCOG, 2010). The first trimester may, however, represent a time point during which women struggle with their food choices and may gain weight, before first contact with maternity services. GWG is the amount of weight gained between conception and the birth of the infant and it supports the growth and development of the foetus (Slack et al., 2018a). GWG is made of maternal components (increase in blood and total body water, tissue in the breasts and uterus, fat mass), the placenta (placental weight and development) and foetal components (fat and fat-free mass) (Slack et al., 2018a). Whilst many countries provide pregnant women with optimal weight gain recommendations during pregnancy, the UK does not (Scott et al., 2014). Excessive GWG for research purposes is most often defined as exceeding the amount of weight recommended by the United States (US) Institute of Medicine (IoM), (Institute of Medicine, 2009). These are dependent on an individual woman's BMI at her initial antenatal visit; underweight (12.7-18.1kg), normal/recommended weight (11.3-15.9kg), overweight

(6.8-11.3kg), obese (all categories) (5.0-9.1kg) (Institute of Medicine, 2009) and are greater in women carrying twin pregnancies (Luke, 2005).

2.1.3 Determinants of gestational weight gain

Factors potentially affecting the total and overall pattern of gestational weight gain are numerous and interlinking (Figure 1). Studies from developed western countries have found that women living with overweight or obesity prior to pregnancy were more likely to gain excess weight when compared to normal weight women (Cheney et al., 2017; Restall et al., 2014), although in countries such as Japan, where the majority of women are normal weight or underweight, the underweight women had the highest gestational weight gain (mean 10.27kg) compared to women who were normal weight (10.11kg), overweight (7.98kg) or obese (5.50kg) (Enomoto et al., 2016). Few studies have differentiated between the classes of obesity, but a study from the US found that women who started pregnancy with class II or class III obesity gained less weight than those in class I (Lindberg et al., 2016). The authors suggest this could be due to successful adherence to weight management guidelines or the effectiveness of weight management services targeting women most at risk (Lindberg et al., 2016).

The WATCH cohort study, in Australia, followed 159 women through their pregnancy and found only maternal age predicted excessive GWG with older participants (34-41 years) less likely to gain excessive weight than those who were 18-24 years (Fealy et al., 2020). Bearing in mind this was a very small study, other demographic factors (pre-pregnancy BMI, parity, smoking status, marital status, or education) were not associated with GWG (Fealy et al., 2020). A much larger Swedish cohort study of 163,352 women found those with fewer years in education were more likely to start pregnancy with an unhealthy BMI and have a greater BMI increase between pregnancies, after adjustment for age at first birth (Holowko et al., 2015). Similarly, Cheney et al., (2017) found women from lower socioeconomic areas were more likely to gain excess weight during pregnancy (OR:1.89, 95% CI, 1.48-2.41).

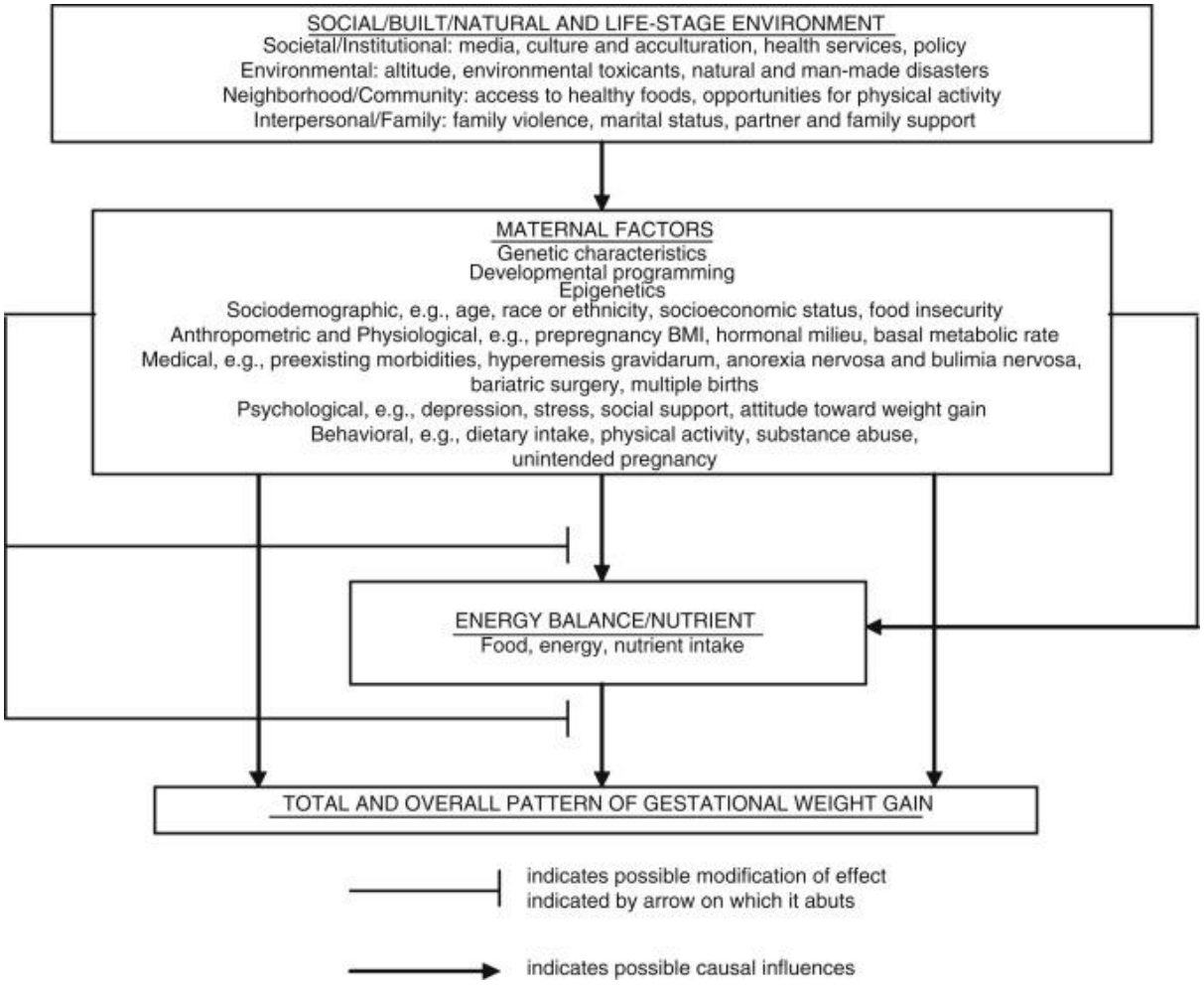

Figure 1: Reproduced with permission from the National Academy of Sciences. Schematic summary of factors influencing gestational weight gain. From Institute of Medicine. *Weight Gain During Pregnancy: Reexamining the Guidelines*. Washington DC: National Academic Press; 2009.

Women with fewer years in education were also more likely to experience a greater positive BMI change between pregnancies (Holowko et al., 2015). Fewer years in education and being in areas of higher deprivation are both predictors of BMI and socioeconomic status but could also be due to differing patterns in compliance to advice, social norms and access to PA and a healthy diet (Holowko et al., 2015). A wider European study found that lower socioeconomic status (fewer years in education and lower household income) and having more children were all associated with an increased risk of maternal obesity, while Caucasian ethnicity, having no previous children, a higher total energy intake (although nutrient intake data were missing for some participants), and smoking during pregnancy were associated with an increased risk of excessive gestational weight gain ($p < 0.05$) (Gaillard et al., 2013).

Other studies exploring differences between ethnic groups suggested these could be dependent on country, region or community. The US is very ethnically diverse but results here have varied. One small study identified African American women in North Carolina as being at greater risk of GWG (Nunnery et al., 2018) whilst other studies identified Black women in Wisconsin and South Carolina as being at greater risk of insufficient weight gain (OR:1.92, 95% CI, 1.49-2.47) and (OR:1.49, 95% CI, 1.41-1.58) respectively (Lindberg et al., 2016; Liu et al., 2014). Both Black and Hispanic women had significantly lower odds (16%-46%) of gaining weight above the IOM recommendations in South Carolina (Lindberg et al., 2016; Liu et al., 2014). Again, the authors highlighted regional differences, especially in the US, as an explanation for inconsistencies in weight gain patterns and birth outcomes between different communities (Lindberg et al., 2016).

A systematic review of 12 studies and a non-systematic review of 35 studies, both exploring psychosocial factors associated with GWG found body image dissatisfaction, restrained eating, depression and social support were associated with excessive GWG, whilst no association was found between anxiety, stress, self-efficacy, or self-esteem (Hartley et al., 2015). Both studies found heterogeneity in the data but higher self-efficacy for healthy eating and an internal locus of control for weight gain were protective (Kapadia et al., 2015). A review and meta-analysis of studies examining mental health in pregnant women found that compared to women who were of normal weight before or in early pregnancy, women living with obesity had elevated odds of both antenatal (OR: 1.43, 95% CI 1.27–1.61) and post-natal (OR: 1.30, 95% CI 1.20–1.42) depression and antenatal anxiety (OR: 1.41, 95% CI, 1.10-1.80), possibly due to concems over their weight, weight stigma or due to pregnancy exacerbating existing symptoms. It could also be the case that women with poorer mental health struggle more to control their weight (Molyneaux et al., 2014).

Eating patterns may deviate from a woman's normal diet during pregnancy, with women reporting increased or decreased appetite, cravings, nausea, and changes in the way that foods taste (Chortatos et al., 2013; Orloff et al., 2016). Women may also try to consciously change what they eat to adhere to guidelines or improve their diet for the health of their baby, although other demands such as financial, relationship and social issues may take priority (Phelan, 2010; Stockton and Nield, 2020). Altered eating patterns, due to these changes may impact on the quality and quantity of food consumed during pregnancy and consequently impact on weight gain.

2.1.4 Pregnancy and obstetric outcomes associated with maternal obesity and excessive gestational weight gain

Maternal obesity and excessive GWG pose a challenge for healthcare services. Health professionals must manage pregnancy outcomes to protect the mother and child whilst promoting public health recommendations for healthy diet and PA, to prevent excessive GWG (Slack et al., 2018a). The cost of antenatal care is greater in women who live with overweight or obesity. Repeat growth scans may be required as measuring with a tape measure is less accurate in women with a raised BMI (RCOG, 2021). Glucose tolerance or glucose fasting tests are also required and ultrasound scans are also harder to obtain from obese women (RCOG, 2021). During birth, women living with obesity are also more likely to require 1:1 midwifery support whilst after birth, longer hospital stays may be required, along with increased input from paediatric teams. This is due to lower infant APGAR scores (a quick measure of a baby's wellness after birth, used to detect potential morbidity: Activity, Pulse, Grimace, Appearance and Respiration) amongst women living with obesity (Heslehurst et al., 2008). Research in the UK is lacking, but studies in France revealed a 5.4-16.2-fold increase in prenatal care cost, compared to women with a normal BMI (18-24.9 kg/m^2) (Heslehurst et al., 2007).

In the UK, over a third (34%) of maternal deaths are amongst women with a BMI ≥30 kg/m^2 and a further 24% were amongst overweight women (Knight et al., 2019). The morbidity associated with maternal obesity, inadequate GWG or excessive GWG is also well established, and the subject of many systematic reviews (Beta et al., 2019; Feng et al., 2021; Gaudet et al., 2014; Hartley et al., 2015; Oteng-Ntim et al., 2018; Poobalan et al., 2009; Slack et al., 2018a; Slack et al., 2018b). An umbrella review of 22 systematic reviews was conducted in 2015, which aimed to summarise the risk to women and infants of maternal obesity (Marchi et al., 2015). Compared to women of normal weight at the start of pregnancy, women with obesity were at increased risk of gestational diabetes mellitus (GDM), pre-eclampsia, gestational hypertension, depression, instrumental and caesarean birth, and surgical site infection (Marchi et al., 2015). Labour and birth complications such as labour induction, longer labour and postpartum haemorrhage are also reported to be associated with maternal obesity (Ellis et al., 2019; Marchi et al., 2015). In the infant, pre-term birth, large for gestational age, congenital abnormalities, shoulder dystocia, foetal and neo-natal death and stillbirth were also more likely when their mother lived with obesity (Marchi et al., 2015). Children born to obese mothers are more likely to have a higher risk of obesity, diabetes and CVD (Poston, 2017).

GDM and pre-eclampsia are of particular importance as they affect so many women. In the review by Marchi et al., (2015), two systematic reviews identifying 76 case-control and cohort studies concluded that the risk of Gestational diabetes was higher amongst women living with obesity. In one review, the unadjusted ORs ranged from 3.05-4.21 for women with a BMI of 30-32.9 and were higher for women living with severe obesity (>33kg/m^2) (unadjusted Odds Ratios of 5.07-16.04) (Chu et al., 2007). Meta-analysis in the second review presented unadjusted ORs of 3.76, 3.01 and 5.55 for class I, II and III obesities respectively (Torloni et al., 2009). Marchi et al., (2015) further identified 5 studies published since the last systematic review which all provided similar results and since 2015, three further systematic reviews have concluded that obesity is a risk factor for GDM in sub-Saharan Africa (OR: 1.9, 95% CI, 1.1–3.3) (Mwanri et al., 2015), that both pre/early-pregnancy BMI and excessive GWG were risk factors for GDM in South Asian women (Slack et al., 2018b) and that central obesity (OR: 2.76, 95% CI, 2.35-3.26) was associated with GDM (Yao et al., 2020).

The review by Marchi et al., (2015) also included two systematic reviews exploring pre-eclampsia and hypertension, a total of 54 case-control and cohort studies from 20 countries. One review found women living with obesity were 3-10 times more likely to have pre-eclampsia whilst the second review found women were 4.5-8.7 times more likely to develop gestational hypertension than normal weight women. The second review found a clear relationship between increasing BMI and risk of pre-eclampsia, with risk ratios (RR) of 2.68 and 3.43 for BMIs of 30-34.9 and ≥35 respectively (Marchi et al., 2015; Salihu et al., 2012; Wang et al., 2013). The exact mechanisms for the increased risk amongst obese mothers are unclear but could be due to genetic predisposition, insulin resistance, immunology, chronic and systemic inflammation, and lifestyle factors such as an unhealthy diet or lack of PA (Lopez-Jaramillo et al., 2018; Marchi et al., 2015).

2.1.5 Guidelines for pregnancy (healthy eating, physical activity, weight gain)

Guidelines for weight management before, during and after pregnancy have been published by NICE, but these contain no recommendations or guidance for weight gain during pregnancy, due to a lack of evidence in UK populations (NICE, 2010). Instead, UK guidance focuses on supporting all women of childbearing age to eat healthily and engage in appropriate levels of PA. Women living with overweight or obesity are advised to lose weight prior to, or after, pregnancy (NICE, 2010). Women's height and weight are usually measured at the first antenatal appointment only, to calculate BMI. If a woman's BMI is ≥30kg/m^2, the risks associated with obesity during pregnancy are explained and a referral offered to a dietitian or

other health professional for personalised support (NICE, 2010). Weight loss during pregnancy is not recommended as this may deprive the foetus of nutrients essential for normal development and to prevent ketonemia which may affect foetal neurodevelopment (Brown and Avery, 2012; NICE, 2010). NICE has recommended that research is needed to investigate weight gain in pregnancy and health outcomes among UK ethnic minority groups before any recommendations could be made. Concerns have been raised about both the lack of guidance for GWG in the UK and the appropriateness of 30kg/m^2 as the cut off for the large South Asian population residing in the UK, which may contribute to widening health inequalities in access to health care (NICE, 2010; Slack et al., 2018b).

A healthy diet is required during pregnancy to support the development of the foetus and to prevent diet-related ill heath in the mother (NHS, 2020a). In the UK, current healthy eating guidance for pregnancy is the same as for the general population (≥2 years of age) (NHS, 2019b). Although requirements for some micronutrients are increased during pregnancy, there is no recommendation for additional macronutrients or calories to be consumed, except in the final trimester where an extra 200 kilocalories per day are required (NHS, 2019b; NHS, 2020a). To maximise micronutrient intake, without increasing the amount of energy consumed, it is recommended that women base meals on starchy foods (including wholegrain where possible), include protein, dairy or alternatives and eat plenty of fresh fruit and vegetables, whilst avoiding foods high in sugar and salt (NHS, 2019b; NHS, 2020a). Foods which carry a risk of food poisoning, are high in vitamin A or contain caffeine (no more than 200mg/day is recommended) should be avoided to avoid an increased risk of miscarriage or birth defects (NHS, 2020b). Current advice regarding supplements is for women to take a 400µg per day folic acid supplement for three months prior to pregnancy and until the end of the first trimester to reduce the risk of neural tube defects, along with 10µg per day of vitamin D throughout pregnancy. Women living with obesity are recommended to supplement the diet with 500µg of folic acid per day as neural tube defects are more likely in obese women (NHS, 2020b).

Globally, women tend not to meet dietary guidelines for pregnancy, and dietary quality is a contributing factor to pregnancy outcomes (Caut et al., 2020). There are no nationally representative dietary surveys of pregnant women in the UK, although some large cohorts have followed women from before or during pregnancy to explore pregnancy-induced dietary changes (Crozier et al., 2009; Rogers and Emmett, 1998). The most recent UK National Diet and Nutrition Survey (NDNS), presents a representative picture of women aged 19-64 years, which includes women of childbearing age but excludes pregnant and lactating women. In this

survey, women consumed less carbohydrate (46.6% of food energy) than recommended (≥50%) (PHE, 2020). Women consumed 35.7% of food energy as fat and 12.8% as saturated fat, slightly exceeding recommendations of 35% and 10% respectively (PHE, 2020). Intakes of free sugars (10.3% food energy) was more than double the amount recommended (≤5%) whilst intakes of fibre were low (18.1g/day, much lower than the recommended 30g/day) (PHE, 2020). Intakes of some micronutrients were also low, for example, 25% of women aged 19-64 years consumed below the lower reference nutrient intake (LRNI) of iron, whilst 12%, 9% and 7% consumed below the LRNI of iodine, calcium, and zinc respectively (PHE, 2020). Intakes of vitamin D were lower (5.5µg/day) than recommended (10µg/day) and only 20% of women took a supplement. Whilst average folate intakes from food sources (211µg/day) and total folates from food/supplements (293µg/day) were sufficient, 18% of women of childbearing age (aged 16 to 49 years) had a red blood cell (RBC) folate concentration of less than 305nmol/L. In the same period, 89% of women of childbearing age had an RBC folate concentration less than 748nmol/L (the level below which there is an increased risk of neural tube defects) (PHE, 2020). Doubly-labelled water showed that energy intake was underreported by 33% in adults and intakes in the NDNS are unadjusted, so it may be that intakes of some nutrients are actually higher than reported. Blood analysis has, however, shown a reduction in both serum folate concentration and 25-hydroxyvitamin D (25-OHD) nmol/L when compared to previous surveys (PHE, 2020). A number of studies have shown that whilst knowledge of advice to consume folic acid supplements prior to and during pregnancy is strong in the UK, less than a third of women actually do so (Bestwick et al., 2014).

Longitudinal studies of pregnant women in the UK have found low intakes of key nutrients, similar to the NDNS. The Avon Longitudinal Study of Parents and Children (ALSPAC) found average intakes of iron, magnesium, potassium, and folate were lower than the RNI, but overall, dietary intakes were similar to those recorded in the Dietary and Nutritional Survey of British Adults (DNSBA), precursor to the NDNS (Rogers and Emmett, 1998). Studies in London and Dublin have found low intakes of folate, iron, vitamin D, potassium, iodine and selenium, when compared to UK recommendations (Derbyshire et al., 2009). Studies exploring the effect of socioeconomic status have found that intakes of most key nutrients were low amongst women living in areas with high levels of deprivation (Haggarty et al., 2009) and that nutrient intake and dietary patterns during pregnancy were associated with maternal education, smoking habits and financial difficulties (Emmett et al., 2015).

A review of 11 studies exploring conscious changes made by women when they became pregnant, found few consistencies between studies (Hillier and Olander, 2017). In the UK, the Southampton women's study explored dietary quality in 12,000 women of child-bearing age. Women completed an initial food frequency questionnaire (FFQ) and if they became pregnant, were asked to complete additional FFQs in early and late pregnancy (Crozier et al., 2009). Amongst the 2057 participants, intakes of white bread, breakfast cereals, crisps, cakes and biscuits, processed meat, dried fruit, fruit and fruit juices, sweet spreads, confectionery, and hot chocolate drinks all increased during early pregnancy (all $P < 0.0001$) and further increases of breakfast cereals, cakes and biscuits, processed meat, non-citrus fruit, sweet spreads, and hot chocolate drinks were seen in late pregnancy (all $P < 0.0001$) (Crozier et al., 2009). Contrary to guidelines, consumption of green vegetables and vegetable dishes decreased in late pregnancy. Caffeine and liver (high in teratogenic forms of vitamin A) intakes decreased throughout pregnancy. Overall, there was a slight reduction in diet quality (Crozier et al., 2009). Women have reported trying to eat more healthily in pregnancy but pregnancy symptoms such as nausea and fatigue may prevent them from doing so (Stockton and Nield, 2020).

Knowledge of healthy eating guidelines and quantitative evidence of how women consciously change their diet during pregnancy are scarce, but the limited data available suggests that recommendations are not being met (de Jersey et al., 2013; Lee et al., 2016; Malek et al., 2016; Soltani et al., 2017). For example, an Australian study of 857 women showed that 61% of pregnant women believed their diet was healthy during pregnancy, but none of the participants met the recommendations for all 5 food groups. Those least likely to meet recommendations for fruit and vegetables had lower household incomes and were more likely to smoke or be overweight (Malek et al., 2016). A further study in Australia explored knowledge of the healthy eating guidelines (energy intake, recommended servings of core food groups, listeria, folic acid etc.) for pregnancy and found that women with higher levels of education (correlation coefficient $r=0.21$, $p<0.05$) and income ($r=0.21$, $p<0.05$) scored more highly, but few women (2%) scored over 80% overall (Lee et al., 2016). Soltani et al (2017) found pregnant adolescents were willing to adopt a healthy lifestyle but sometimes unnecessarily reduced or avoided food groups such as red meat (22.7%), eggs (40.6%) and oily fish (60.4%), because they thought they needed to or those foods posed a risk to their baby's health (Soltani et al., 2017).

PA has been demonstrated to reduce the risk of some cancers, CVD, obesity, weight gain and type 2 diabetes in the general population (Chief Medical Officers, 2019). Additionally, PA demonstrably reduces the risk of hypertensive disorders, excessive gestational weight gain,

gestational diabetes, preterm birth, caesarean section, and low birth weight in pregnant women (ACOG, 2015; Chief Medical Officers, 2019; García-Patterson et al., 2001; Magro-Malosso et al., 2017; Meher et al., 2006). Any amount of PA confers benefits, especially if an individual is normally sedentary, but to maximise benefits, adults (including pregnant women) should aim to engage in at least 150 minutes of moderate intensity or 75 minutes of vigorous intensity PA per week (or a mixture of both moderate and intense activity) and resistance training two or more times a week (Chief Medical Officers, 2019). Studies have indicated, however, that to achieve a reduction in risk of adverse pregnancy outcomes such as gestational diabetes, the amount of PA should be much higher with a minimum of 16 metabolic equivalent task (MET) hours per week and preferably 28 MET h/week (equal to walking at 3.2 km/h for 11.2 hours per week or cycling for 4.7 hours a week) would be required to reduce the risk of gestational diabetes in those most at risk (Zavorsky and Longo, 2011). If women were sedentary pre-pregnancy, they are not advised to exercise vigorously, whilst active women are advised to 'keep going' but reduce the intensity of activity if they need to (Chief Medical Officers, 2019). The level at which PA may harm the developing foetus is unclear and as women's physiology changes during pregnancy, pregnant women are advised to make sure they do not get too hot or dehydrated, that they consume sufficient calories and stop exercising if they experience pain, bleeding, headache, chest pain or dyspnoea before exertion (ACOG, 2015).

Evidence from the UK suggests that women may not meet guidelines for PA in pregnancy. One online study of 1001 women found that almost half reduced their exercise during pregnancy due to tiredness (62.7%), aches and pains (44.8%), morning sickness (41.4%) and worry about miscarriage (27.4%) (Atkinson et al., 2014). This is understandable but worrying in the context of the amount of PA required to improve pregnancy outcomes, particularly amongst women living with overweight or obesity. Misconceptions around miscarriage have appeared in several studies (Atkinson et al., 2014; Duncombe et al., 2009). A study in Australia which explored perceptions of PA and the amount of activity undertaken showed that women decreased the length of time spent doing PA and the intensity of the activity as pregnancy progressed. Most women believed that any high intensity activity was unsafe and 57% thought weight bearing activity was unsafe during pregnancy (Duncombe et al., 2009). Pregnant women are discouraged from heavy lifting in pregnancy which may make guidelines around weight bearing exercise difficult to interpret. The development of clear infographics and their impact on understanding of PA during pregnancy has yet to be assessed but it is possible these may help, if promoted properly by health professionals.

2.1.6 Interventions to prevent excessive gestational weight gain: Diet & PA

Excessive GWG (greater than 0.5-2kg) in the first trimester is predictive of excessive GWG throughout pregnancy (Institute of Medicine, 2009). Targeting women early in pregnancy could be the most effective strategy for preventing excessive GWG but is challenging as most women do not see a health professional until their first booking appointment (at up to 10 weeks of pregnancy in the UK) and few interventions are targeted at the first trimester. Data show the prevalence of overweight, and obesity continues to increase, demonstrating that national obesity prevention strategies are ineffective in women of childbearing age (Walker et al., 2018).

The literature evaluating the effectiveness of interventions designed to reduce GWG or prevent excessive GWG is large and presents a confusing picture, but overall, suggest interventions result in lower GWG. The impact this has on clinical outcomes is negligible, however, with pre-pregnancy BMI of potentially greater importance (Poston, 2017). Most interventions are also targeted at mid to late pregnancy, which may be too late to have a clinical impact, although physical activity exerts an independent effect on reducing adverse infant outcomes such as macrosomia and neonatal waist circumference (Pomeroy et al., 2013). There are many reviews exploring the effects of dietary interventions, PA, or a combination of both, on GWG. Although the results for individual studies vary considerably, most systematic reviews have found at least a small but significant weighted mean difference (WMD, the pooled average difference in weight gain, based on the size/weight of each trial) of somewhere between 0.3-4.96kg less GWG in intervention groups when compared to a control group (receiving standard care). There was considerable variation in the type, duration, content and delivery of interventions but reviews have failed to identify the specific factors which make interventions successful (Choi et al., 2013; Elliott-Sale et al., 2015; Fair and Soltani, 2021; Fealy et al., 2017; Gardner et al., 2011; Hill et al., 2013; Kominiarek et al., 2019; Muktabhant et al., 2015; Shieh et al., 2018; Spencer et al., 2015; Walker et al., 2018).

Before discussing the systematic reviews further, it is worth noting two of the largest and most comprehensive trials, conducted since Bumps and Beyond (our paper) (McGiveron et al., 2015). The UK Pregnancy Better Eating and Activity Trial (UPBEAT) and the Australian antenatal lifestyle advice for women who are overweight or obese (LIMIT) (Dodd et al., 2010; Poston et al., 2015). Both studies were well funded, designed and conducted and it was hoped they would provide some conclusive evidence. The UPBEAT RCT included over 1500 obese women and aimed to prevent GDM and large for gestational age (LGA), using sessions with health trainers to deliver the intervention. GDM and LGA were also primary outcome measures

of LIMIT, along with macrosomia, hypertension, and pre-eclampsia. In the LIMIT trial, research dietitians and research assistants delivered antenatal lifestyle advice on diet, exercise, and behavioural management. No differences in GDM or LGA were observed at the end of either RCT, although infants whose mothers received lifestyle advice as part of the LIMIT trial were less likely to have a birthweight exceeding 4000g (Dodd et al., 2010; Poston et al., 2015). Women in the UPBEAT intervention group engaged in more physical activity than women receiving standard care at 27-28 weeks (1836 versus 1386 MET (min/week) p=0.0015) and more than they had at 15-18 weeks (1386 MET (min/week)). The intervention group also had lower GWG (WMD = -0.55, 95% CI, -1.08 - -0.02) and maternal skinfold thickness -3.2mm, 95% CI (-5.6 - -0.8) p=0.0081 which was not observed in the LIMIT trial (Dodd et al., 2010; Poston et al., 2015). Interestingly, during the UPBEAT pilot study (n=183), at 35-36 weeks' gestation, moderate intensity activity and sedentary activity were inversely and positively associated with neonatal waist circumference (respectively), but this was not observed in the main trial (Hayes et al., 2014; Hayes et al., 2015).

A meta-review using data from overweight or obese women only, found a reduction of 0.3-2.4kg in women in intervention groups when compared to standard care (Fair and Soltani, 2021). Only dietary interventions were found to be successful (not PA or combined diet & PA), although data had high heterogeneity (Fair and Soltani, 2021). A systematic review published at the same time found no significant difference between groups, using data from women of all weight categories; WMD = −1.24 kg, 95% CI, −2.65, 0.18 (Beauchesne et al., 2021). Interestingly, in the review by Beauchesne et al (2021), the rate of GWG decreased in both the second and third trimester (WMD= −0.07 kg/week, 95% CI, −0.12 - −0.03), despite no significant weight change overall. This further demonstrates that early pregnancy could be key in managing GWG. A review of 89 RCTs including 23,000 women of any weight, found no optimal duration of dietary intervention, diet type, setting, frequency of contact with participants but there was a WMD of −3.27 kg (95% CI, −4.96 - −1.58), weighed at >24 weeks (9 studies) showing dietary interventions were successful at reducing GWG (Walker et al., 2018). A further review identified components of successful interventions included monthly contact and in-person sessions with a dietitian, although results were mixed and details of interventions were not explicit (Vincze et al., 2019).

Shieh et al., (2018) focussed on women living with overweight and obesity only, examining 21 studies of 6,920 participants. They found that dietary interventions focussed on healthy eating were most successful at preventing GWG with a WMD of -1.81kg (95% CI, -9.34- -2.21) in

the intervention group. Prescribed daily energy intake and macronutrient goals limited weight gain by 4.28kg and 4.23kg respectively (Shieh et al., 2018) but another systematic review found only energy intake (and not macronutrients) was associated with greater GWG (Tielemans et al., 2016).

The International Weight Management in Pregnancy (i-WIP) Collaborative Group (analysis on individual level data from 33 trials) found that diet was only effective in combination with PA (WMD -0.70 kg, 95% CI, -0.92- -0.48 compared to a non-significant -0.72, 95% CI, -1.48-0.04 for diet alone) after adjusting for baseline weight and clustering within interventions. No differences were observed according to pre-pregnancy BMI, age, parity, ethnicity or underlying medical conditions, or when poorer quality studies were excluded from the analysis (Khan, 2017) but contrasted with the findings of Walker and colleagues who found trials using a combination of diet and physical activity (19 studies, at >24 weeks) had a non-significant WMD of −0.92 (95% CI, −1.48 - −0.36) (Walker et al., 2018). The UPBEAT trial found a combined diet and PA intervention had a more pronounced effect on lowering GWG amongst women with Class III obesity, compared to classes I or II (Peacock et al., 2020). A review of PA only, found that exercise significantly reduced GWG compared to a usual care group (WMD=-2.22kg, 95% CI, -3.14—1.3). Only one of the five studies included women living with obesity and they were the least likely to have a lower GWG than the usual care group. Interventions had similar characteristics: duration 45–60 min, frequency 3–5 times per week and were of moderate intensity, in line with recommendations (Elliott-Sale et al., 2015). A further review explored the type of exercise undertaken, including supervised exercise (aerobic, strengthening and stretching guided exercises) which was the most common type of exercise assessed (45.9 % of studies); yoga (8.1 % of studies), walking, (8.1 % studies); static cycling sessions (10.9 % of studies), water exercise, (24.3 %) and dance activity (2.7% of studies), but only supervised exercise (SMD= 0.15, 95 % CI: 0.28, 0.02) and cycling sessions (SMD= 0.32, 95 % CI: 0.59, 0.05) had a protective effect on GWG although both meta-analyses showed high heterogeneity between the studies (Díaz-Burrueco et al., 2021). A review of women living with overweight, and obesity found no adverse effects of supervised exercise during pregnancy. GWG was lower in supervised exercise groups as compared to control (WMD = 0.88 kg, 95% CI, -1.73 - −0.03, P = .04) (Muhammad et al., 2021). Heterogeneity appears to be problematic due to large variations in timing (which trimester) and length of the intervention and the frequency and length of the sessions which women participated in. Supervised exercise appears to be most beneficial but may not be feasible for all pregnant women due to cost of attending

gyms or the cost of staff time if delivered by the intervention team (Elliott-Sale et al., 2015). New and more accessible methods of increasing physical activity, such as mobile phone apps and Facebook groups are cheap and could be made more widely available, but these have not proved to be effective in studies evaluated so far. One review found mixed results when looking for an association between time spent sedentary and GWG. Some studies showed an association, while others did not (Fazzi et al., 2017).

Meta-analyses of RCTs showed no reduction in Caesarean delivery, macrosomia, large for gestational age or birthweight, following interventions designed to prevent excessive GWG in the systematic review by Oteng-Ntim et al., (2012). Although GWG was significantly lower in the intervention groups (WMD= -2.21, 95% CI, -2.86- -1.57) and there was a reduction in GDM amongst overweight and obese women in the intervention groups (OR=0.80, 95% CI, 0.58-1.10). This result was not replicated amongst observational studies in the same systematic review, although results in individual studies varied greatly. The design of many included studies was weak, and the components of the interventions were poorly described in most studies (Oteng-Ntim et al., 2012). A further review focussed on physical activity also showed a beneficial effect of intervention of GWG but no effect on infant outcomes (Sui et al., 2011).

Group interventions were more effective in the review by Walker et al (2018), but not significantly so. A review focussing on the effectiveness of group interventions in 15 studies found little difference between women receiving group ante-natal care and those receiving traditional individual care (Kominiarek et al., 2019) and in a subset of five high quality studies, group care appeared to show an increase in the risk of excessive GWG to women receiving group sessions (RR: 1.15, 95% CI, 1.01-1.30) (Kominiarek et al., 2019). This is despite an assumption that women would be more motivated by the increased emotional and social support from others (Walker et al., 2018). Gardner et al., (2011) and more recently Hill et al., (2013) explored the theory behind interventions and the success of intervention components to determine which were more effective. Both noted that many published studies did not adequately describe the interventions they undertook which could explain why it is so challenging to pinpoint the successful attributes of interventions.

Some studies have reported on the behaviour change techniques used within their interventions. Of these, the most successful were those which provided information on the consequences of behaviour to the individual, rewards contingent on successful behaviour, self-monitoring of behaviour and the use of motivational interviewing (Hill et al., 2013). They also found that the

use of more techniques resulted in a trend towards better outcomes (Hill et al., 2013). Goal setting may also be key as part of health coaching interventions to improve healthy lifestyle behaviours, suggesting that interventions which incorporate behaviour change theory may be more successful (Brown et al., 2012). Opportunistic conversations can also set goals and implement change (Lawrence et al., 2020). Who delivers the intervention may also be of importance. Vincze et al., (2019) reported on whether interventions involved dietitians but did not mention midwives. Midwives are trusted sources of guidance and information, and women build a relationship with their midwife throughout pregnancy (Phelan, 2010; Soltani et al., 2017). Interventions delivered by midwives might be better received than those delivered by other health professionals as well as offering opportunistic interactions, rather than planned opportunities for behaviour change (Lawrence et al., 2020). Two studies found that interventions delivered by midwives and doctors or midwives alone were more successful then interventions delivered by other professionals, resulting in a significantly less GWG (10.6kg weight gain compared to 13.5kg (p=0.007) and 10.76 kg compared with 17.11 kg) respectively (Bogaerts et al., 2013; Yeo et al., 2017). Women appear not to take up referrals to weight management or disengage early after accepting a referral to a dietitian. Better communication between midwives and dietitians has been identified as one way to improve services (Super et al., 2019). Qualitative studies in the UK have found that women saw dietitians as experts but the referral process itself could be problematic (Atkinson et al., 2013; Heslehurst et al., 2017). Exploring why women did not take up the Maternal and Early Years Healthy Weight Service (MAEYS) in the West Midlands, UK, Atkinson et al. (2013) found that some women may be offended that they have been referred or do not fully understand what the referral was for.

2.1.7 Weight management advice during pregnancy

A study by Brown and Avery (2012) found that in line with guidelines, few women were provided with advice regarding GWG. Midwives may avoid raising weight status with women due to the complexity and time needed for discussion (Oteng-Ntim et al., 2018) and a belief their advice would not make any difference (Wilkinson et al., 2013). UK NICE recommendations for women with a BMI >25kg/m^2 were followed by health professionals and 84% of women were weighed during their pregnancy, with women living with overweight or obesity, weighed more regularly than normal weight or underweight women (Brown and Avery, 2012). Pregnant women appear to want advice on GWG, although in the US, where guidelines are available, few women had prior knowledge of them (Shulman and Kottke, 2016). A lack of advice, however, may lead to anxiety and women seeking information from other

sources (for example, the internet) (Brown and Avery, 2012; Heslehurst et al., 2017) and worryingly, making their own decisions about the amount of weight they should gain (Brown and Avery, 2012; Wiles, 1998). Control over GWG was considered important by many women, some of whom restricted their intake when they thought this would not harm their baby (Wiles, 1998). Other studies have reported that repeated weighing during pregnancy or a strong focus on weight and the risks of obesity would result in increased anxiety and stigma, especially amongst women who know they are overweight or obese and feel guilty about how this may affect their pregnancy (Campbell et al., 2011; Johnson et al., 2013). The risks associated with obesity were not understood by women in some studies, indicating a fine line between making risks clear and placing too much emphasis on weight (Johnson et al., 2013). Midwives may also normalise obesity reinforcing the misunderstanding that obesity during pregnancy does not pose a risk (McCann et al., 2018). Routine monitoring of women's weight without their consent and without sufficient explanation or feedback, may also be unacceptable and responses by pregnant women have been mixed (NICE, 2010). This fits with accepted thinking that personalised, tailored advice can improve the effectiveness of health interventions, but general advice on weight management, healthy eating and PA may not be adequate or have the desired effect. Midwives are a trusted source of information and advice for women, but they have high workloads, lack confidence around dietary advice and weight management and may experience a lack of clinical leadership around weight management (Johnson et al., 2013; McCann et al., 2018; Soltani et al., 2017). High rates of obesity among patients may contribute towards a normalisation of obesity amongst midwives, despite the associated risks to pregnant women and their offspring (McCann et al., 2018).

2.1.8 Teachable moments

'Teachable moments' are described as life events or life stages during which individuals have increased motivation to modify their health behaviours (McBride et al., 2003). First described by educators working with children in early years settings, teachable moments are opportunities to enhance knowledge and skills (Havighurst, 1953). The term teachable moment has since been used more widely to describe opportunities for both education and behaviour change in areas such as smoking cessation, cancer treatment and treatment of type 2 diabetes (Miller and Szymusiak, 2021). Teachable moments for the educator or health practitioner are also 'learnable moments' for the patient or pupil (Haug, 2014) but preparedness by both learner and teacher are necessary for a teachable moment to be successful (McBride et al., 2003). Teachable moments can be both spontaneous and planned. Pregnancy is a 'teachable moment',

where midwives and other health professionals have an opportunity to engage women with health promotion activity and where women may be more motivated and receptive to advice than at other life stages (ACOG, 2015; Phelan, 2010; Smith et al., 2018). To cause an adoption of healthier behaviours, an event must be significant enough to motivate via: 1) An increased perception of personal risk related to outcomes; 2) A strong, effective personal response; 3) A re-defining of an individual's self-concept or social role (McBride et al., 2003). Pregnancy elicits this response in some women, when they have an immediate personal experience with risk, may be fearful for the health and wellbeing of the foetus and are often forced to reconsider their personal and social role when they become a mother (Phelan, 2010). Women also welcome discussion around their own health, not just that of their baby (Lawrence et al., 2020).

In qualitative studies, some women have expressed a desire for more tailored support around diet, PA, and weight management during their pregnancy, although others view pregnancy as a 'break' from adhering to healthy behaviours (Rockliffe et al., 2021; Stockton and Nield, 2020). Studies which have used interventions to reduce GWG and improve diet during pregnancy, have achieved success, but are resource intensive and challenging to scale up (Lawrence et al., 2020). Targeting all women of childbearing age, with obesity prevention policy, has also achieved little success and the prevalence of women living with obesity has only increased (Butland et al., 2007). Women are, however, more likely than men to be the household food gatekeepers with the potential to influence attitudes towards food and food behaviours within the household, particularly of children (Bassett et al., 2008; Burton et al., 2017). Shorter breastfeeding duration and poor maternal eating behaviours, for example, are both associated with poorer response to hunger and satiety cues in children (Yelverton et al., 2021; Zarychta et al., 2019). Healthier eating habits established within pregnancy can also impact the long-term health of the foetus via foetal programming (Langley-Evans, 2015). To ensure the longer-term health of both mother and infant, the focus of dietary interventions should, therefore, aim to support the adoption and role-modelling of healthier eating behaviours, not just focus on preventing excessive GWG (Hanson et al., 2015; Savage et al., 2007).

2.2 The complementary feeding period

A second window of opportunity and a further teachable moment for improving nutrition in children, arises during the complementary feeding period, where parents must make decisions surrounding the timing, type, and style of solid food introduction.

Complementary feeding is the gradual transition from a milk-based diet to one composed of the same foods as the rest of the family (WHO, 2002). During this time, the proportion of milk (breast or formula milk) which makes up the diet is gradually reduced and then ended (WHO, 2002). In early infancy, breast or formula milk should be the only food offered to infants, but as the infant grows, milk alone is no longer sufficient to meet their nutritional requirements (WHO, 2002). The age at which the infant's gut and immune system are ready for solid foods, along with the capability of breastmilk to provide energy and nutrients sufficient to meet the infants' metabolic demand is subject to debate amongst researchers. So, in 2001, the World Health Organisation (WHO) considered the evidence of the risks of introducing solid food early (at 4-6 months), compared with later (from 6 months) (Kramer and Kakuma, 2002; WHO, 2002). The aim was to provide worldwide guidance on infant feeding to relieve the burden of diarrhoeal disease, measles, malaria, and lower respiratory infections, all of which are linked to inadequate nutrition or premature introduction of solid foods (WHO, 2002). Childhood obesity has also been associated with early introduction of solid food and should also be included in the preparation of recommendations (SACN, 2018).

The WHO recommends all infants are breastfed until at least two years of age, although feeding beyond two years is encouraged for the health of both the mother and child (WHO, 2002). Breastfeeding is safe, clean and provides antibodies which reduces the risk of sudden infant death syndrome, otitis media, non-specific gastroenteritis, severe lower respiratory tract infections, childhood leukaemia, and necrotizing enterocolitis (Ip et al., 2007). It may also be protective against obesity, although the results of systematic reviews have been mixed (Arenz et al., 2004; Lefebvre and John, 2014). Breastfeeding is important for the development of the infants' immune system and helps protect infants from infectious disease (Kramer and Kakuma, 2012). In the UK, a longer breastfeeding duration reduces hospital admissions and in developing countries, where infectious diseases and poor sanitation are common, significantly reduces the risk of infant morbidity and mortality (Payne and Quigley, 2017; Sankar et al., 2015). Maternal benefits of breastfeeding include better uterine recovery, delayed return of menstruation to protect iron stores and exert a contraceptive effect, as well as protecting against breast cancer and endometriosis (Ip et al., 2007). Breastfeeding rates are high in developing

countries where breastfeeding is socially normal and expected, and where formula milk is not so easily accessible or affordable, but rates are low in developed countries like the UK and USA (WHO, 2021b). Complementary feeding is assumed to occur from 6-24 months of age, although in countries with low breastfeeding rates, it may finish much earlier, with the cessation of breast/formula feeding (WHO, 2002). Little or no breastfeeding has been associated with the early introduction of solid food by parents (McAndrew et al., 2012). The timing of the introduction of solid foods (described as any food other than milk, water, vitamins, or medicine), should, therefore, encourage exclusive breastfeeding for as long as breastmilk is sufficient to meet the demands of the infant (DoH, 2003; Kramer and Kakuma, 2002; Kramer and Kakuma, 2012; WHO, 2002).

2.2.1 Timing of the introduction of solid food

The 2001 WHO review (published 2002), concluded that breast milk should provide normal, term infants with adequate nutrition for the first 6 months of life, after which complementary foods should be introduced in a way which is timely (when energy/nutrient needs exceed what can be provided by frequent breastfeeding), adequate (that foods are sufficiently nutritious to meet the needs of a growing child), safe (hygienically stored and prepared, fed with clean hands and utensils) and properly fed (recognising cues of hunger and satiety, appropriate meal frequency, encouraging use of fingers, a spoon or self-feeding, suitable for the child's age) (WHO, 2002). The WHO recommend that infants who receive formula milk should also be introduced to solid foods from 6 months of age, in a separate report (Dewey, 2005). The WHO reports were aimed to provide countries with information and actions which they should implement immediately (WHO, 2002; Dewey, 2005).

Following the WHO report, the UK Department of Health updated their guidelines, recommending the age of initiation of solid foods change from 4-6 months to around 6 months (DoH, 2003). This has remained the case, with the last review of the evidence published by the Scientific Advisory Committee on Nutrition in 2018 (SACN, 2018). The WHO recommend finger foods by the age of 8 months, but the UK guidelines suggest introducing finger foods, alongside purees 'as soon as they are ready', although the focus is starting with pureed foods, before moving onto lumpier textures and then family foods by 12 months of age (NHS, 2019c; WHO, 2002). Despite the UK adopting WHO guidelines, many European countries and the USA have continued to recommend that solid food be introduced at 4-6 months depending on the availability of safe complementary foods and the achievement of developmental milestones (Eidelman and Schanler, 2012; Gartner et al., 2005). Most countries stipulate that the

introduction of solid foods should not be before the age of 17 weeks, as before this, babies may not have adequate psychomotor, gastrointestinal, or renal development for solid food ingestion (Agostoni et al., 2008; Eidelman and Schanler, 2012; SACN, 2018).

The UK's adoption of these guidelines has been questioned (Fewtrell et al., 2011). Infants may vary slightly in terms of their nutritional needs, degree of psychomotor, gastrointestinal, and renal development (Martinon-Torres et al., 2021). Researchers have raised concerns that later introduction of solid foods may increase the risk of zinc deficiency, iron deficiency, childhood obesity, coeliac disease, and other food allergies (Daniels et al., 2018b; Ferraro et al., 2019; Fewtrell et al., 2011).

Zinc deficiency may lead to poor motor and cognitive development, poor growth and reduced activity levels in children and is prevalent in many developed countries (Bailey et al., 2015; Black, 1998). Breastmilk is low in zinc (typically 0.3mg/100g) and may be lower where maternal zinc status is poor, but despite this, the prevalence of zinc deficiency at 6 months of age is lower than in older children (Finglas et al., 2015; Lennox et al., 2011). Lower reserves of zinc at birth, however, coupled with a lower concentration in breast milk, may predispose infants to zinc deficiency (Dumrongwongsiri et al., 2015; King, 2000). A recent systematic review showed that zinc supplementation of infants aged 6-23 months, but not of mothers during pregnancy or lactation, had a significant effect on child weight for age z-score and weight for height z-score but not on height for age z score or risk of stunting, wasting or underweight (Petry et al., 2016). Exclusive breastfeeding for 4-6 months, rather than ≤4 months resulted in a higher mean plasma zinc concentration (Eneroth et al., 2009).

Infants are born dependent on their reserves of iron, which may run low by 6 months (Fewtrell et al., 2011), leading to microcytic anaemia, impaired immune and endocrine function and in later life, a decreased capacity for work (Bailey et al., 2015; Lozoff and Georgieff, 2006). Iron is also required for optimal growth and cognitive functioning (Bailey et al., 2015; Lozoff and Georgieff, 2006). Breastmilk is very low in iron (haem iron; 0.07mg/100g, bioavailability estimated at around 12-25%) so little is consumed via the diet prior to the introduction of complementary feeding (Dewey, 2002; Finglas et al., 2015). Formula milk contains much more iron, but this is non-haem which is less bio-available (<5%), particularly during complementary feeding where food components such as phytates may reduce absorption. Infants fully breastfed for longer than six months have demonstrated an increased risk of iron deficiency at both 6 and 12 months, when compared to those fed for 3-5 months (Chantry et al., 2007; Hong et al., 2017;

Wang et al., 2016). Furthermore, infants first fed solids at 4 rather than 6 months had higher haemoglobin levels in developing countries and higher serum ferritin levels in both developing and developed countries (Qasem et al., 2015). Fewtrell et al., (2011) suggested exclusive breastfeeding to 6 months may lead to an increased prevalence of iron deficiency which is of greater concern in developed countries than morbidity and mortality due to unhealthy poor hygiene, poor access to healthcare services and infection (Fewtrell et al., 2011). Most term babies with healthy mothers are at low risk of iron deficiency, but low birth weight infants or infants of mothers with prenatal iron deficiency, who smoke, who are obese or who suffer from gestational hypertension, may be at greater risk of iron deficiency (SACN, 2018). Pregnant women are screened for anaemia in the UK (NHS, 2020c) and iron drops are suggested where babies are at risk or iron deficiency is detected but babies are not routinely screened for iron deficiency (NICE, 2021; SACN, 2018).

Despite concerns over iron, iron deficiency is not seen as a reason for giving complementary foods earlier than suggested (Dewey, 2002; SACN, 2018) but could be a reason for health professionals to be concerned when babies are not eating enough iron-rich foods from 6 months of age (Cameron et al., 2012; D'Andrea et al., 2016). Evidence from the National Diet and Nutrition Survey of infants and young children (DNSIYC~~NDNSIYC~~) aged 4-18 months found intakes of iron were below the lower reference nutrient intake (LRNI) in 14% of 7-9 month olds and 10% of 10-11 month olds (Lennox et al., 2011). Iron remains a key concern for governments when determining the timing of the introduction of solid foods. The change in UK guidelines has resulted in a welcome shift away from very early introduction of solid food, with a reduction in the number of babies introduced to solids before four months (51% to 30% between 2005 and 2010), although 75% had received solids by 5 months in 2010 (McAndrew et al., 2012; SACN, 2018). No more recent national surveys are available. SACN highlight that a diverse complementary diet is required, from age 6 months, to meet the increasing iron requirements of the infant (SACN, 2018).

A further concern around the timing of the introduction of solid foods is a possible association with childhood obesity. Rates of childhood obesity continue to increase in all countries, globally, despite preventative public health measures (UNICEF/WHO/The World Bank Group, 2020). As the complementary feeding period has been linked to the development of eating habits and rapid growth during infancy it can be associated with later obesity (Monteiro and Victora, 2005; Ong and Loos, 2006). Animal models have shown that early weaning does not affect growth in the absence of in utero growth restriction but does affect satiety-responsiveness

which may lead to obesity in the long-term (Oliveira et al., 2011). This does not mean however, that the timing of the introduction of solid foods may be related to obesity in humans.

There have been numerous studies and reviews which examine the impact of the timing of introduction of solid foods on growth parameters in different groups (including/not including middle-income countries and studying children at various age ranges) (SACN, 2018). A systematic review conducted in 2010 included data from 34,000 participants from 24 studies and found no association between the age of initiation of solid food and obesity in infancy, childhood, or adolescence in developed countries (Moorcroft et al., 2011). Since the publication of our review (Pearce et al., 2013), a further systematic review carried out in 2015 looking just at pre-term infants identified three randomised-controlled trials (RCTs) and two cohort studies but also found no clear association between the age at introduction of solids and overweight at 12 months of age (Vissers et al., 2018). The SACN report (2018) also identified several more recent studies. A study of 3462 infants in Scotland showed that solid food introduction at 4-5 months compared to 0-3 months was associated with a lower risk of obesity at age 4 years (OR 0.74; 95% CI 0.57-0.97) whilst a study on children born in Rotterdam and a prospective cohort including children born in Cincinnati, Mexico city and Shanghai found age at solid food introduction was not associated with skinfold thickness at 6-12 months or weight and length at 1 year respectively (Abraham et al., 2012; Van Rossem et al., 2013). Finally, a research study carried out in Cambridge, UK, explored age at introduction of solid food and growth parameters at 0-24 months in a birth cohort of 571 infants (Vail et al., 2015). They also included a systematic review of the literature for comparison, identifying all studies available in similar populations (Vail et al., 2015). They found that an earlier age at weaning (between 3 and 6 months) did not promote later infant growth or weight gain but on examining causality, determined that infants who were heavier pre-weaning or who grew faster, were introduced to solid foods earlier (Vail et al., 2015). Reverse causality was also identified by the Rotterdam study and a further study examining formula fed children across Europe (n=671) who found children introduced to solid foods ≤3 months were lighter at birth and grew more rapidly between 3 and 6 months (Van Rossem et al., 2013). One study suggested that obesity was more likely in formula fed infants where complementary feeding adds additional energy to the diet, rather than displacing energy obtained from formula milk (Grote et al., 2011). Babies being larger was cited as a reason for cessation of breastfeeding and switching to formula or introducing complementary foods earlier in UK surveys (McAndrew et al., 2012),

also larger babies are more likely to have been given solids earlier or may have a genetically pre-determined larger appetite (McAndrew et al., 2012; SACN, 2018; Vail et al., 2015).

Fewer studies have explored the late introduction of solid foods as families are most likely to wean early (McAndrew et al., 2012) but a large Europe-wide study (10,808 children aged 2-9 years), found later (≥7 months) introduction of solid food was associated with increased prevalence of overweight and obesity in babies who were exclusively breastfed (OR, 95% CI: 1.38;1.01-1.88) but not amongst children introduced to solids at 6 months who continued to be breastfed for at least 12 months, adjusting for birthweight (Papoutsou et al., 2018). Early solid food introduction (<4 months) was not associated with overweight/obesity in the same study (OR, 95% CI: 0.80, 0.66-0.96) (Papoutsou et al., 2018).

2.2.2 Type of food introduced during the complementary feeding period

The type of food introduced during the complementary feeding period may also impact on risk of childhood obesity (SACN, 2018). This type of research is challenging as the intake of food is heavily confounded by the intake of milk and the type of milk being fed, as well as demographic factors such as birthweight, parental BMI and potentially the timing of the introduction of solid food (Figure 2) (Grote et al., 2018; Pearce et al., 2013).

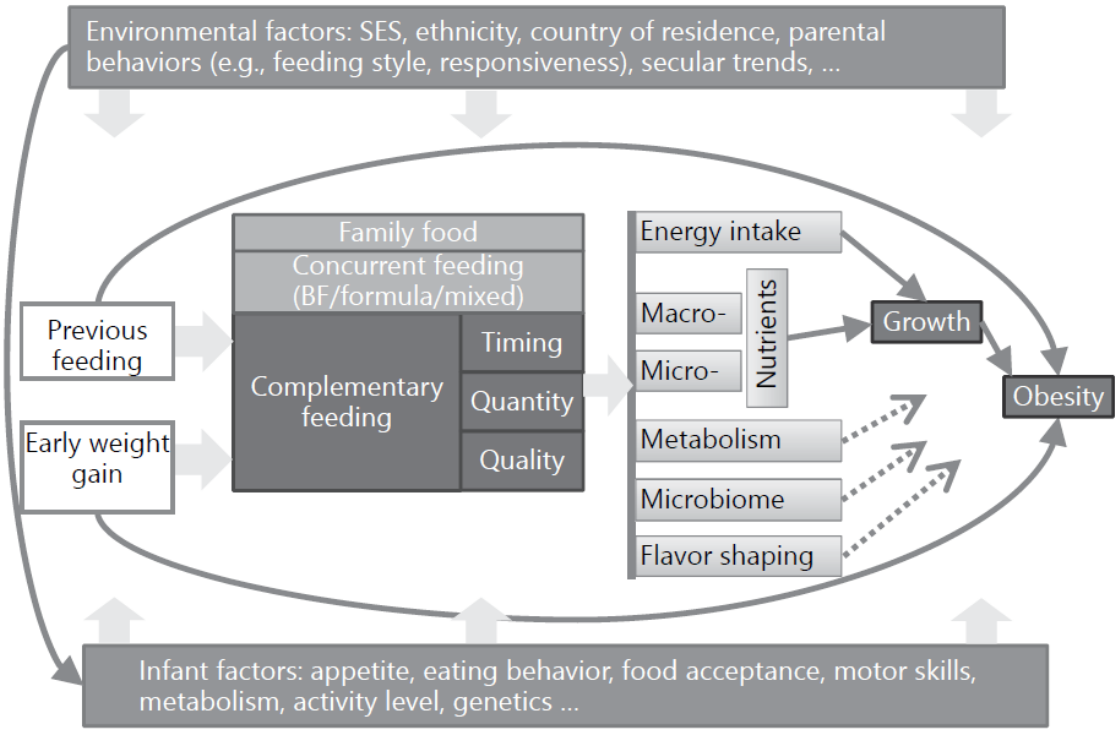

Figure 2. Adapted from Grote et al., (2018). Infant feeding variables affecting the development of childhood obesity. Copyright © 2018 Karger Publishers, Basel, Switzerland.

Breastfeeding may be protective against childhood obesity and formula fed babies have greater length and weight at 12 months than infants who were exclusively breastfed then breastfed alongside solids until 12 months (Grote et al., 2011). This could be because it is easier to breastfeed responsively and so avoiding over-feeding in breastfed babies (Brown and Lee, 2012). Or it could be because a slightly higher protein content of formula milk results in greater weight gain during infancy (Koletzko et al., 2009).

The UK recommends introducing a range of foods to infants during weaning, exposing them early to a variety of tastes and textures. Guidelines suggest introducing vegetables and fruits, then sources of protein, starchy foods, and full fat dairy (NHS, 2019b). The quality and quantity of complementary foods offered varies between parents, but the complementary feeding period universally represents a decrease in the percentage of energy from fat, while total daily protein and carbohydrate intake are increased (Grote et al., 2011; Rolland-Cachera et al., 2016). Increased energy intake in formula fed (but not breast fed) infants has been shown to increase obesity risk (Ong et al., 2006). Protein is the macronutrient most likely associated with increased weight gain in infancy and subsequent obesity risk. Those with higher intakes of animal protein or in the highest quartile of protein intake carry the greatest risk of obesity (Gunnarsdottir and Thorsdottir, 2003; Gunther et al., 2007).

The use of commercial infant foods is widespread in many countries (Theurich et al., 2020). Commercial infant foods have contained higher proportions of sugar and carbohydrate in some studies, although carbohydrate has not been implicated in subsequent risk of childhood obesity (Grote et al., 2018; Theurich et al., 2020). A study of commercially available infant foods in the UK showed that in the majority, the energy and nutrient content was very like breastmilk and would not provide the greater energy density required of complementary foods (García et al., 2013). Commercial foods offer a solution for parents who are confused about what to feed their babies as they progress on to solid foods (Brown, 2017), but the appeal of commercial foods may also differ depending on income or culture (Cook et al., 2021). The impact of these foods on growth remains unknown, although an RCT exploring the use of commercial infant food pouches was underway in New Zealand at the time of writing (Taylor et al., 2021).

The method of weaning (traditional or baby-led) may also be associated with childhood obesity, although long term studies are lacking (Grote et al., 2018).

2.2.3. Baby-led weaning

The term 'baby-led weaning' (BLW) appeared in around 2001 but was promoted more widely by a book published as a guide for parents in 2008 (Rapley, 2003; Rapley, 2005; Rapley and Murkett, 2008). BLW differs from traditional weaning (TW) in several ways (Table 2). Some of the principles of BLW may have been followed by parents for generations, but BLW as a 'method' became possible following the change in complementary feeding guidelines (from 4 to 6 months) (Brown et al., 2017). At 6 months of age, most healthy, full-term infants can sit up unaided, reach out for food, bring it to their mouth, chew and swallow whilst a 4-month-old baby would not be able to do this (Brown et al., 2017; Naylor and Morrow, 2001; Rapley, 2011; Wright et al., 2011). Describing BLW as an 'alternative' to TW, offered parents something novel and an opportunity to deviate from convention (Brown et al., 2017).

Given the current world-wide following of BLW and the number of websites, books, forums, and opinions available to parents, it is surprising how little original research has been done (Arden and Abbott, 2015; Arias-Ramos et al., 2021). There are no nationally representative studies estimating the prevalence of BLW, but the DNSIYC~~National Diet and Nutrition Survey of Infants and Young Children (DNSIYC)~~ reported over 70% of infants who consumed solid food at 4-6 months usually ate smooth puree, whilst 90% of babies aged 7-9 months chewed or sucked some finger foods (Lennox et al., 2011). Another study found that 56% of babies could reach for food before age 6 months and 40% first ate finger foods before 6 months (Wright et al., 2011). Despite the lack of a large evidence base or longitudinal studies lasting more than 1-2 years, it is widely accepted that BLW has several health benefits for the offspring, including satiety responsiveness, greater acceptance of a range of foods, less pickiness, increased dietary diversity, prevention of obesity, improved mealtime behaviour, increased dexterity and promoting speech and language development (Brown et al., 2017; Rapley, 2015). Importantly, it is suggested that BLW allows the baby to decide what and how much they eat which removes parental control and allows the baby to regulate intake which could improve satiety responsiveness and promote a healthier long-term relationship with food (Birch and Fisher, 1998; Birch and Fisher, 2000; Brown and Lee, 2011a; Brown, 2017; Rapley, 2015; Savage et al., 2007). Infancy and early childhood are key in the development of children's eating habits (Birch and Fisher, 1998). Evidence suggests that the eating habits which are formed in early childhood track through later childhood and into adulthood (Nicklaus, 2011). Whether parents follow TW or BLW, the complementary feeding period is an opportunity for parents to model behaviour and provides opportunity for children to learn

about food (taste, colour, texture) and eating (how, what, when and how much to eat) (Rapley, 2015). BLW may also promote introducing solids from around 6 months, as few babies have the required coordination long before this age.

2.2.4. Characteristics of baby-led weaning

BLW does not conflict with UK guidelines, but should be 'baby-led', where some control of the feeding process is handed to the baby from the outset (Table 2) (Rapley, 2003).

The definition of BLW for use in research varies by publication (Brown et al., 2017; Rapley, 2015). According to Rapley (2015), BLW is an overall approach to the introduction of solid foods, rather than a simple method. BLW consists of several practical elements underpinned by a central ethos of respect for the baby and that the baby should lead the process (Rapley, 2015). Parents should 'trust the baby's instincts' (Rapley, 2015). This makes measuring whether parents follow BLW challenging, although some key aspects (Table 2) can be measured to report adherence to the principles (Schramm, 2013). Previous studies have used different methodologies to identify BLW (Table 3).

Some studies have included more than one weaning group, for example, 'baby led, partial baby-led and traditional weaning' or 'strict BLW/predominant BLW/predominant TW/Strict TW' (Komninou et al., 2019; Morison et al., 2016; Rowan et al., 2019a; Watson et al., 2020). All definitions are subjective, however, and it is difficult for parents to estimate in terms of the percentage of food given in puree form. Participants may report following BLW whilst also using spoon feeding and purees to some extent (Morison et al., 2016; Swanepoel et al., 2020). These methods are also reductive and may fail to determine if all the underlying principles of BLW (Table 3) are being followed (Rapley, 2011). Evidence suggests adherence to all the characteristics may be low. Morison et al., (2016) found that amongst infants following full BLW, only 67% of infants in their study (n=51) were all or mostly self-fed, whilst only 72% were given mostly finger foods when solids were first introduced. Few studies have explored multiple measures of BLW within the same individual for comparison, as self-definition may not always be accurate. Swanepoel et al., (2020), found that many mothers following TW self defined as BLW, for example, one parent following BLW said '…he just got what we ate, but blended' which would not be considered BLW using other researchers' methodologies.

Table 2: Similarities/differences between BLW and TW

TW	BLW	Measurement
Adult decides when to initiate solid foods	Baby-decides when solids are initiated by reaching for food	Adult-led or Baby-led
Adult feeds baby using a spoon, although finger foods are encouraged alongside spoon-feeding	The baby chooses food from a selection provided by the adult, self-feeds whole foods, picks up pre-loaded spoons or uses dippers*	Percentage foods spoon-fed/self-fed
Adult decides how much to feed the infant or continues feeding until the infant turns their head away	The infant decides how much to eat	Following responsive feeding cues
Foods are initially offered in pureed form, moving on to lumpier textures, then mashed foods, then the family diet	Foods are in their whole form, but may be cut into smaller pieces which allows the infant to pick them up more easily	Percentage pureed food
Families are encouraged to eat together at the same time	Families are encouraged to eat together at the same time	Percentage meals eaten together
Infant should move towards a diet the same as the rest of the family at 12 months	Food should be the same as the rest of the family from the outset	Percentage foods which are the same (between adult and baby)
Breast or formula milk should continue to be fed on demand.	Breast or formula milk should continue to be fed on demand.	Whether fed on demand or on a schedule.

* Dippers are firm foods used to eat runnier foods, for example, toast fingers with hummus.

Table 3: Methods of determining whether parents are following baby led (BLW) or traditional (TW) weaning

Method/question	Study
'Do you follow baby-led weaning or traditional spoon feeding? Yes/no' (essentially self-defined BLW)	(Cameron et al., 2012; Morison et al., 2016; Townsend and Pitchford, 2012)
To estimate the percentage of foods given to their baby via spoon feeding or in pureed form (0%, 10%, 25%, 50%, 75%, 90% or 100%). Parents who spoon-fed their infants 10% of the time or less are reported as following BLW in some studies. In some studies, parents have to use both spoon feeding and purees less than 10% of the time to be classified as BLW. Other studies use three groups (strict adherence to BLW, loose adherence to BLW and TW)	(Alpers et al., 2019; Brown et al., 2011; Brown and Lee, 2011b; Brown and Lee, 2013; Brown and Lee, 2015; Brown, 2016; Komninou et al., 2019; Morison et al., 2016; Rowan et al., 2021; Watson et al., 2020)
To select the frequency of using spoon-feeding using a five-point scale. Participants were grouped as "predominantly self-fed" if they answered self-feeding always or often, and "predominantly spoon-fed" if they reported self-feeding sometimes, rarely or never	(Jones et al., 2020)
If babies are self-fed (self-fed >50% of the time) or parent led (self-fed <50% of the time)	(Cameron et al., 2013)
To answer yes/no to an author-derived statement which describes BLW; "*baby and letting them feed themselves – picking the food up themselves and putting it in their mouths unassisted, rather than being spoon-fed by a parent. This could involve them using a spoon themselves. BLW tends to involve offering the baby family foods rather than offering pureed foods" – Do you follow a baby-led weaning approach*?" followed by a 7-point Likert scale from 'Always' to 'Never' in relation to whether the baby is 'spoon fed by an adult' and 'receiving purees'. Parents who answered 'Never or Rarely' were classed as strict BLW.	(Rowan et al., 2019) Statement also used by Rowan et al, 2021.
To answer an author-derived statement; 'what approach to infant feeding you were using around the time you completed the food diary: 'Spoon-feeding' or 'Baby-Led Weaning' or 'Other''	(Morison et al., 2016).

2.2.5. Similarity to the family diet

There is some evidence that babies following BLW are more likely than TW babies to eat a diet similar to, but not the same as, the family diet. The DNSIYC found that children aged 4-12 months, receiving complementary food, 'almost always' (28%) or sometimes (31%) had the same food as their parents but did not differentiate between BLW or TW (Lennox et al., 2011). A small study (n=10) by Rowan & Harris (2012) used food diaries to assess the similarity between parental and infant diets of those following BLW and found 57% of foods (on average) were the same at each meal occasion, significantly greater than the DNSIYC. Most additional foods were fruit and vegetables provided as snacks and it is worth noting that some foods eaten by the parent were eaten at different times of day by the baby and were not counted in the similarity (Rowan and Harris, 2012). Brown & Lee (2011) and Komninou, Halford et al. (2019) conducted larger studies of 702 and 565 parents respectively (655 and 557 of whom were the child's mother), both of which were online surveys using self-reported parental responses. Brown & Lee (2011) found that spoon-fed infants were less likely to participate in family mealtimes (Spearman's rho= -0.424, P<0.001) and were less likely to be fed the same foods as the rest of the family (Spearman's rho= -0.550, P,0.001) (Brown and Lee, 2011) whilst Komninou, Halford et al. (2019) found parents following strict BLW were more likely to share mealtimes than parents following predominantly BLW (p=0.006), predominantly TW (p=0.001) or strict TW (p<0.001) (Komninou et al., 2019). Komninou, Halford et al. (2019) also found parents following strict BLW were significantly more likely to eat the same meals as their children, than parents following predominant BLW (p=0.024), predominant TW (p=0.003) or strict TW (p<0.001), whilst Brown & Lee (2011) found that mothers who spoon-fed were more likely to follow a schedule of introducing foods, rather than feeding family foods, another key principle of BLW (Spearman's rho= 0.427, P,0.001). A study in Brazil also found 71.5% of infants were sharing family food in the BLW group, compared to 11.5% in the TW group (Rapley et al., 2020). The BLISS trial found intervention infants were more likely to eat meals with their family and to consume the same foods as the family at all meals at 7 months. In the BLISS trial, the intervention group were more likely to consume the same ingredients as the rest of the family (27% to 42% of foods compared to 9% to 22%) and to eat meals with their family at 7 months of age (79% to 88% of meals compared to 61% to 75%), compared to the control group. Intervention infants were still twice as likely to be eating the same foods as their family at lunch and evening meals (50% to 69% of foods compared to 22% to 55%) at 12 months, but differences had disappeared by 24 months. Families were encouraged to do this, as part of the intervention protocol (Williams Erickson et al., 2018). A smaller cross-

sectional New Zealand study, however, also found that BLW infants were significantly more likely to consume ingredients the same as the family meal at lunchtime (OR: 10.56, 95% CI: 2.51-44.39) and in the evening (OR: 9.00, 95% CI: 2.64-30.62) (Morison et al., 2016). Amongst BLW infants, meals were also prepared in the same way as the family meal at lunchtime and in the evening, but not at breakfast time (Morison et al., 2016).

2.2.6. Comparing nutritional intake and food group consumption between babies following traditional or baby-led weaning

Health professionals have raised concerns that self-feeding may reduce the amount of food that babies are able to consume (Cameron et al., 2012; D'Andrea et al., 2016). This may result in reduced intakes of energy and key minerals such as iron and zinc from food, leading to growth faltering or deficiency (Cameron et al., 2012; D'Andrea et al., 2016). Concerns have also been raised that following the family diet and eating 'family foods' from an early age may result in levels of sugar and salt exceeding guidelines for infants and the provision of food which may pose a risk of choking (Brown et al., 2017). Despite this, few studies have explored differences in either nutritional intake or food group consumption between babies following BLW or TW, and more research is needed in this area. At the time of writing our paper, eleven papers reporting results from seven separate studies have explored food group or nutrient intake at the time of writing and further study was published just after ours (Alpers et al., 2019; Daniels et al., 2018b; Daniels et al., 2018c; Dogan et al., 2018; Morison et al., 2016; Morison et al., 2018; Pearce and Langley-Evans, 2021; Rowan et al., 2019; Rowan et al., 2021; Townsend and Pitchford, 2012; Williams Erickson et al., 2018). Three further trials are planned. A trial in the Basque region aims to explore the effect of weaning method on infant intake, as well as relationships between maternal diet during pregnancy and infant intake during the complementary feeding period (Urkia-Susin et al., 2021). A further observational study (First Foods New Zealand or FFNZ) aims to compare users of baby food pouches, compared to BLW or TW in terms of; iron status, growth, food and nutrient intakes, breast milk intake, eating and feeding behaviours, choking risk, oral motor skills and dental health (Taylor et al., 2021). Finally, a version of the BLISS trial is planned for the local population living around Porto Alegre, Brazil (Nunes et al., 2021).

Of the previously published studies, five have explored nutrient intake. The 'Baby-Led Introduction to SolidS' (BLISS) RCT was conducted in 206 infants (101 control and 105 intervention) in New Zealand from 2012-14 (Daniels et al., 2018b; Daniels et al., 2018c; Williams Erickson et al., 2018). BLISS infants received advice, information, and support for a

BLW approach, whilst the control group received only standard care. The aim of the intervention was for participants to include high fat and iron-rich foods at each meal to reduce growth faltering or iron deficiency (Williams Erickson et al., 2018). This methodology was also followed by another trial in Turkey (280 infants) (Dogan et al., 2018). Both studies assessed intake using 3-day food diaries. Neither study identified differences in iron intake, plasma ferritin, body iron, iron deficiency, iron deficiency anaemia, zinc intake or plasma zinc concentration at 7 or 12 months of age (Daniels et al., 2018b; Daniels et al., 2018c; Williams Erickson et al., 2018) or differences in iron intake or in hematologic parameters predicting iron status (Dogan et al., 2018). Consistent with the intervention design, BLISS infants did have higher intakes of fat at 7 months and percentage energy from saturated fat at 12 months, when compared to the control group. They also consumed more sodium (Williams Erickson et al., 2018). Two cross-sectional observational studies have been carried out in the UK, one before and one after our study. Higher intakes of fat, saturated fat and sodium from food alone, were apparent amongst BLW babies in the first study (134 infants, aged 6-12 months, assessed by FFQ and 24-hour recall) (Alpers et al., 2019). In the later study, however, TW infants consumed significantly more energy from food, along with significantly higher intakes of almost all nutrients, including fat and saturated fat but not sodium (26-39 weeks, n=35) (Rowan et al., 2021).

A smaller study using some BLISS control infants with age-matched and sex-matched infants from other studies (25 self-reported following BLW and 26 reporting no BLW allocated as TW, assessed using food diaries) found several significant differences between babies following TW and BLW (Morison et al., 2016). BLW infants aged 6-8 months had higher intakes of total fat, saturated fat and lower intakes of iron, zinc and vitamin B12 (Morison et al., 2016). Alpers et al. (2019) found BLW babies also had lower intakes of iron from milk and Rowan et al. (2021) found lower intakes of iron in younger BLW infants, compared to TW, when analysing food alone or food and milk together. In both studies, BLW infants had a higher likelihood of consuming breast milk (almost double in the study by Alpers et al. (2019)), which would have contributed to low intakes. Breast milk appears to be low in iron, compared to formula, as the iron is in the haem form and more bioavailable (Finglas et al., 2015). Higher intake of free sugars was observed amongst TW babies aged 6-8 months in both the UK studies (Alpers et al., 2019; Rowan et al., 2021), but not in the other studies. Alpers et al. (2019) noted that 70% of BLW infants took a vitamin D supplement compared to 48% of TW and Rowan et al. (2021) found intakes of vitamin D were significantly higher amongst TW infants.

Differences in vitamin D intake may be explained by the higher prevalence of breastfeeding amongst BLW infants in both studies. Formula milk is fortified with vitamin D whilst breastmilk contains no vitamin D in nutrient analysis software (Finglas, 2015; Nutritics, 2021). Formula fed infants would subsequently appear to have higher intakes from their milk. Vitamin D supplements are not recommended for babies consuming more than 500ml of formula per day, so infants receiving breastmilk (and so more likely to be BLW) would be more likely to be supplemented. Rowan et al. (2021) excluded intake from supplements in their analysis which would also exacerbate differences between breast and formula fed infants.

Four studies have explored food group exposure amongst infants following BLW. In the UK a study of 178 caregivers to infants aged 6-12 months, measured exposure to different food groups, classifying infants as following one of three weaning approaches; 'strict baby-led', 'loose baby-led' or 'traditional' (Rowan et al., 2019). Those in the strict BLW group had significantly higher exposure to both protein and vegetable portions at 6-8 months, when compared to the group following a traditional approach. The traditional group had a significantly greater exposure to composite meals, when compared to the strict BLW group at both 6-8 and 11-12 months, although the content of these meals was vague (Rowan et al., 2019). Alpers et al., (2019) found no significant differences in exposure to fruit, vegetables, fish, meat, starchy foods or sugary foods in their study (Alpers et al., 2019) but like Rowan et al. (2019), infants in the TW group were offered more pre-prepared baby foods, salty snacks, dairy and dairy-based desserts and pre-prepared baby foods than babies following BLW, whilst the BLW group were offered more oily fish and processed meats (Alpers et al., 2019). In a Canadian study, infants following TW were exposed to 27% more baby-specific foods (for example, enriched baby cereals, baby ready-to-eat-meals) in comparison to those following BLW (Campeau et al., 2021). In the BLISS trial, infants in the intervention group had greater total food variety (difference: 3.0, 95% CI, 1.1 to 4.8) at 7 months when compared to infants in the control group (Morison et al., 2018), including with a greater variety in the intake of 'core foods' (grains, dairy and milk (as a drink) (difference: 1.3, 95% CI, 0.4 - 2.2), 'non-core foods' (high-fat savoury dishes such as pies and battered fish, cakes/sweets and drinks other than milk or water) (difference: 0.6, 95% CI, 0.2 - 0.9), and 'meat and other protein' (difference: 1.3, 95% CI, 0.8 - 1.9), with no difference in the 'fruit and vegetable' variety (difference: −1.1,95% CI, −2.4 - 0.2). By 24 months of age, all the differences had disappeared, but higher intakes of fruit and vegetables became apparent in the BLISS group compared to the control groups (difference: 2.0, 95% CI, 0.4 - 3.6) (Morison et al., 2018).

Differences in dietary intake have also been explored between BLW and TW groups, as they progress to toddlerhood. A UK study founds infants who had followed BLW during the complementary feeding period were more likely to have consumed carbohydrate, sweet foods, fruit, protein-containing foods, vegetables and 'meals' when babies were on average 32.12 months (BLW) and 41.62 months (TW) (Townsend and Pitchford, 2012). In this study, parents self-reported using BLW with 32.6% of those in the BLW group exposed to pureed food. There were also significant differences between the groups in the way in which subjects were recruited (a campus-based toddler lab for TW and online for BLW) (Townsend and Pitchford, 2012). That said, all the studies exploring dietary intake were small, participants were mostly self-selecting, well-educated professional women, who are known to be most likely to take part in surveys (Brown et al., 2011; Brown and Lee, 2013; Rowan et al., 2019b). Studies also estimated the contribution to nutritional intake of breast milk, using estimates based on average volume consumed per feed or per day, dependent on age. Given the high rate of breastfeeding amongst study participants in all the observational studies, and support to breastfeed until at least 6 months in the RCTs, a high proportion of energy and nutrients were received via breastmilk at 6-12 months of age. This is likely to contribute to significant error within most studies including estimated intake from breastmilk in their analyses (Alpers et al., 2019; Williams Erickson et al., 2018).

2.2.7. Risk of choking in infants following baby-led weaning

A major concern of both parents and health professionals in some studies is that BLW may pose an increased risk of choking for the infant (Arias-Ramos et al., 2021; Cameron et al., 2012). Choking is a risk for all babies who are learning to eat, because they must learn to co-ordinate biting, chewing, moving food around the mouth with their tongue and swallowing. These are key developmental milestones in the development of oral-motor skills for both eating and speaking (Chichero, 2016; Cook et al., 2021). Larger, harder, or rounded objects have the potential to become lodged in the infants' airway (Cameron et al., 2012). Infants will develop the ability to move chewed food to the back of their mouths for swallowing, after they have learned to chew (Naylor and Morrow, 2001). Whilst purees are easy to move around the mouth, consumption of whole foods may require more advanced development and co-ordination, and this is not possible for younger babies, premature babies or those with developmental delay (Chichero, 2016; Rapley, 2003).

To date, seven studies have explored incidence of choking amongst parents following either TW or BLW (Brown, 2018; Cameron et al., 2013; Dogan et al., 2018; Fangupo et al., 2016;

Morison et al., 2016; Townsend and Pitchford, 2012) and choking has been covered by most of the reviews (Arantes et al., 2018; Brown et al., 2017; D'Auria et al., 2018; Gomez et al., 2020; Utami et al., 2020). No studies have identified an increased risk of choking in either the TW or BLW group, although one study only reported chocking incidence in BLW babies (6.5%) (Townsend and Pitchford, 2012) and two studies reported non-significant differences. Morison et al., (2016) found that babies following full BLW were more likely to be offered foods which posed a choking risk (particularly raw vegetables, raw apple and dried fruit) than babies following TW or partial BLW, but this was not statistically significant (OR 2.57, 95% CI: 0.63-10.44) whilst Fu et al. (2018) found parents were feeding the infant in a higher percentage of choking incidents (3% versus 2% when self-feeding), but the numbers were too small to analyse. The only study to specifically investigate weaning style and choking rates suggested that choking risk may be lower for infants who consume finger foods regularly (Brown, 2018). It has been suggested recruiting participants from BLW websites, where the difference between gagging and choking is discussed frequently, may have influenced correct reporting amongst BLW infants, whilst TW parents may over-report (Taylor et al., 2021).

2.2.8 Responsive feeding

Individuals who are more food responsive are more likely to eat in the absence of hunger, and when in the presence of food (Carnell and Wardle, 2008). Along with poor satiety responsiveness, this is a risk factor for overweight and obesity and has been observed in very young children (Carnell and Wardle, 2008). Satiety responsiveness is the ability to recognise when full and stop eating and is associated with healthier outcomes. This is likely an interaction between genetically determined appetite traits, inherent preference for sweet and salty flavours and the environment within which children live (Birch and Fisher, 1998). Evidence suggests that 6-week-old infants regulate their intake of energy well, when consuming a milk diet (Fomon, 1993) and on-demand milk feeding allows infants better control of intake than feeding on a schedule (Ventura, 2017). Parents who respond to their children's cues of hunger and satiety are described as feeding responsively (Ventura, 2017). Research has demonstrated that mothers who breastfeed are more likely to feed responsively than those who formula feed, but spending time with the infant, understanding feeding cues and avoiding distractions whilst feeding can assist parents in feeding responsively regardless of milk feeding type (Redsell et al., 2021; Ventura, 2017). Critical dimensions of responsive feeding include balancing assisted/self-feeding, using verbal encouragement but not coercion, responding to early feeding cues, feeding in a comfortable environment, using age-appropriate feeding utensils, and

feeding by someone who has a positive emotional relationship with the child and can recognise changes in the child's physical or emotional state (WHO, 2002). One of the key tenets of BLW is responsive feeding; handing control of feeding to the baby, allowing them to regulate their own intake, in terms of how, what, when and how much is eaten (Rapley, 2015). BLW has also been identified as an enabler for responsive feeding (Redsell et al., 2021). Three studies have explored responsive feeding, two of which found babies who followed BLW had a greater satiety responsiveness. These were conducted amongst UK children aged 18-24 months and Canadian infants aged 10-14 months (Brown and Lee, 2015; Campeau et al., 2021). The BLISS trial, however, found infants following the modified BLW intervention had lower satiety responsiveness at 24 months (Taylor et al., 2017). It might be easier for mothers who have breastfed to follow BLW as both methods of feeding are low in control (Brown & Lee, 2015). Furthermore, Brown & Lee, (2015) suggested that spoon-feeding may have the potential to override appetite control, as control is maintained by the parent (Brown and Lee, 2015; Ventura, 2017). Involving a baby in food decisions may consequently lead to better appetite regulation and healthier weight gain during pre-school years (Brown and Lee, 2011).

2.2.9 Long-term eating habits

The promotion of health and influencing the development of long-term healthy eating habits, are of key importance to this thesis. They are included here as an accepted, but yet to be proved, benefit of BLW. Alongside genetics and the early developmental environment, parental characteristics may also shape dietary diversity and food preferences.

In terms of parental characteristics, Brown & Lee (2011) first suggested that women who follow BLW had a longer breastfeeding duration. This has been further demonstrated by other studies including ours (Pearce and Langley-Evans, 2021; Perez-Rios et al., 2020; Townsend and Pitchford, 2012). As women who have spent longer in education and who are in a higher income bracket are more likely to breastfeed (Brown et al., 2010), it could be assumed that participants in surveys relating to BLW or comparing traditional and baby-led weaning also have a higher socioeconomic status. Baby-led weaning may feel like the most appropriate next step for breastfeeding mothers, as breast-feeding frequency, size and duration is baby-led, allowing for the more responsive feeding theoretically promoted by BLW, where control of feeding is handed to the baby (Dewey et al., 1991). Baby-led mothers have described this style of feeding as 'logical', 'natural' and 'made sense' (Cameron et al., 2012; Cameron et al., 2013; D'Andrea et al., 2016). Breastfeeding infants must work harder to obtain milk from the breast and must take an active role in feeding. This may also translate more easily to BLW (Cameron

et al., 2012). Higher conscientiousness and lower maternal control, eating restraints, anxiety and obsessive-compulsive disorder scores were found amongst mothers following BLW, compared to those following TW (Brown, 2016), although this could be reverse causality (Arden and Abbott, 2015) with mothers higher in anxiety choosing TW where infants' intake is more controlled and supportive literature and government guidelines abound (D'Auria et al., 2018). Mothers who followed BLW also used fewer food restrictions and were less likely to pressure children to eat (Brown and Lee, 2011; Brown and Lee, 2015), both of which have been shown to increase the risk of obesity in childhood (Birch and Fisher, 1998; Birch and Fisher, 2000; Fisher and Birch, 1999; Savage et al., 2007). Mothers following BLW were also more confident about introducing solid foods to their baby and that their baby would self-regulate their intake to meet their nutritional requirements. This was not ubiquitous, however, with some mothers adapting the infant diet amid concerns it would not satisfy nutrient requirements (Arantes et al., 2018; Arden and Abbott, 2015). A qualitative paper suggested BLW mothers may be more value-driven with stronger ideals, wanting their infants to enjoy and explore foods, allowing them to be more independent, whilst mothers following traditional weaning made decisions more pragmatically (Swanepoel et al., 2020). There is a lack of research exploring how infant feeding decisions are affected by maternal psychological wellbeing, perceived self-efficacy and parental stress (Urkia-Susin et al., 2021). These feelings may determine infant feeding style and confidence in feeding or feeding responsively during the complementary feeding period.

In theory, BLW may make children more receptive to a range of textures and flavours. One New Zealand study explored food fussiness (a rejection of a substantial number of foods that are often familiar) and found BLW infants had lower food fussiness scores at 6-36 months than TW (Fu et al., 2018). A further study in the UK ~~No studies have explored~~ found neophobia (characterized by "the reluctance to eat, or the avoidance of new food" was not more likely in BLW, TW or mixed methods feeding groups (Watson et al., 2020). Finger foods should provide an opportunity for babies to learn about textures and the way that individual foods look, feel and taste, so proponents of BLW argue that if babies are exposed to pureed food alone, without the use of finger foods, then this learning opportunity may be jeopardised and children may be less receptive or fussier in childhood (Komninou et al., 2019; Rapley, 2015). Komninou et al. (2019) discuss the 'flavour window' of opportunity between 5 and 7 months where infants accept sweet, salty, umami, sour and bitter tastes equally. They suggest infants should be exposed to bitter tasting food (such as green vegetables) before this opportunity is lost

(Komninou et al., 2019). There may also be a 'sensitive window' for the introduction of finger foods, to promote acceptance of a range of textures. Commercial infant cereals as first foods may have little taste and are more likely to be first foods amongst infants following TW (Komninou et al., 2019; McAndrew et al., 2012). P~~p~~ureeing changes the texture, appearance and possibly the taste of the food, especially if several foods are mixed. Liking of a food in pureed form may not extend to liking that food later, when it is offered in a different form (Rapley, 2015) and toddlers who followed BLW in infancy have reported a greater enjoyment of food in toddlerhood (Komninou et al., 2019). Complex textures should be introduced by 10 months of age according to some research. Few studies have explored the impact of the form of foods on the development of eating habits but Townsend & Pitchford (2012) and Morison et al., (2016) both explored whether weaning style effected food preferences. Morison et al., (2016) found no association whilst Townsend & Pitchford (2012) found that spoon-fed infants showed a preference for sweet food. Foods provided to infants should not contain added sugar or salt (NHS, 2019c), but commercially produced infant foods often mix sweeter-tasting fruits in with other foods (García et al., 2013), whilst foods prepared for the family at home and some finger foods, for example bread products and cheese, may be high in salt (Morison et al., 2016). Data from the Millennium Gateshead study in the UK found that 56% of children had reached out for food before 6 months of age but only 65% were self feeding to some extent by 8 months of age (Wright et al., 2011). Babies must be given the opportunity to feed themselves to be proficient at chewing and swallowing, which is linked to better muscle development and sensory perception (Arantes et al., 2018).

2.2.9. Qualitative studies exploring baby-led weaning

Qualitative studies exploring BLW are few, but common themes are present, for example, mothers trusting their baby to regulate intake, waiting until around 6 months to introduce solid foods, having a positive experience of weaning with fewer mealtime battles and believing BLW would help children to develop long term healthy eating habits. In New Zealand, Cameron et al., (2012) interviewed mothers who reported using BLW (n=20) and they reported that BLW was healthier, more convenient, and less stressful than TW, although participants described the process as messy. Swanpoel et al., (2020) also identified convenience as key in choosing BLW. Choking risk was a common theme in qualitative analysis of interviews conducted with mothers following BLW in the UK (n=36) and Jakarta (Indonesia) (n=13) (Brown and Lee, 2013; Utami et al., 2020). Women in these studies described feeling anxious at the start of the weaning process but much less anxious or controlling as weaning progressed and infants were

healthy and gained weight. They also thought their baby had a better experience as they were eating foods in natural, rather than processed forms (Brown and Lee, 2013). Arden & Abbott (2015) suggest that both Cameron et al., (2012) and Brown & Lee (2013) used questions designed to elicit discussion of themes, for example, asking about 'mess' or 'choking' (Brown & Lee (2013) and using the 'main lines of enquiry (knowledge, attitudes, experiences) as an initial guide to direct content analysis' (Cameron et al., 2012). Arden & Abbott (2015) interviewed 15 women about their experiences of weaning, whether they had used purely BLW or a mixture of approaches and used emergent themes rather than using interview questions to code data. Mothers in the study described wanting to hand control to their infants in terms of the type, timing and amount of food eaten, which adheres to the principles of BLW and demonstrates a responsive feeding style. Various forms of trust (timing of solid food introduction, selection of food and being able to eat or handle food safely) were also identified by a study in Australia (Swanepoel et al., 2020). Some parents allowed their baby to dictate when solid foods were first introduced by sitting their baby on their lap whilst eating, enabling them to take food off their parents' plate (Arden and Abbott, 2015; Brown and Lee, 2013). This fits with calls to focus on signs of readiness rather than age (Chichero, 2016). Parents also recognised signs of readiness for weaning (Brown and Lee, 2013). However, other parents made steps to control the timing of solid food introduction and the amount eaten, which creates conflict with the guiding principles of BLW (Arden and Abbott, 2015). Whereas early introduction of solids was seen as bad, late introduction or babies still not consuming solid foods by 8 or even 12 months, was acceptable and there was a shared belief that this would not be problematic, despite WHO guidelines based on the importance of timely and iron-rich foods to prevent growth faltering and iron-deficiency from around 6 months (Dewey, 2002; WHO, 2002). Parents also withheld less healthy food items (for example, cakes and biscuits), differing from the observations made by Brown & Lee (2013) who suggested low maternal control. That said, current guidelines suggest limiting foods high in salt and sugar to children under one year of age (NHS, 2019c). These findings contrast with the principles of BLW where babies should make their own choices and should be trusted to do so.

2.3. Early childhood

2.3.1. Universal infant free school meals

A final opportunity to influence children's eating behaviours presents itself when they start school. School lunch could provide both a healthy meal and an opportunity to learn about the environmental, social, and scientific value of food (Department for Education, 2013; Hart, 2016). This represents a significant teachable moment.

The recent National Food Strategy, produced by one of the authors of the School Food Plan, has called for more focus on food in schools (Dimbleby, 2021). In England, all children aged 4-7 years attending reception, Y1 and Y2 in state-maintained schools, are eligible to receive a universal infant free school meal (UIFSM). UIFSM were introduced in September 2014, and are not means tested, unlike free school meals (FSM) which are available to families in receipt of certain benefits or financial support (UK Government, 2014). School meals have, on average, a healthier nutritional profile than a packed lunch brought from home. In part this is because school meals must meet strict standards but also due to a greater diversity of food on offer across a typical 2–4-week menu cycle (Evans et al., 2010; Pearce et al., 2011; Pearce et al., 2013). Unfortunately, the quality of food in schools and schools' food culture do not always make school meals a positive experience for children (Department for Education, 2013).

School meals represent a significant contribution to a child's intake on a school day, so if school meals were free for all then dietary intake could be improved (Spence et al., 2020). School meals offer an opportunity for role modelling by adults and peers (Department for Education, 2013). The aims of the UIFSM policy were also to increase the take up of school meals and by doing so, ensure that children had fair access to a healthy meal every day, which aimed to improve their social skills, their behaviour; their educational attainment, to aid the development of long-term healthy eating habits, to remove stigma attached to receiving a free school meal, to help families with the cost of living and to remove disincentives to work (Golley et al., 2010; Holford and Rabe, 2020; Storey et al., 2011). Prior to the publication of the paper included in this thesis (Goodchild et al., 2017), little research had been completed on UIFSM. A report evaluating the UIFSM pilot study, which paved the way to the introduction of UIFSM, found universally-free meals had a greater impact than extending the then current means-tested provision to all families earning less than £16,190 (rather than just those receiving benefits (Kitchen et al., 2013). The UIFSM pilot had little impact on children's nutritional intake, BMI or school attendance, but in the UIFSM meal group, there was a positive impact on attainment (Kitchen et al., 2013). Although comments from headteachers were generally positive and

many saw UIFSM as an opportunity to improve the dining experience (Day et al., 2015), an evaluation of one local authority's decision to provide UIFSM, prior to national introduction (Hull, 2004-2007) found that whilst the food provided met standards, children were not eating the food and had low intakes of most nutrients at lunchtime, compared to children taking a packed lunch (Gatenby, 2011). Although evaluated in only two schools, UIFSM children also compensated for low intakes at lunchtime, by consuming other foods across the school day, but these often-included items with a poor nutrient profile, such as crisps, biscuits and chocolate (Gatenby, 2011).

Since Goodchild et al., (2017), a report has used a variety of data sources including the school census, National Child Measurement Programme and household expenditure to assess the impact of the UIFSM policy against its aims (Holford and Rabe, 2020) whilst a further journal article has explored changes in dietary intake following introduction of the UIFSM policy (Spence et al., 2020). In the report by Holford & Rabe (2020), take up of UIFSM has remained between 85% and 86.3%, just short of the Government target of 87%. This is still considerably higher than the 30-35% figure in the years before the introduction of the policy but may have had the unintended consequence of reducing the number of eligible children (aged 7-11 years) registering for a means-tested FSM in primary schools where infants receive UIFSM. This could be due to busier canteens and longer queuing times and will reduce funding for schools who receive extra funding for children registered for FSM (Holford and Rabe, 2020). UIFSM may have reduced the proportion of children who are obese by 0.7 percentage points in the first year of school, although this is against a background of policy designed to reduce childhood obesity and may be countered by the reduced FSM take up by older children (UK Government, 2017). It is also unclear if benefits persist in the second and third year of the scheme as no nationally representative data is available (Holford and Rabe, 2020). The number of absences amongst children registered for FSM reduced by 1.2 school days across the academic year, after UIFSM introduction, but results on attainment were mixed (Holford and Rabe, 2020). At age 5, children registered for FSM had caught up with their more affluent peers, but at age 7, non-FSM children receiving UIFSM had made 2 more weeks progress, compared with FSM children. It is not clear what is responsible for observed differences. Spence et al., (2020) found intakes of sodium, NMES and saturated fat had decreased following the introduction of the UIFSM, but consumption of cakes, biscuits and sweet puddings increased in the school where these were available every day. Although cakes and biscuits are allowed under the food-based

standards for school lunches, the opportunity to encourage a cultural shift towards healthier options may not always be capitalised upon by schools (Spence et al., 2020).

Overall, UIFSM appears to have positive effects on children's/family's health outcomes, but around 15% of children are not taking the UIFSM they are entitled to. There is a gap in the literature concerning why parents may not take up the offer of UIFSM and identify what schools need to do to improve the quality of food and food culture for their pupils.

3.0. Aims of the thesis

To consider whether 'teachable moments', starting in pregnancy and continuing through the complementary feeding period and the start of school, have the potential to improve the health outcomes of women and children.

4.0. Research objectives

- To investigate women's dietary behaviours during pregnancy, and their experiences and motivations for behaviour change.
- To evaluate whether a midwife-delivered intervention, amongst severely obese pregnant women, could motivate behaviour change and improve health outcomes for mother and infant.
- To explore whether the impact of the timing and type of food provided during the complementary feeding period impacts on later childhood obesity.
- To explore whether changes in weaning style (TW or BLW) may lead to differences in nutritional intake in infants.
- To explore objectively, the similarity between infant diet and parental diet in BLW and TW infants.
- To explore the meaning of BLW for parents, why parents use this style of weaning and whether an opportunity for health promotion exists.
- To explore how parental attitudes to school food may prevent their children from taking the offer of a universal infant free school meal.

5.0 Methodological Issues

5.1 Introduction

This thesis largely comprises peer reviewed publications focused around the areas of pregnancy, infancy, and early childhood. The research is presented in lifespan order; pregnancy, complementary feeding, UIFSM. Each of those papers has its own methods section. This chapter will present the timeline for the research included in the thesis, the strengths and limitations of the PhD by published works. The ~~discuss~~ methodological issues across the eight studies included in the thesis are then discussed, in more general terms. The ~~following~~ text will present how I have used different methodologies to gain ~~and contribute to~~ knowledge, the logic and rationale underpinning the use of each method, and the limitations encountered.

5.2 Research timeline

The timeline for the included research, alongside the PhD by published works application and completion timescale is detailed below (figure3).

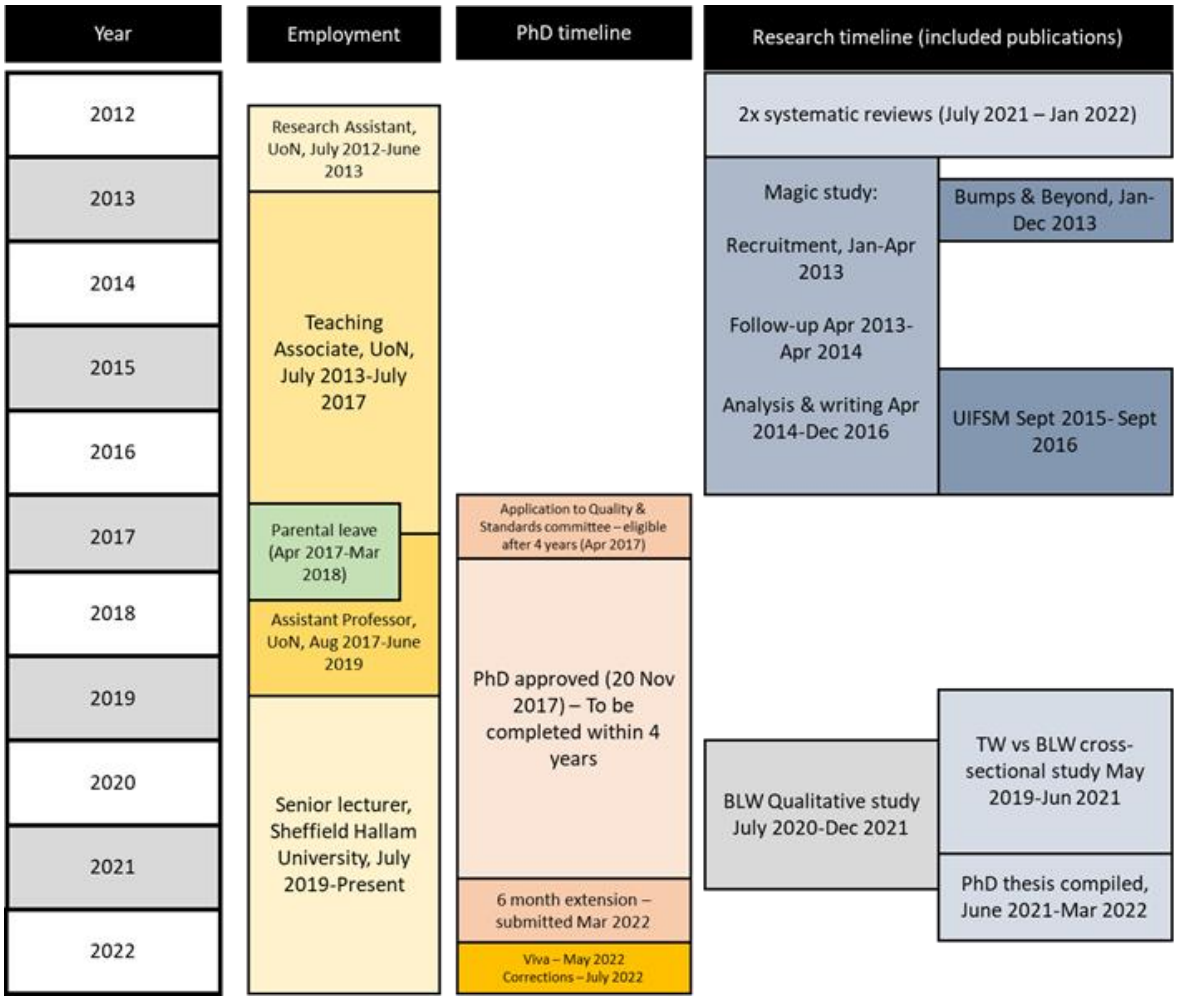

Figure 3. Research timeline showing PhD and research timelines, against year and employment history.

5.3 Strengths and limitations of a PhD by published works

Surprisingly little has been written in the academic literature about PhD by published works and neither the Higher Education Statistics Agency HESA nor the UK Council for Graduate Education (UKCGE) publish statistics (HESA, 2022; UKCGE, 2022). The last report which examined guidelines across institutions and collated statistics on the number of individuals completing a PhD by published works was reported in 2004 (Powell, 2004). Each higher education institution publishes its own guidelines, which vary in requirement and the level of detail provided to prospective candidates. Generally, however, the publications included in the published works thesis should be journal articles, books, book chapters or conference proceedings and the thesis may also contain work which has been is unpublished but completed and formatted for publication. Common across institutions is that a 'PhD should be awarded on the basis that the candidate has contributed to knowledge in an area of intellectual endeavour' and that a PhD candidate 'should be capable of continuing to do so in an independent and original way'(Powell, 2004).

There are several strengths of the published works route. For example, the potentially longer time frame may allow the researcher to complete a wider range of research projects or longer projects, than could be achieved during a 3-4 year programme. Including a range of articles provides more opportunity to demonstrate recruitment of different study groups and data management and analysis. Publishability has already been demonstrated and encourages the researcher to establish a publication record which is professionally useful. Completing the PhD as a series of steps helps to manage the enormity of the task (Cowden, 2013). There are also two external examiners to review the thesis and conduct the viva voce and at UoN, a Prima Facie case must already be established with respect to quality assurance (University of Nottingham, 2016). Despite these strengths, there are also some limitations. Frick (2019) suggested that individuals following the published works route may find it difficult to accept reviewers' critique or rejection of their work. Similarly, that a lack of theoretical knowledge, methodological skills, and/or familiarity with journals in the field could all make a PhD by publication more challenging (Frick, 2019).

Peer review could, however, benefit the candidate by providing formative feedback and any candidate starting out on their PhD journey would require time to familiarise themselves with journals and relevant academic skills. Publishing is also a challenging process which can support the researcher to become both more confident and more thick-skinned (Cowden, 2013).

University staff should also be offered or have access to training as part of their job role which can help to develop required skills.

A more significant limitation is that the guidance on preparing the thesis is vague and inconsistent between institutions, raising the question of consistency and equivalency

(Badley, 2009; Shaw and Green, 2002). At UoN, published works candidates usually have one advisor who provides general advice but does not have a supervisory role (University of Nottingham, 2016). The advisor provides guidance on the selection, coherence and quality of the published works and advice on the structure of the thesis, but at some institutions, the advisor may have more of a supervisory role (Badley, 2009). There is no minimum or maximum number of articles or book chapters to include and this also varies between institutions. At UoN, the final thesis should be the same length as a traditional PhD (70,000 – 100,000 words) including the 'published works' along with a critical narrative of the subject area and the included works (University of Nottingham, 2016). Badley (2009) suggested that the published works route focuses more on the products of learning and research, rather than on the process of learning and research, but the process of publishing requires a researcher to complete a standard of research that stands up to peer review, and to write in a way suitable for academic journals. Finally, and of critical importance is the timeline. The length of time over which research spans may mean that research is out of date by the time the thesis has been completed (Badley, 2009, Shaw & Green, 2002). In this thesis, the systematic reviews were both nine years old at the time of writing, and further papers exploring the type and timing of food introduced during the complementary feeding period have expanded the evidence base. The literature review and discussion have considered the literature published since the original articles to acknowledge this, but without repeating the systematic review, it would be hard to determine the extent to which the more recent literature would have changed the result. Finally, the critical narrative of a PhD by published works must be coherent and included articles should fit within a theme which, when read together, contributes more than the individual articles (Cowden, 2013). The published works and narrative must also demonstrate the key attributes of any PhD; appropriate methods, coherence, contribution of knowledge, critical appreciation, independence, and intellectual merit (Badley, 2009). Finally, it may be necessary to challenge the assumption that the published works route is 'not a proper PhD' (Cowden 2013). I would wholeheartedly disagree that this is the case, but more consistent guidance within and between UK institutions would support this.

5.4 Research Philosophy

The research presented in the thesis takes a mixed methods approach to investigate issues in early life nutrition and as such, is more closely aligned to social sciences research, rather than pure science, although in the discipline the two approaches are somewhat muddled together. My underlying research philosophy is one of critical realism, which encompasses aspects of both realist and constructionist philosophy, allowing an explanation of social phenomena (Bhaskar, 2008). The ontology of critical realism is that reality exists and is ordered (similar to realism). The epistemology of critical realism is that our ability to observe reality directly is limited by subjectivity (Bhaskar, 2008). Critical realists, therefore, use methodology to observe the world as best they can, using their findings to generate knowledge as theories (Danermark, 2002). This is done by looking for relationships between exposures and outcomes, then describing or generating theories about those relationships, identifying possible causal mechanisms driving social events, activities, or phenomena (Archer, 1998). Critical realism allows us to attempt to explain causal relationships which makes this philosophy useful for analysing social science and suggesting solutions for social change (Fletcher, 2017). This is 'retroduction', an explanation or reasoning to explain why data appear as they do and is a feature of critical realism (Olsen, 2007). Critical realism is not associated with individual research methodologies, making this philosophy compatible with a mixed methods approach (Fletcher, 2017).

5.5 The MAnaging weiGht In pregnanCy (MAGIC) cohort study

The MAGIC prospective cohort study was completed between 2012 and 2014 (Swift et al., 2017; Swift et al., 2016) by an interdisciplinary team of nutritionists, social scientists, and a musculo-skeletal specialist. Few studies had previously explored women's dietary behaviours longitudinally throughout pregnancy, and their experiences and motivations for behaviour change. In nutritional studies, cohort studies are usually used to determine the aetiology of disease, by recording dietary intakes, weight, height, or biochemical measurements at an initial timepoint and then studying the relationship of these indicators with later outcomes (Lovegrove et al., 2015; Margetts and Nelson, 1997). Cohort studies have also been used to study food-related behaviour (Dean et al., 2015). The first objective for MAGIC was to collect data on demographic characteristics, weight, height, diet and PA and changes in diet and PA over time. The second objective was to explore the complexity of weight-related experiences, food-related behaviours, and weight-related behaviours both during and following pregnancy. Here, we used both quantitative scales and analysis of open-ended questions to identify behavioural

phenomena using an inductive, descriptive content analysis, which can be used to provide new insights and representation of facts by identifying meanings, intentions, consequences, and context (Elo and Kyngäs, 2008). An inductive approach is usually used where there is no former knowledge of the phenomena (Elo and Kyngäs, 2008; Swift et al., 2016). This methodology accepts the subjective natures of individual's experiences but also allows theories to be generated about the relationships between personal characteristics and personal experiences, contingent with an approach of critical realism. The first 12 weeks of pregnancy could be key to establishing healthy behaviours, but may be challenging for women due to sickness, nausea, changes in taste perception or tiredness, which we wanted to capture (Jarvis and Nelson-Piercy, 2011; Orloff et al., 2016; RCOG, 2016; Santos-Antonio et al., 2020). A strength of the MAGIC study was the use of an initial questionnaire to record changes since becoming pregnant and how behaviour or feelings toward diet and PA had changed during the first trimester. This is the part of pregnancy which is often difficult to observe and address with intervention studies. A further advantage of prospective cohort studies in general, includes participants behaving more naturally, with respect to their diet or dietary behaviours. Although it is likely that many MAGIC participants had changed their diet due to their pregnancy, qualitative questions explored why they had done so.

The clinics from which participants were recruited served the whole of Nottingham, and all pregnant women were approached during clinics, over the course of 6 weeks (n=786). Of the 360 who agreed to take part in the study, 193 completed and returned the initial questionnaire. Of these, 79.6% had a National Statistics Socio-Economic Classification score of 1 or 2 indicating they or their partner where in a managerial or professional occupation (ONS, 2010). Although women of all backgrounds were approached, women of lower socio-economic status and black and minority ethnic women were less likely to take part in the study. This represents a significant limitation as we were unable to explore the effect of ethnicity or socioeconomic status on weight expectations or outcomes, and it is likely that differences would exist. Women in the study were also likely to be older than the average age of mothers at birth (32.8 years compared with 30.0 years) and were older than women in both the Southampton women's study or ALSPAC, although these are older studies and average age of women at birth is increasing annually (Crozier et al., 2009; Rogers and Emmett, 1998). The nature of the study did not deter women of a higher weight, although body image and weight concerns were underrepresented, suggesting women worried about their weight may have declined to take part, due to the nature of the study (Swift et al., 2016). Recruitment was also conducted face-to-face by an enthusiastic member of the study team, which has been shown to increase enrolment in cohort studies

(Golding and Birmingham, 2009). Issues preventing women of lower SES from taking part include the complexity of consent forms for those with fewer years in education, and a lack of identification with the researcher (Brannon et al., 2013). Some families also attended with pre-school children, although both parents were usually present when this was the case. Women with known higher-risk pregnancies may also have been more reluctant to take part (the healthy volunteer effect) (Froom et al., 1999). Although a change of address proforma was included with every questionnaire, along with an email address where researchers could be contacted for change or address, research has suggested that lower income families are more likely to move and be lost to cohort studies (Brannon et al., 2013). The most motivated women are those most likely to have completed the entire study, which included several participants who reported being researchers, dietitians, or medical doctors, who may also have been conscious of their behaviours. The Norwegian Mother and Child Cohort Study (where 43.5% of the 73,579 women invited took part) evaluated bias in the prevalence of 23 exposure and outcome variables and found bias existed in most variables. Younger women, mothers living alone, mothers who already had two or more children or with a previous still birth were underrepresented (Nilsen et al., 2009). Furthermore, these issues mean there are likely to be differences between responders and non-responders which introduce a risk of bias into the sample. Questions aimed to capture changes over time may have appeared repetitive to participants who may not have proceeded with the study beyond the first questionnaire at 12 or 20 weeks.

5.6 'Bumps and Beyond' – Service evaluation

The 'Bumps and Beyond' intervention was carried out by midwives and healthy lifestyle advisors working for Lincolnshire Community Health Services in 2009-10. This was a community intervention which aimed to reduce GWG, and the prevalence of adverse pregnancy and labour outcomes associated with severe obesity (BMI≥35 kg m^{-2}) (McGiveron et al., 2015). We did not design the intervention but carried out a service evaluation on behalf of the Bumps and Beyond team.

Although it was an evaluation rather than a true intervention study, Bumps and Beyond can be likened to a community-based lifestyle intervention, for the purposes of evaluation. This kind of study can help to establish links between diet or nutritional status and health outcomes and are higher up the hierarchy of scientific evidence, than observational studies (Lovegrove et al., 2015). This type of study generates knowledge by looking at changes in outcomes, dependent on participation in the study. A philosophy of critical realism allows the researcher to look for

and attempt to explain the associations between exposure and outcome, recognising that the effect will be different for each participant. Strengths of the study include a strong evidence base for the benefits of an intervention of this nature. The intervention and the materials, sessions and booklet received by the participants were well designed by individuals previously experienced in smoking cessation. Although Bumps and Beyond was a small study, all pregnant women in the Lincoln area with severe obesity (BMI≥35 kg m^{-2}) were invited to participate, following their booking appointment (where height and weight were measured) between April 2012 and February 2013 (McGiveron et al., 2015). Fifty percent initially agreed to take part and differences between the control (those who declined to take part) and intervention groups were minimal, although few demographic variables were recorded. The intervention had a wide geographical coverage, using 'health shops' to access harder to reach local communities. Each participant received seven 1:1 appointments with either the lead healthy lifestyles midwife or one of three healthy lifestyles advisors, all of whom were trained and experienced in delivering weight management interventions for families, although each may have varied in their agency. Advice focussed on healthy eating and further supported participants with practicalities and challenges such as shopping, cooking, food labels and eating out and used food diaries to identify dietary patterns for modification (McGiveron et al., 2015). A wide range of outcome measures was collected, in additional to weight and height at 36 weeks gestation. These included pregnancy complications (gestational diabetes, gestational hypertension, pre-eclampsia, thrombosis, musculoskeletal disorders, symphysis pubis disorder, premature rupture of membranes, polyhydramnios, small-for-gestational age, large-for gestational age) and labour complications (post-partum haemorrhage, shoulder dystocia, failure to progress, induction, nonvaginal delivery, manual removal of placenta) identified from hospital records (McGiveron et al., 2015). Adherence to all seven appointments was low. Weaknesses of the study design included a lack of randomisation. Few recorded demographic differences were noted between the groups, but women in the intervention group may have been more anxious about the health of their baby, more health conscious, more motivated, or better supported by family, friends, or partner to take part in the intervention. Alternatively, the control group may have declined to participate, but could still have been motivated to make positive changes to their diet and PA, due to concern over their pregnancy. Olander et al. (2016) suggest that making lifestyle changes may extend beyond just motivation, based on the COM-B model (that behaviour is influenced by capability, opportunity, and motivation) (Michie et al., 2011). Even if women have increased motivation to, for example, increase physical activity or dietary change during pregnancy, they may not have the capability (for example, difficulty

exercising after a long working day or due to back or pelvic girdle pain) or opportunity (accessible spaces or classes) (Olander et al., 2016).

5.7 Systematic reviews of observational studies

Systematic reviews offer an original contribution to research by providing an exhaustive review of the literature focusing on the relationship or association between an exposure and outcome. They should appraise and synthesise all the empirical evidence that meets pre-specified eligibility criteria and synthesise new results or interpretation (Cochrane Reviews, 2021). This is of great importance to healthcare providers and policy makers who are required to review the available evidence before designing interventions or making decisions. Systematic reviews are ranked above observational studies and RCTs in the hierarchy of research evidence (Evans, 2003). They have numerous strengths, including the use of a systematic and robust method for finding and selecting studies, analysis of the risk of bias, analysis of the methodological strengths and weaknesses of included studies, meta-analysis where possible, critical analysis of the type of data collected, re-interpretation and analysis of data in the context of other studies (Cochrane Reviews, 2021). In systematic reviews of intervention studies, the effectiveness, appropriateness, and feasibility of interventions can be explored and the generalisability for the general population discussed. Numerous tools have been developed, which aid researchers with assessing the quality of the studies included in systematic reviews, including AMSTAR, the Newcastle-Ottawa Scale (NOS), Jadad Scale and National Heart, Lung and Blood Institute (NHLBI) (Jadad et al., 1996; NHLBI, 2021; Shea et al., 2017; Wells et al., 2021).

Despite their usefulness, systematic reviews have several limitations. The first is publication bias, where studies with a 'positive' result are more likely to be published, and therefore, included. Goldacre (2003) discusses the implication of this, describing incidences of drugs being prescribed, despite their ineffectiveness. Authors often fail to assess publication bias or describe how this may limit their findings, however, registers such as the International Prospective Register of Systematic Reviews (PROSPERO) allow researchers to search for registered trials and to assess if researchers completed trials as they said they would (NIHR, 2021). Authors may also not be clear in their objectives, inclusion/exclusion criteria, measures of study quality or may not have adequately summarised the included studies.

The NOS (Table 4) has been used widely for systematic reviews of observational studies but items on the scale, such as generalisability have been questioned (Stang, 2010). For example, studies recruiting from the general population would score higher for generalisability, than

studies recruiting from a single hospital. This would be despite the first study potentially having a lower number of participants, poorer outcome measurement, participant retention or poorer internal validity (Stang, 2010). The NOS (Table 4) also awards 'stars' (points) for adjusting for the 'most important confounding factors' which are left up to the user to decide (Stang, 2010). Subsequent studies of inter-rater reliability have found kappa coefficients varied for different parts of the scale. Reliability for overall score was fair between reviewers (k= 0.29, 95% CI, 0.10 - 0.47) in one assessment of reliability, but was poor for "selection of the nonexposed cohort" and "demonstration that the outcome was not present at the outset of the study" (k= -0.03, 95% CI, -0.06-0.00) and (k = -0.06, 95% CI, -0.20, 0.07) (Hartling et al., 2013), however, no other suitable validated tools were available at the time the reviews were completed and there is still no internationally agreed quality assessment tools for observational studies (Garcia-Doval et al., 2017). It is also worth noting that PROSPERO was not widely used at the time the systematic reviews on complementary feeding were written, and so was not part of the protocol.

Table 4. Newcastle-Ottawa Quality Assessment Scale – Cohort Studies

Note: A study can be awarded a maximum of one star for each numbered item within the 'Selection' and 'Outcome' categories. A maximum of two stars can be given for 'Comparability'.	
Selection	1) Representativeness of the exposed cohort a) truly representative of the average _____ (describe) in the community* b) somewhat representative of the average _____ in the community* c) selected group of users e.g. nurses, volunteers d) no description of the derivation of the cohort 2) Selection of the non-exposed cohort a) drawn from the same community as the exposed cohort* b) drawn from a different source c) no description of the derivation of the non-exposed cohort 3) Ascertainment of exposure a) secure record (e.g., surgical records)* b) structured interview* c) written self report d) no description 4) Demonstration that outcome of interest was not present at start of study a) yes* b) no
Comparability	1) Comparability of cohorts on the basis of the design or analysis a) study controls for ___(select the most important factor)* b) study controls for any additional factor* (Criteria could be modified to indicate specific control for a second important factor.)
Outcome	1) Assessment of outcome a) independent blind assessment* b) record linkage* c) self report d) no description 2) Was follow-up long enough for outcomes to occur a) yes (select an adequate follow up period for outcome of interest)* b) no 3) Adequacy of follow up of cohorts a) complete follow up - all subjects accounted for* b) subjects lost to follow up unlikely to introduce bias - small number lost - > ____ % (select an adequate %) follow up, or description provided of those lost)* c) follow up rate < ____% (select an adequate %) and no description of those lost d) no statement

Systematic reviews are also cheap compared to other types of research, which may have contributed to an explosion of available reviews, with differing results. Systematic reviews are held as a gold standard, but this assumes a rigorous review of quality studies and the existence of a 'real' relationship between exposure and outcome being observed, when in reality the conditions and participants in every study or trial will cause a variation in the results produced, particularly where observational studies are included. Systematic reviews may provide 'an answer', rather than 'the answer'. Although of better quality than narrative reviews with supposed reproducibility, different results have been obtained by reviews assessing the same research question. This suggests considerable subjectivity in establishing and applying inclusion criteria, assessing methodological quality, and interpreting findings, resulting in different conclusions. Studies which are inherently different may also be parcelled together without highlighting their differences (Garcia-Doval et al., 2017). There are, for example, five systematic reviews covering BLW, the most recent of which (Gomez et al., 2020) identified only 17 original research articles. The five reviews ranged broadly in their reporting of outcomes and their study design (Arantes et al., 2018; Babik et al., 2021; D'Auria et al., 2018; Gomez et al., 2020; Martinon-Torres et al., 2021). This may not help to alleviate confusion around an exposure/outcome relationship or provide the authoritative unbiased source of information for policy makers. Systematic reviews are also quickly out of date, as the literature exploring relationships between exposure and outcome continues to expand after publication. This was particularly evident in the literature on interventions to prevent excessive GWG where a vast array of systematic reviews has failed to agree on whether diet, PA, or a combination of both were the most effective.

At the time of writing the systematic reviews included in this thesis, there were few reviews available on complementary feeding and consequently these are the most cited of the papers included in the thesis (Pearce and Langley-Evans, 2013; Pearce et al., 2013). Since publication, several other reviews have been published, although with slightly different parameters, for example including only pre-term infants or including growth parameters such as length/height (English et al., 2019a; English et al., 2019b; Vissers et al., 2018). The Cambridge study and review is discussed further in the literature review (section 2.2.1) (Vail et al., 2015).

5.8 Baby-led weaning and Universal infant free school meals: Cross-sectional studies

The studies in the thesis which cover these stages of life observe social phenomena and whilst as cross-sectional studies they cannot establish cause and effect, they can generate theories about the nature of the relationships between exposure (weaning style or socio-demographic

characteristics) and outcome (dietary intake or UIFSM take up) consistent with a critical realist approach. Cross-sectional studies in general have many advantages, including their low cost, compared to longitudinal studies, rapidity to complete and low respondent burden (depending on study tools used) (Margetts and Nelson, 1997). This was true of both studies included here which except for the paper-based UIFSM questionnaire printing, were completed without funding (Goodchild et al., 2017; Pearce and Langley-Evans, 2021). The UIFSM study had a response rate of 26.4%. Although the response rate was higher-than-expected, responses were unlikely to be truly representative of all parents at the schools resulting in selection bias. A diverse range of parents completed the questionnaires, however, including 159 parents (23.5%) whose child did not take UIFSM (13% nationally) (Goodchild et al., 2017). The cluster analysis helped to differentiate between groups of parents, based on multiple characteristics, which are hard to determine using a simple comparison. Selection bias was also a feature of the BLW study, which recruited a high proportion of women who were white British, in managerial or professional occupations, breastfeeding and following BLW. Nationally representative surveys have shown both breastfeeding and BLW to be minority activities in the UK (McAndrew et al., 2012). Women were also recruited largely from parenting forums which limits the diversity of the sample (see section 5.7) below. Despite no mention of BLW in the study name and a statement that anyone could participate in the study, regardless of their approach to weaning, it is also likely that the sample included a high proportion of respondents who would be concerned with health or a general interested in complementary feeding (Gosling et al., 2004).

One further impact on both studies was my own agency. Prior to completing the cross-sectional studies, I had invested considerable time in researching both school food (Golley et al., 2010; Pearce et al., 2011; Pearce et al., 2013; Storey et al., 2011) and complementary feeding (Pearce and Langley-Evans, 2013; Pearce et al., 2013), along with my own experiences of BLW, which influenced the type and wording of questions used during the studies. For example, the UIFSM study provided parents with a tick list of reasons for taking/not taking UIFSM, shaped by my own understanding and work within the promotion of school meals, which was unlikely to be unbiased (Olsen, 2007). Likewise, my 'threshold' for deciding on whether a parent follows BLW is shaped by other researchers and an extensive review of the literature but may be viewed as extreme or reductionist by others (Pearce and Langley-Evans, 2021). It is not possible to be truly objective in interpreting findings when you have designed the questions used.

5.9 Baby-led weaning: Qualitative study

This study aimed to understand how individuals interpret the meaning of BLW, using an interpretative thematic approach, a form of inductive reasoning (Swift and Tischler, 2010). This is not at odds with a philosophy of critical realism and has been used in previous mixed methods studies in the development of theory about phenomena in social epidemiology and specifically in a study exploring infant feeding cues (Eastwood et al., 2014; McNally et al., 2020). An interpretive thematic approach fits with the philosophy of accepting others' approaches to weaning are socially constructed, based on their experiences, allowing meanings to emerge from the data itself (Swift and Tischler, 2010). There should be no pre-existing theory (Swift and Tischler, 2010), however, which was challenging when I had previously created an objective list of BLW characteristics and created reductive measures of adherence to the method of BLW (Pearce and Langley-Evans, 2021). Also, my previous research showed more parents reported following BLW, than were observed doing so on the day of the 24-hour recall, using objective measurements such as percentage of spoon feeding or puree use (Pearce and Langley-Evans, 2021). This suggests findings on the forums would likely be different from my own interpretation of BLW. For this reason, I chose to work together with an experienced qualitative researcher, who had not read my previous work and had fewer pre-conceived ideas about BLW. We coded the data independently before discussing and agreeing on themes.

Parenting forums offer a range of benefits for this study, such as the collection of unsolicited data discussing BLW, which is not influenced by researchers. This method has been used previously to discuss parents' response to the sugar tax and guidelines for gestational weight management (Arden et al., 2014; Swift et al., 2018). This study was the first to explore discussion of BLW on parenting forums and has allowed me to consider parents thoughts and discussion during this teachable moment.

Parenting forums offer a form of purposive sampling for complementary feeding, as researchers know this topic is often discussed (Swift et al., 2018). Parenting forums also offer researchers an opportunity to collect data under the umbrella of "netnography", although, as with all the studies in the thesis, the prevalence of higher income families is likely to be greater, due to the intensive parenting approach advocated by forums and the higher cost of intensive parenting (Faircloth and Lee, 2010; Yerkes et al., 2021). Discussion of food is a further method of developing affiliation with others (Ogden, 2010). Research on *mumsnet* has suggested that online communities use posts to establish normative values and set boundaries of what is acceptable and unacceptable, which may limit honesty and inclusivity to some extent. This

offers insights into social construction (Giles, 2016). This was noted in our study, where parents weaning their infants at 3 months of age were strongly discredited by the majority of the group. Parents in this study were self-selecting by participating in forums, and so the voices on the forum are likely to belong to a group characteristically different from, and unrepresentative of, the population as a whole (Botelle and Willott, 2020). Demographic and geographical location of forum users could not be determined, so neither could their influence on the discussion, although most users are likely to be women. Other studies which have used parenting forums have suggested data is less likely to be influenced by social desirability or recall bias (Chivers et al., 2020), also that there was no guarantee that users of parenting forums were the parents of young children or had recently introduced solid food to their children. Chivers et al. (2020) also question whether users' posts relate to their real-world experiences, or whether the positive or negative experiences with the introduction of solid food ha ves been exaggerated. Some posts may have been edited or deleted by the user, prior to data collection (Botelle and Willott, 2020) and although no users mentioned moving to direct private communication to continue discussion, this is possible on the forums. Giles (2016) discusses the use of discussion forums in psychology and how some aspects of a 'synchronous conversation' are lost online, such as tone of voice and the sequence of replies (which may have been typed at the same time and do not appear in order). Although we chose threads which had been started within the last 6 months, there were potential lapses in time, of weeks or months, between responses. Finally, working with another, experienced qualitative researcher, to code and analyse data was an unexpected challenge as we had to agree on the emergent key themes of the data and my colleague had a more relativist approach. Our initial coding was similar, but creating, agreeing, and refining themes and accepting each other's subjectivity, took longer than expected. In terms of checking methodological quality, methods such as triangulation, member checks and saturation to assess quality were not possible, although parameters for data collection and an audit trail were part of our methodology.

5.10 Estimating dietary intake in women and children

No methods perfectly measure dietary intake in free-living individuals. It is assumed that most methods will, however, provide some insight and information on the diet of an individual or group, which can be explored mathematically to generate theories about the relationships observed. Although often treated as objective measures, both multi-pass 24-hour recall (MPR) and FFQs are subjective measurements of dietary intake, which depend on information derived from the participants senses, experiences, and perceptions, which are stored in their memory

(Medical Research Council, 2021). Our ability to know the truth or exact intake of nutrients is imperfect but we can suggest reasons for associations we see in the data.

During the MAGIC study, the short form of the Dietary Instrument for Nutrition Education (DINE) FFQ (DINE© copyright holder University of Oxford) was used to estimate dietary intake (Swift et al., 2017). FFQs are easy to administer, quick to complete and have a low responder burden (Medical Research Council, 2021). DINE is a very short 19-item FFQ which has been used extensively to rank fat, unsaturated fat, and fibre intakes as low, medium, and high. It has a low participant burden and is easy to interpret and analyse which was a significant advantage for the MAGIC study. When initially developed, DINE correlated well to intakes obtained by 4-day semi-weighed food diaries (Roe et al., 1994), although some of the food items on the FFQ could now be considered dated and the tool has not been validated in pregnant women. FFQs may also be less accurate amongst younger women and those of a lower socio-economic status (Crozier et al., 2007). To supplement the DINE questionnaire, participants also reported the number of portions of fruit and vegetables that they consumed and any vitamin, mineral or supplement that they took (Swift et al., 2017).

MPR was used to collect dietary data from infants and mothers in the study of BLW (Pearce and Langley-Evans, 2021). Infant MPRs also recorded the form of each food offered (in its whole form, mashed, chopped, or pureed), how each food was eaten (self-fed or parent-fed) and whether the food was eaten with an adult present (not eating) or with an adult also eating (regardless of the type of food consumed) (Pearce and Langley-Evans, 2021). Strengths of the MPR include its ease of use, relatively quick administration, low cost, low participant burden, sensitivity to ethnic diets, flexible recording mechanism and suitability for larger studies (Medical Research Council, 2021) which were advantageous in our study which had no funding. It has been suggested that human cognition may also be more suited to retrospective recall, rather than a prospective approach, which may make them more suited for use in studies which contain large numbers of participants (Moshfegh et al., 2008).

Intakes of energy and nutrients, food group intake/exposure, meal frequency, the eating environment and meal composition can all be obtained from MPR (Medical Research Council, 2021). The United States Department of Agriculture (USDA) conduct the National Health and Nutrition Examination Study (NHANES) and have extensively explored the effectiveness of MPR, reporting that in all men and women combined, subjects underreported energy intake by 11% (although this was highest in obese women, at 21%) compared with total energy

expenditure (TEE) measured objectively using doubly labelled water (Moshfegh et al., 2008). Analyses in young children (aged 4-7) found dietary intake via 3 x MPR did not predict TEE on an individual basis but at the group level, under-reporting only averaged 3% (-54kcal/day) of TEE, although the standard deviation was very high (570kcal) (Johnson et al., 1996). MPR in 7-11-month-old infants showed a 13% overestimation in energy intake and higher intakes of all macro- and micro-nutrients using a single telephone-administered MPR, when compared to 3-day weighed diaries (Fisher et al., 2008). Although MPR and diaries recorded similar patterns of eating, greater overestimation was observed when babies consumed a greater number of food items, which could problematic amongst babies eating a range of family foods. Breastmilk intake was estimated via a fixed volume/day, based on age, similar to our study. Although this methodology resulted in less overestimation than a time-based calculation of breast milk intake, milk was another significant contributor to over-estimation. Both observations have implications for our study (Fisher et al., 2008).

Obvious limitations of this method are recall bias and social desirability bias where the participant purposefully or accidentally withholds information or alters the 'truth'. Portion size estimation is challenging for most people and inputting the MPRs was also labour intensive. One researcher inputted all the MPRs following a consistent approach and standard operating procedure, but interpretation of the food and portion sizes remains subjective. Many of the brand name foods on Nutritics® software lacked micronutrient information, in which case, the most closely matching generic food item was chosen. Cooking methods used for recipes were also not always clear and adjustments such as water lost during cooking of recipes, used average values available within Nutritics® (Bognár and Piekarski, 2000). In our study, we only carried out one MPR per participant and these were conducted during the working week (leaving out Fridays and Saturdays). Two MPRs, including one weekend day and one weekday would have provided a more accurate picture of dietary intake, but given the resources available and number of participants, one MPR per participant was thought to be sufficient.

5.11 Measuring PA in pregnant women

The International Physical Activity Questionnaire (IPAQ) is subjective, relying on the memory, honesty, and accuracy of participants (Medical Research Council, 2021). Developed to assess population-level PA, the short form of the questionnaire was suitable for MAGIC. The IPAQ-SF has good test-retest reliability and like both FFQ and MPR, is suitable for demonstrating changes over time, consistent with the study protocol (Sanda et al., 2017). Validity for the

IPAQ has been demonstrated to be low to fair in pregnant women, with active women under-reporting and inactive women over-reporting, compared to a SenseWear Armband® accelerometer (Sanda et al., 2017). Although retrospective, the IPAQ asked about PA during the preceding week and was included with each questionnaire received by participants. The IPAQ would not have been able to determine changes in PA over the first trimester of pregnancy, although supplementary questions asked about the impact the pregnancy and later, of having an infant, impacted on PA, and included open questions about changes in physical activity levels.

5.12 Self-selecting samples

Most studies on baby-led weaning have been conducted on self-selecting samples, often via the internet (Alpers et al., 2019; Brown et al., 2011; Brown and Lee, 2013; Brown and Lee, 2015; Brown, 2016; Rowan et al., 2019; Rowan et al., 2021). But such samples are subject to self-selection bias and are more likely to recruit those more involved in a subject (Gosling et al., 2004; Khazaal et al., 2014). It is likely that those with more extreme interests or involved views around weaning are more attracted to surveys which explore this. Previous studies have cited internet access as a limitation to completing studies, which may be valid amongst older studies (Brown and Lee, 2011; Cameron et al., 2013), but in 2020, 99% of 16–44-year-olds (including most parents of childbearing age) in the UK were recent internet users (ONS, 2021). Most of the studies on BLW contain data largely from white, educated women of higher socioeconomic status (Alpers et al., 2019; Brown et al., 2011; Brown and Lee, 2013; Brown and Lee, 2015; Brown, 2016; Rowan et al., 2019; Rowan et al., 2021). This is further highlighted by the proportion of UK mothers breastfeeding at 6 months, (71.9% in our study) in most surveys of BLW. A figure which is significantly higher than the 34% of babies being breastfed at 6 months, reported by the nationally representative infant feeding survey (McAndrew et al., 2012). Underweight mothers, overweight mothers, mothers who reported daily smoking during pregnancy, and mothers with fewer years in education, were less likely to follow recommendations on breastfeeding and the timely introduction of solid food and may be less likely to follow BLW (Papoutsou et al., 2018). Children living in areas with high deprivation are also more likely to be overweight (NHS Digital, 2022). Dietary quality may be lower in deprived households and where this is true, TW and commercially available infant foods may offer better nutrition than the family diet (Hayter et al., 2015).

5.13 Conclusion

The studies included in the thesis all have methodological limitations, which have been identified. In the next section, the findings from the included studies will be discussed, recognising these limitations and that acknowledging that these limitations will influence the conclusions drawn.

6.0 Published works

6.1 Article 1 (Page 8579)

McGiveron A, Foster S, **Pearce J,** Taylor MA, McMullen S, Langley-Evans SC. (2015) Limiting antenatal weight gain improves maternal health outcomes in severely obese pregnant women: findings of a pragmatic evaluation of a midwife-led intervention. *Journal Human Nutrition and Dietetics*, 28(Suppl. 1):29-37

Statement of joint authorship

Contribution to the paper by Jo Pearce

Jo Pearce contributed to around 20% of the published journal article. Jo coded, entered, and cleaned data, assisted with analysis, wrote the methodology section, and commented on the draft paper.

I can confirm that the above is an accurate description of Jo's contribution to the above paper.

Name

Professor Simon Langley-Evans

Signed

6.2 Article 2 (Page 871)

Swift JA, **Pearce** J, Jethwa PH, Taylor MA, Avery A, Ellis S, Langley-Evans, McMullen S. (2016) Antenatal Weight Management: Women's Experiences, Behaviours, and Expectations of Weighing in Early Pregnancy. *Journal of Pregnancy*, pp. 8454759-9

Statement of joint authorship

Contribution to the paper by Jo Pearce

Jo Pearce contributed around 20% of the published journal article. Jo recruited the study participants from ante-natal clinics, coded, cleaned, entered, and checked data, managed data collection at 32 weeks gestation and 2 weeks, 6 months and 12 months postpartum. Jo also assisted with data analysis, writing, and editing the draft paper.

I can confirm that the above is an accurate description of Jo's contribution to the above paper.

Name

Professor Simon Langley-Evans

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March 17th 2022

6.3 Article 3 (Page 893)

Swift JA, Langley-Evans SC, **Pearce J**, Jethwa, P, Taylor MA, Avery A, Ellis S, McMullen S, Elliott-Sale KJ. (2017) Antenatal weight management: Diet, physical activity, and gestational weight gain in early pregnancy. *Midwifery* 49: 40-46

Statement of joint authorship

Contribution to the paper by Jo Pearce

Jo Pearce contributed around 20% of the published journal article. Jo recruited the study participants from ante-natal clinics, coded, cleaned, entered, and checked data, managed data collection at 32 weeks gestation and 2 weeks, 6 months and 12 months postpartum. Jo also assisted with data analysis, writing, and editing the draft paper.

I can confirm that the above is an accurate description of Jo's contribution to the above paper.

Name

Professor Simon Langley-Evans

Signed

March 17th 2022

6.4 Article 4 (Page 9185)

Pearce J, Langley-Evans SC. (2013) The types of food introduced during complementary feeding and risk of childhood obesity: a systematic review. *International Journal of Obesity*, 37(4): 477-485

6.5 Article 5 (Page 9387)

Pearce J, Taylor M, Langley-Evans, SC. (2013) Timing of the introduction of complementary feeding and risk of childhood obesity: a systematic review. *International Journal of Obesity*, 37(10): 1295-1306

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6.6 Article 6 (Page 9589)

Pearce J, Langley-Evans SC. (2021) Comparison of food and nutrient intake in infants aged 6-12 months, following baby-led or traditional weaning: a cross-sectional study. *Journal Human Nutrition and Dietetics*; 1-15. https://doi.org/10.1111/jhn.12947

6.7 Article 7 (Page 971)

Pearce J, Rundle R. (Submitted to Journal of Human Nutrition & Dietetics) Baby-led weaning: A thematic analysis of comments made by parents using online parenting forums.

This paper was submitted for consideration at the Journal of Human Nutrition and Dietetics. The version here is a first revision, following comments made by reviewers.

6.8 Article 8 (Page 993)

Goodchild GA, Faulks J, Swift JA, Mhesuria J, Jethwa P, **Pearce, J**. (2017) Factors associated with universal infant free school meal take up and refusal in a multicultural urban community. *Journal of Human Nutrition and Dietetics* 30: 417-428

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Statement of joint authorship

Contribution to the paper by Jo Pearce

Jo Pearce contributed around 80% of the published journal article. Jo designed the study and data collection tools, recruited schools, coded and cleaned data, analysed the data and wrote the draft version of the journal article.

I can confirm that the above is an accurate description of Jo's contribution to the above paper.

Name

Gabriella Goodchild

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7.0 General Discussion

7.1 Introduction

Each of the published studies included in the thesis contains its own discussion, considering the results of that study in the context of the literature available at the time. When it was published, each study represented a unique contribution to knowledge. What follows is a general discussion of the key themes, a review of progress since the papers were published and suggestions for future research.

7.2 Key findings

The published studies found that women's weight and weight gain during pregnancy are problematised, often with no support or solutions provided. In the UK, women are expected to manage their weight gain in the absence of appropriate recommendations or tailored advice on diet or PA (Swift et al., 2016). Women would like more engagement from health professionals on weight management and pregnancy should be seen as an opportunity to reframe health promotion advice, considering both women's lived experience of pregnancy and their priorities (Swift et al., 2017). Interventions can be successful if they are tailored and personalised. Whilst pregnancy is a teachable moment for some women, others would prefer not to engage with health promotion advice (McGiveron et al., 2015).

The timing of complementary feeding and the type of food provided during the complementary feeding period have little association with the development of childhood obesity, although avoiding the very early introduction of solid food and excessive intakes of protein up to 12 months could be protective (Pearce et al., 2013). BLW delays and slows the pace of the introduction of solid foods, resulting in lower intakes of vitamins B12 and D from food and lower intakes of iron, zinc, iodine, vitamin B12 and vitamin D when intakes from food and milk are combined. Higher rates of breastfeeding are observed amongst BLW infants and both the bioavailability of nutrients within breastmilk and estimation of the volume of breastmilk consumed, may confound the differences observed. Early differences in nutritional intake have disappeared by 9-12 months, suggesting BLW babies get more proficient at self-feeding and catch up with their TW peers (Pearce and Langley-Evans, 2021). Based on the findings from our systematic reviews, a slower pace of feeding may be protective against childhood obesity risk. Parents' understanding and interpretation of BLW varies, with the use of finger foods considered as a key characteristic, even when used alongside purees (Pearce and Langley-Evans, 2021; Pearce and Rundle, n.d). Some parents consider BLW an ethos, with a purpose,

but others struggle with the process, which is clearer when following the stages of TW (Pearce and Rundle, n.d). Both TW and provision of packed lunches allow parents more control over what their child eats, and parents want to know that their child is well fed. When children start school, parents need to feel confident their child has a healthy meal, which they will eat and different subsets of parents, with differing concerns challenge schools to promote the meals they offer (Goodchild et al., 2017).

7.3 Teachable moments

The term 'teachable moment' has often been used in the study of education, but has also been used in health, to describe periods of time where individuals are experiencing change (Miller and Szymusiak, 2021; Phelan, 2010). I use the term here to discuss three life stages; women during pregnancy, parents and infants during the complementary feeding period and young children when they start school. Breastfeeding as a further teachable moment is discussed in section 7.6 below.

In addition to pregnancy and early childhood being teachable moments, they are linked by problematisation. Pre-pregnancy weight, GWG and complementary feeding are all described as problematic rather than normal stages of life which present opportunities for behaviour change. Despite the huge number of intervention studies globally, there is little consensus on how to prevent pre-pregnancy overweight and obesity or excessive GWG. Conversely, there is an overwhelming number of 'solutions' offered by commercial organisations to solve the 'problem' or process of introducing solid foods to babies. UIFSM have been presented as a moral or welfare problem, particularly during the COVID-19 pandemic in 2020-2021, where the quality and diversity of the food served in schools was reduced or replaced by providers who were unlikely to meet school food standards (Iacobucci, 2020; Rose et al., 2021). Lunchtime and school food represent a significant part of the school day for all children and should also be represented as a further opportunity for behaviour change, healthy eating and the development of longer-term eating habits. Engaging parents with UIFSM, increasing their confidence that the meals are healthy and that children will eat them, could help to ensure that children take the meals throughout primary school. Recent evidence suggests this could help to decrease obesity prevalence, reduce absence rates, and increase attainment (Holford and Rabe, 2020).

7.4 Problematisation of weight during pregnancy

The teachable moment during pregnancy represents an opportunity for women to change both their short-term behaviour whilst pregnant and their long-term behaviour in the post-partum period and beyond, which may also serve to influence the eating habits of their child. Teachable moments described in the context of behaviour change in pregnancy, suggest increased motivation amongst pregnant women is met with the opportunity for more frequent interaction with healthcare professionals during routine antenatal care (Olander et al., 2016; Phelan, 2010; Stockton and Nield, 2020). Although pregnancy amongst women living with overweight and obesity, along with the potential for excessive GWG is described as 'the biggest threat to women's health' by the medical community, women report a lack of engagement and tailored advice (Swift et al., 2016). NICE guidelines also recommend that dietary advice from pregnant women should be 'practical and tailored' (NICE, 2010). Women reported not receiving this, however, most likely because of time pressures and a need to prioritise by midwives, or a reluctance to alienate women early in their antenatal care, particularly if they live with overweight or obesity (Heslehurst et al., 2015). Even though women in our study weighed themselves at home and did not express concern at being weighed, there are no weight gain recommendations for pregnancy in the UK (NICE, 2010; Swift et al., 2016). The NHS website states that most women gain between 10kg and 12.5kg during pregnancy but is vague about what counts as not enough or too much weight (NHS, 2018). Women obese at their booking appointment may be referred to a dietitian or consultant-lead care but those who are overweight and potentially at greatest risk of excessive GWG, would not. There is no clear pathway for referral to a dietitian unless women are living with obesity, even though many women would benefit from a consultation and this would take the pressure off midwives to provide weight management advice (Super et al., 2021). Women also report a broad range of experiences and behaviours related to diet and PA during pregnancy, which can only be addressed by tailored advice (Rockliffe et al., 2021; Swift et al., 2016).

Women may also (quite rightly) feel that overweight and obesity in pregnancy is excessively problematised, placing women at the centre of the 'war on obesity', and making women feel guilty for the poor management of their own health and both their baby's short and longer-term health (Parker and Pausé, 2018).-There are other potentially negative implications arising from the discussion of health promotion. As well as guilt, pregnant women and new mothers may experience stigma because they are living with overweight or obesity at the start of their pregnancy, or because they have gained excessive weight whilst pregnant. Conversations

around weight may exacerbate this and cause women to become disenfranchised with health promotion activity (Arden and Abbott, 2015; Parker and Pausé, 2018). Parker and Pausé (2018) go further and suggest that the anti-fatness discourse within public health and medicine constructs women's bodies as 'defective, deviant, and dangerous', both oppressing women and potentially creating a negative and medicalised start to their parenting experience. Women are made responsible for their health, despite the inequalities in healthcare or capability/opportunity they may suffer (Olander et al., 2016; Parker and Pausé, 2018). Although a high BMI during pregnancy increases the risk of adverse health outcomes for both mother and infant, weight stigma during pregnancy can also negatively affect maternal psychological health, which increases the risk of maternal stress and postnatal depression and may also have implications for the infant including lower birthweight, prematurity and increased levels of cortisol (an indicator of stress). These have the potential for long-lasting health implications for the infant (Field et al., 2006). Approaching a discussion around weight must, therefore, be sensitive and non-stigmatising (Incollingo Rodriguez et al., 2019) . Alienating women or making antenatal appointments an area where women feel stigmatised may be detrimental to the health of women and their babies. Research with pregnant women has shown that they welcome discussion around weight and would prefer to know the risks associated with their weight or behaviour. Women also want to be treated with respect and non-judgementally (Christenson et al., 2019). Our studies suggested reframing health promotion advice to talk about nutrients which nourish the baby and alleviate pregnancy symptoms, which is in accordance with other studies which suggest acknowledging weight is a sensitive issue, that losing weight is challenging and that using open body language and using terms such 'weight category, BMI and weight change' rather than 'overweight or obesity' are less negatively loaded (Christenson et al., 2019). Women also want a treatment plan, which when translated into implications for practice, is where a referral to a dietitian could be helpful.

A further issue with health promotion is that ~~Some~~ women may already follow, or think they follow, guidelines for healthy eating or physical activity and have no need for change (Lee et al., 2016; Malek et al., 2016). Others believe healthy eating is unaffordable or view pregnancy as a time when they can finally have a break from healthy eating as the expectations and normal rules around food consumption eased (Rockliffe et al., 2021; Stockton and Nield, 2020). In our study, we also reported that supplements may be used as insurance to cover poorer food choices and released women from the need to eat healthily (Swift et al., 2017). Women reported eating more since becoming pregnant and 82.9% reported changing the type of food and drink that

they ate. Although the predominant reason for change was to avoid foods which may pose a risk to the foetus, many women changed their eating behaviour to cope with gastrointestinal problems (nausea, heartburn, constipation, and feelings of fullness), perceptual changes (in taste, smell or texture) or to combat an increase in appetite or low energy levels (Swift et al., 2017). Other than some advice on nausea, there is little mention of coping with these changes in official guidance and women's individual lived experience is not recognised in a "one size fits all" approach (NHS, 2020a). Midwives and dietitians could focus on relieving these symptoms as an opportunity for behaviour change. Moreover, sStandard guidance for healthy eating in pregnancy may not be culturally appropriate for all women (Stockton and Nield, 2020; Swift et al., 2017). Finally, tThe changes in eating behaviour reported in our study also occurred very early in pregnancy, further emphasising the need for early, individual, tailored support, which considers the diverse and challenging experiences that women encounter. Since publication of our study, studies exploring weight stigma have suggested health professionals may generalise about the lifestyle of women living with obesity, focusing on weight rather than health (Incollingo Rodriguez and Nagpal, 2021). This further emphasises the problematisation of weight within maternity services and a lack of focus on women's' lived experiences. Other dietary concerns may also be ignored. A very recent dietary survey of pregnant women in Liverpool revealed that whilst energy intakes met DRVs, intakes of sugar and saturated fat were high and intakes of iron, iodine, folate, and vitamin D were low (Charnley et al., 2021). Focussing on the quantity of food eaten, rather than the quality of the diet may have the desired effect of preventing excessive GWG but may pose additional risk to women living with both obesity and micronutrient deficiency, two risk factors for obstetric complications (Charnley et al., 2021).

7.5 Reframing health promotion advice

Olander et al. (2016) suggest that women require capability and opportunity as well as motivation to affect behaviour change. Being told to exercise more when you your lived experience of pregnancy is one of continued physical discomfort may be interpreted by women as a lack of understanding by health professionals. Framing behaviour change in terms of how to cope with these lived experiences, by suggesting PA to improve mood and low energy levels and a healthy diet which also alleviates gastrointestinal symptoms, food cravings and an increased desire to snack (Swift et al., 2017). Other researchers have suggested emphasising nutrients for good maternal and foetal health, rather than a focus on reduction or limitation (Charnley et al., 2021). Identifying barriers and facilitators may help to tailor advice but

requires midwifes to undertake relevant but lengthy and specialised training which may be unrealistic. Although ad hoc conversations between midwives and pregnant women have proved beneficial for health promotion (Lawrence et al., 2020), midwives still require time and specialist training to focus on behaviour change. It is also questionable whether dietary counselling and behaviour change should fall under the remit of midwives, when other health professionals are better equipped for this (Mahase, 2022; Olander et al., 2016). Furthermore, our study found that adaptions to diet and PA (whether positive or negative) made during pregnancy are not considered 'normal' by women and may not be maintained beyond pregnancy (Swift et al., 2017). Olander et al. (2016) suggest that breastfeeding, the 6–8-week postnatal check, introduction of solid foods and returning to work after maternity leave may present further teachable moments to reinforce behaviour change, but except for the 6-8-week postnatal check, these teachable moments may not bring women into contact with health professionals in the same way as pregnancy. If women are to maintain a healthy diet and adequate PA following the birth of their child, positive reinforcement may be required at each of these teachable moments, considering women's current situation and challenges.

In our study, many women reported intuitively knowing what they needed to eat and that they were 'listening to their bodies' (Swift et al., 2017). This 'wisdom of nature' heuristic may be hard to challenge in terms of cravings or food consumed during pregnancy but could be used positively to encourage intuitive eating and responsive feeding of babies postnatally (Swift et al., 2017). Regardless of who promotes healthy eating to pregnant women, our paper suggested that conversations around diet and physical activity in pregnancy should counter the negative reductionist dialogue around GWG, by focussing on empowerment and the body's capabilities (Swift et al., 2016). Promoting healthy behaviours during pregnancy as the start of a journey towards healthy eating and adequate physical activity for the whole family, rather than with a focus on maternal weight or weight gain weight, could result in establishing longer-term eating habits, which also impact on children.

The Bumps and Beyond evaluation showed that a tailored, personalised intervention can achieve a reduction in GWG amongst women with a pre-pregnancy BMI >35kg/m^2 with some reduction in gestational hypertension, pre-eclampsia, and pregnancy complications (McGiveron et al., 2015). Bumps and Beyond included eight one-to-one appointments and included advice on diet and physical activity, along with monitoring of changes by specialist midwives and healthy lifestyle advisors. Despite the limitations of the study (it was not an RCT, only half of the women invited into the intervention chose to take part and all women fell

into obesity classes II or III), it was successful (McGiveron et al., 2015). Other larger, well-conducted and resource-intensive trials such as UPBEAT and LIMIT used dietitians and research staff to achieve some success, which was more pronounced amongst women with class III obesity, compared to classes I or II, in the UPBEAT trial (Peacock et al., 2020). Other trials have demonstrated smaller reductions in GWG, however, with little effect on clinical outcomes (Dodd et al., 2010; Poston et al., 2015). UPBEAT followed women after they had given birth and found that taking part in the intervention resulted in both improved maternal diet and reduced infant adiposity at 6 months post-partum (Patel et al., 2017). Breastfeeding was also protective against increasing weight z-scores amongst children of women with a BMI $\geq 30 kg/m^2$ in the trial (Patel et al., 2018).

Since the publication of our studies (McGiveron et al., 2015; Swift et al., 2017; Swift et al., 2016) the literature has of course, moved on. Interesting developments relevant to our findings have include the use of tailoring the intervention dosage for each study participant and using Smartphone Apps to monitor diet and physical activity (Downs et al., 2021; Lawrence et al., 2020). The results have been mixed but none resulted in a significant reduction in GWG, even where weekly tailored consultations with a dietitian were used. The intervention group (n=15) had a 21% lower, but non-significant reduction in GWG, compared to a control group (n=16) receiving standard care. Sessions included GWG, PA, healthy eating goals and energy intake which were monitored using activity monitors, the MyFitnessPal phone app and mHealth resources (Downs et al., 2021). Smartphone apps have not had any effect on GWG but mixed success in reducing GDM (Kennelly et al., 2018; Sandborg et al., 2021; Yew et al., 2021). Effective interventions are resource-intensive, often achieve little success but achieve more success in women of higher weight categories. Advice which focuses less on pregnancy and more on longer-term eating patterns may be more effective across BMI categories and have a more pronounced impact on infant outcomes.

NICE recommend weight loss before or after pregnancy to improve pregnancy outcomes and prevent weight retention or a higher weight during subsequent pregnancies (NICE, 2010). Non-pregnant women do not receive the specialist support available during pregnancy but have the advantage of explicit guidelines for an ideal weight (WHO, 2021a). Pre-pregnancy BMI is a stronger predictor of pregnancy outcomes than GWG so weight management services may be better targeted here. Public health measures to prevent or reduce the prevalence of obesity, however, have largely remained ineffective (Jebb et al., 2013) but if tailored, individual advice works for pregnant women, then perhaps weight management services should be free for and

targeted at women of child-bearing age or at least for women who are planning a pregnancy. This could make more of a difference, clinically, than addressing obesity/excessive GWG once women are pregnant.

Finally, most of the studies included in the thesis focus on pregnant women or mothers who are white and living in a household classed as professional or higher managerial (classes I and II) (McGiveron et al., 2015; Pearce and Langley-Evans, 2021; Pearce and Rundle, n.d; Swift et al., 2017; Swift et al., 2016). These women have spent longer in education, have a greater disposable income and could have better coping strategies (for example access to a car, childcare or a cleaner), affording them a greater opportunity to research recommendations, buy the foods required for a healthy diet, access to gym classes and leisure facilities and engage with the intervention (Stockton and Nield, 2020).

7.6 Breastfeeding as a further teachable moment

There is conclusive evidence that breastfeeding promotes both maternal and infant health (Ip et al., 2007; Kramer and Kakuma, 2002), but despite this, breastfeeding rates in the UK, remain low compared to other countries (McAndrew et al., 2012; Unicef, 2022). Promoting breastfeeding and ensuring a supportive and enabling environment for women who want to breastfeed, remains a key objective for public health in the UK (Unicef, 2022). Olander et al (2016) identified breastfeeding in their list of potential teachable moments. There is no elaboration, but it would be assumed this related to both the promotion of breastfeeding and encouragement for women to adopt healthier behaviours whilst breastfeeding. One of the key challenges of promoting breastfeeding is the short time frame within which breastfeeding needs to be established. If the baby does not feed or is fed with formula milk, then milk production slows and stops within a few days (although this may be longer in some individuals). Breastfeeding must, therefore, be established as soon as possible after birth, and continued regularly, in pace with demand by the infant, if it is to be successful. Although this comes at a time where women are vulnerable and face many challenges as they recover from birth and care for their new baby, birth also brings women into contact with midwives, other health professionals, peer supporters, family and other breastfeeding mothers, which all have the potential to promote and support breastfeeding.

There is no research relating specifically to breastfeeding in the thesis, although the close association and confounding which exists between milk feeding and complementary feeding is discussed (Pearce & Langley-Evans, 2013; Pearce et al., 2013, Pearce & Langley-Evans,

2021). Research exploring breastfeeding was not omitted by design and I would have liked to have used existing data to explore the breastfeeding and weight-related experiences of the MAGIC cohort up to 12 months post-partum, or micronutrient intake in the mothers of infants included in the TW versus BLW cross-sectional study, from whom I collected MPR data (Pearce & Langley-Evans, 2021). The omission of breastfeeding does leave a significant gap, however, in the exploration of teachable moments through pregnancy to early childhood and this needs to be recognised. Also worth mentioning in the context of teachable moments is the over-emphasis of a healthy diet whilst breastfeeding, which may cause women to think they cannot breastfeed and deter women from continuing to breastfeed their babies. The websites of formula milk companies list essential foods and nutrients, intimating that a healthy (and expensive) diet is essential for breastfeeding and eating 'enough but not too much' is required to maintain milk supply (Aptamil, 2022). In reality, the Institute of Medicine (1991) state that a diet which fails to meet dietary reference values will have little impact on the nutritional quality of breastmilk. Macronutrients and most minerals can come from a woman's diet or her stores and it is only when women are severely malnourished that there may be an impact on some breast milk components (some vitamins, iodine or selenium), although evidence for this is lacking (Institute of Medicine, 1991).

7.7. The timing and type of solid food introduction

Complementary feeding presents another teachable moment (Olander et al., 2016). The timing of the introduction of solid food, the type of food provided to infants and the method by which food is introduced is complex and can be a source of stress or anxiety for parents (Pearce and Rundle, n.d). In England, health visitors are scheduled to visit infants at 6-8 weeks and at 9-12 months, but this does not routinely bring them in to contact with families at the recommended age for the introduction of solid food (NHS, 2020d). Parents may also mistrust complementary feeding advice from health visitors and turn to friends, family and the internet for advice, where advice of varying quality abounds (Arden, 2010; Garcia et al., 2019).

Guidelines for the timing of the introduction of solid foods are clear and have not changed in the UK since 2003 (DoH, 2003; NHS, 2019c; SACN, 2018; WHO, 2002). Despite this, parents often choose to introduce solid foods early (Alder et al., 2004; McAndrew et al., 2012). Parents with fewer years in education, a lower socioeconomic status and a higher BMI are also more likely to introduce solid foods to their infants earlier than recommended (Doub et al., 2015; McAndrew et al., 2012). Our systematic review revealed that the very early introduction of solid foods (≤3months) may increase the risk of later childhood obesity, but it is likely that the

type of milk feeding (breast or formula), the family diet (≥12 months) or other socio-demographic factors are stronger predictors of childhood obesity (Pearce et al., 2013).

Studies in Cambridge and Rotterdam (see section 2.2.1), published after our review, also explored the relationship between the timing of the introduction of solid food and childhood obesity risk. Both found evidence of reverse causality, that is, heavier or faster-growing babies were introduced to solid foods earlier as their parents perceived milk feeding alone was not sufficient for their growth (Abraham et al., 2012; Vail et al., 2015; Van Rossem et al., 2013). The last infant feeding survey (2010) reported that 52% of parents introduced solid foods before 6 months because they perceived the baby was no longer satisfied with milk feeds (McAndrew et al., 2012) and in other smaller, qualitative studies, mothers said that they intuitively knew when their baby was ready for solid food (Walsh et al., 2015), similar to the 'wisdom of nature' heuristic reported by women in the MAGIC study (Swift et al., 2017). Parents keen for their baby to reach their next developmental milestone clearly misinterpret other normal infant behaviours such as a baby's interest in their food or watching them eat, chewing their fists or waking at night, believing them to be a sign of hunger (Brown, 2017; McAndrew et al., 2012). The early introduction of solid food displaces breast or formula milk from the diet, most likely with purees made from fruit, vegetables, or infant cereal, which are of a similar energy density but poorer nutrient density (Brown, 2017). This could mean infants are receiving poorer nutrition because of the early introduction of solid food and health professionals need guidance and training on how to challenge parents' beliefs, to encourage more families to wait until around 6 months. Many behaviour change models encompass social norms and beliefs, but translating these theories into practice, especially as a busy health professional, during a short visit or consultation, is challenging. Also, the timing of health visitor visits means this valuable teachable moment is underutilised. The Government Start4life website provides clear guidance on waiting until around 6 months, with a focus on the signs of readiness for solid food and frequently asked questions for parents (NHS, 2019c). Despite this, the average age at which solid foods are introduced remains at (estimated from small or older studies) around 5 months (Garcia et al., 2019; McAndrew et al., 2012).

The type of food or food group introduced during the complementary feeding period had little impact on later childhood obesity risk (Pearce et al., 2013). There was some suggestion, however, that higher energy intake and high intakes of protein, particularly from dairy foods could be associated with a higher BMI or fat mass during childhood (Pearce and Langley-Evans, 2013). Intake from food during the complementary feeding period was heavily

confounded by milk feeding in the studies in our review, but one suggestion is that formula feeding contributes to a higher intake of protein. Reviews exploring growth in breast versus formula fed infants found formula fed infants have a higher weight gain than breastfed infants, consisting of higher lean mass and more visceral fat. Although overall percentage of body fat was the same in both breast and formula-fed infants, breastfed infants have greater deposition of subcutaneous fat which could be protective against metabolic risk and obesity (Dewey et al., 1991; Gale et al., 2012). A trial which randomised infants to follow a lower or higher (1.77 or 2.20g/100kcal) protein formula, found infants on the lower protein formula had a lower weight for length z score, similar to breastfed infants (Koletzko et al., 2009). The protein content of breast and first (stage 1) formula milk are usually equivalent, but formula milks contain more casein and follow-on milks are higher in protein than breast milk (Finglas et al., 2015; Nutritics, 2021). Follow-on milks are not necessary, as stage 1 formula continues to provide sufficient energy and nutrients beyond 6 months of age. They are widely used, however, and are also mis-used (introduced earlier than recommended, prior to 6 months) by some parents, increasing protein intake amongst younger formula-fed babies (Brown et al., 2020; Langley-Evans, 2022). Formula-fed infants are more likely to receive solid food earlier than breast-fed infants and if these infants progress quickly on to protein-rich foods, this could further increase protein intake. The recent article by Caroli et al (2021) modelled different diets and suggested that the foods offered during complementary feeding should be different for breast and formula-fed infants because the milks are so different and should be complemented differently for optimal nutrition. They suggested that formula fed infants should be offered fewer protein-rich foods from 6 months, to prevent excessive intakes of protein, especially when using follow-on milks (Caroli et al., 2021). A recent RCT in Sweden randomised infants to follow a standard or reduced protein (26% decrease) diet from 6-18 months, but the diet did not depend on the type of milk feeding (Johansson et al., 2019). Babies compensated for lower protein intake by consuming more carbohydrate from fruit and vegetables (the purpose of the study) but no difference in growth or iron status was observed (Johansson et al., 2019). In our BLW study, infants following BLW were more likely to be offered protein and dairy foods, although intakes of protein were not significantly different between TW and BLW groups. The slightly later study by Rowan et al. (2021) found TW babies consumed more protein at 26-39 weeks (9.7g compared to 4.6g from food only and 18.9g compared to 13.9g from food and milk combined). The major limitation in our study, as with Rowan et al. (2021) and previous studies comparing TW and BLW, is the estimation of breastmilk intake, which makes accurate comparisons around protein intake impossible (Alpers et al., 2019; Dogan et al., 2018; Morison et al., 2016;

Morison et al., 2018; Williams Erickson et al., 2018). Interestingly, the protocol for a new BLW study in New Zealand, published by Taylor et al. (2021), will be the first to measure breast milk intake using a stable isotope method rather than using infant weighing or estimated intake per feed or per day. A comparison between the results of this study and those previously published, based on estimation of breastmilk consumed, will add a valuable contribution to the evidence base, particularly around protein intake and any association with growth parameters.

Our study found that babies ate different food from their parents, on the day of measurement, at 6-12 months of age. This was the case with babies following both TW and BLW, even though BLW infants had a slightly higher similarity to their parents (Pearce and Langley-Evans, 2021). This is not consistent with the ethos of BLW but is consistent with dietary guidelines to feed more energy and nutrient dense foods to infants, and with previous qualitative studies where the early complementary feeding period is recognised as a special, separate time for infant food (Nielsen et al., 2014). In another UK study, parents qualitatively reported giving infants following BLW an adapted or supplemented version of family meals (Arden and Abbott, 2015) which is also demonstrated in our study (Pearce and Langley-Evans, 2021). Other ~~studies have~~research has shown that when babies reach 12 months, parents may relax and feed their infant similar meals to themselves (Nielsen et al., 2014). It was expected that as infants got older, they would show a preference for foods consumed by adults and older children, for example, sugary foods, which parents knew were unhealthy. Despite this, sugary or other discretionary foods are often ascribed social and cultural importance, and so parents felt they should introduce these into their child's diet as they would eat them sooner or later anyway, and to fully integrat~~ing~~e them into the family's shared food experiences (Nielsen et al., 2014). Our systematic review found that the family diet beyond 12 months and general adherence to dietary guidelines had a more significant impact on later obesity outcomes, than the types of food given during the complementary feeding period (Pearce and Langley-Evans, 2013). Assimilation into the family's food culture may result in deviation from the Eatwell Guide, towards which children should transition between 12 and 24 months (NHS, 2019b). The 'family diet' does not necessarily mean a healthy diet, especially where families are unable to afford a wide range of healthy foods for their children or where the preparation of separate meals is onerous. This issue may prove problematic for health promotion and the promotion of BLW on the grounds of improved health outcomes. In terms of an impact on practice, health professionals need to highlight the need for adherence to healthy eating guidelines for children under 2 years, such as keeping salt and free sugars to a minimum. Whilst this could benefit the

whole family by improving the family diet, this advice could also have the unintended consequence of a high cost for families who buy expensive commercial infant foods or other 'healthy' foods for their children.

Considering nutritional intake, in our study, babies who followed BLW consumed less energy from food and more energy from milk than TW infants (although this was not significant) at 6-8 months (Pearce and Langley-Evans, 2021). They also consumed less iron, iodine and zinc from food and milk combined. Intakes of iron and zinc were low amongst all the babies in the study. All the younger babies and older BLW consumed below the RNI for iron with 44.4% of younger TW babies and 62.5% of younger BLW babies consuming below the LRNI. Younger BLW infants, on average, also consumed an amount of zinc below the RNI, with 25% of BLW babies and 5.6% of TW babies falling below the LRNI (Pearce and Langley-Evans, 2013). This suggests less food was consumed by younger BLW infants, when compared to those following TW, a result very similar to the study published just after ours (Rowan et al., 2021) and a study in Canada which found BLW infants had a slower feeding pace but better grasping skills score and fine motor quotient score than TW infants (Campeau et al., 2021). Although the pace of feeding in BLW babies was likely slower in both studies, the need to include foods rich in iron and zinc, early in the complementary feeding process is highlighted. Even if infant iron stores were good at birth and taking bioavailability of minerals in breast milk into account, infants could be at risk of poor iron and zinc status, especially where the family diet or maternal nutritional status during pregnancy was potentially poor. Confusion around the process of BLW has been highlighted by parents (Pearce and Rundle, n.d) and so much clearer guidance around which foods to introduce early are required. Part of the ethos of BLW is for the baby to consume family foods but it is also clear from our work and qualitative work carried out previously (Arden and Abbott, 2015), that families are replacing family foods or supplementing the baby's diet with additional or alternative foods. These could be opportunities to focus on iron and zinc-rich foods to improve dietary intake.

Our study comparing nutritional intakes between infants following BLW or TW present a self-selecting sample of mothers who have successfully followed a BLW approach (see section 5.10). Rates of breastfeeding were more than double the UK average and the sample was clearly not representative. BLW was likely positive for this group, as they chose to start and continue using BLW beyond the initiation of solid food. Mothers who struggled or decided against the method may not be well represented, along with mothers who displayed less positive or healthful behaviours towards their infant. A BLW approach does not necessarily involve

healthy foods and positive feeding behaviours and this needs to be recognised. Many of the parents forgot to take their vitamins or give vitamin D to their breastfed infants which also suggests some complacency towards guidelines, even amongst women likely to be well nourished and healthful. Despite its flaws, however, our study both adds to a growing evidence base around BLW and highlights the paucity of the data, for example, a lack of understanding of how infants are fed in lower-income or minority ethnic families in the UK.

7.8~~7~~ Are TW and BLW different?

Our study explored what BLW means to parents and their adherence to characteristics of BLW. We found that although parents agreed BLW had an ethos, they followed this to different extents, with loose adherence to the key characteristics (allowing the baby to self-feed, feeding foods in their whole form, the baby sitting in on family meals and eating the same food as the rest of the family) (Pearce and Langley-Evans, 2021). Several authors have called for a broader definition of BLW to encompass strict and loose adherence and have included three groups in their analysis (Brown, 2017; Komninou et al., 2019; Morison et al., 2016). This may be a more representative of the picture of weaning style employed. This is further emphasised by our research which showed that far more parents report following BLW and report lower use of spoon feeding and purees than were observed in their 24-hour recalls (Pearce and Langley-Evans, 2021). The social desirability of BLW, along with misreporting of its use can make findings difficult to interpret, particularly when looking at longer-term outcomes in children, such as obesity or eating habits. Conversely, self-selecting samples could attract participants at the extremes, where the use of spoon feeding or purees are militantly avoided, which would also make generalisations questionable. The results of retrospective studies or where parents self-report use of BLW should also be interpreted with caution. Arden & Abbott (2013) noted a 'discursive gap' between BLW and TW, where BLW was 'idealised', and TW was 'devalued', similar to the way in which breastfeeding is seen as superior to formula feeding (Knaak, 2010). Although the evidence base for BLW is nowhere near as convincing as the evidence base for breastfeeding, BLW may be viewed as healthier due to its associations with breastfeeding. This may serve to cloud real discussion or differentiation between TW and BLW and prevent participants from being honest. If BLW is perceived as making someone 'a better parent', BLW may be adopted where intensive parenting is the prevailing norm, and parents are concerned with how best to use resources (energy, time and money) to maximise children's health and educational opportunities (Fuentes and Brembeck, 2017; Meyer and Milestone, 2016). BLW has been associated with better health outcomes such as a healthier relationship

with food, less picky eating, better appetite control and healthier weight gain (Brown et al., 2017) which are outcomes that parents want for their children. Alternatively, parents may just follow BLW because they want a more relaxed approach, free from being bogged down in what, where, when and how much food to give their baby, where the baby fits in with the rest of the family. This approach is comparable to previous research which found mothers who followed BLW had lower levels of anxiety around CF and feeding children, and scored significantly lower on scales measuring control, restrained eating, anxiety and introversion and obsessive-compulsive symptoms (Brown and Lee, 2011; Brown and Lee, 2015; Komninou et al., 2019).

7.98 Process versus purpose

The purpose of responsive feeding is to promote appetite regulation in infants. A further purpose of complementary feeding is for the infant to transition to a healthy family diet where a diverse range of foods are consumed. Previous research has established that parents are aware of dietary guidelines and want the best for their children (Nielsen et al., 2014). Our research suggests, however, that these purposes may be forgotten as parents struggle to find a process within BLW (Pearce and Rundle, n.d). Women frequently turn to family for advice, which may be based on outdated guidance, where purees were the only complementary feeding option and were introduced from 3 months (Matvienko-Sikar et al., 2018). The more process-focussed 'stages' of traditional weaning, along with recipes for fruit and vegetable purees or other baby-suitable foods, offer a step-by-step guide, over which parents may feel they have more control. Labelling of commercial infant foods into foods suitable for different stages and staged formula milks give the impression of growth or reaching developmental milestones, which parents are keen for, evidenced by the prevalence of early introduction of solid food. This may be comforting and relieve anxiety around complementary feeding for some families as they feel a sense of progress. Parents know what and how much their baby has eaten and can be satisfied that their baby is adequately fed (Pearce and Rundle, n.d). These feelings of control and a need to monitor intake were also important in our study of UIFSM.

7.109 Control

Parents are important role models in the development of children's eating habits. Parents provide food to their children, demonstrate how, what, when and how much to eat and also share cultural and familial beliefs and practices around food and eating (De Cosmi et al., 2017). Studies have shown that fruit and vegetable preference in children correlates with fruit and vegetable presence and availability within the home and that homes with greater availability

had higher self-efficacy and knowledge amongst parents (Hearn et al., 1998; Savage et al., 2007). Role modelling may also exert a stronger influence of children's food choices than parental control (Dickens and Ogden, 2014). If children are eating with their family and witnessing others eat food, infants were more likely to accept those foods themselves (Nicklaus, 2011). Role modelling also occurs when children are amongst their friends, with children likely to eat more when their friends or co-eaters eat more and favour foods consumed by other children (Houldcroft et al., 2014). This could serve to improve the food choices of children at school, where children eat similar meals together and represents a significant teachable moment in the lives of young children. If meals are healthy and appetising, eating UIFSM could help to prevent or resolve picky eating or food refusal in children aged 4-7 years. This fits with the wider need for lunch to be recognised as an important part of the school day and part of a whole school food policy (Dimbleby, 2021). We identified three subsets of parents, however, whose children did not take UIFSM (Goodchild et al., 2017). Firstly, those where the decision was parent-led, who were unimpressed by the menu and wanted to provide their own food. We suggested that these may be authoritative parents with strong feelings and a high level of demandingness about their child's diet. Secondly, those whose decisions were joint (parent and child-led), concerned with what and how much their child eats, and who worry about their child not eating the meals provided. Finally, those who are child-led, possibly more permissive and let the child decide on a packed lunch and potentially what goes into that packed lunch.

Concerns about the quality of meals may be justified. The physical quality of food, the quality of the cooking and food presentation is highly variable between schools, even when school meals meet food-based or nutrient-based standards. Our first two groups of parents, however, appear to retain some control over what or how much their child eats. This refutes trust in the child and does not follow the principles of responsive feeding by allowing children full autonomy over their food choices at school.

7.110 Recommendations

Weight gain recommendations for the UK would offer pregnant women something to aim for and counteract women from sourcing information elsewhere or engaging in unsafe weight monitoring practices or weight control.

Reframing and tailoring health promotion advice during pregnancy, to reflect women's lived experiences of diet and exercise. Advice should empower women and not blame them for living with obesity.

Promoting the introduction of solid food from around six months, arming health professionals with strategies to help parents achieve this recommendation. Despite the wealth of evidence to the contrary, parents continue to introduce solid foods early.

Promoting the daily use of vitamin D supplements amongst breastfeeding women and breastfed infants.

Promoting iron-rich and zinc-rich foods from 6 months but avoiding high intakes of protein during the complementary feeding period, especially where follow-on milks are used.

Including and promoting safe and appropriate BLW advice in guidelines, to allow health professionals to promote BLW safely and avoid alienating followers of BLW.

Continue to promote UIFSM as an opportunity for children to eat with their friends and peers, not just as a money-saving or time-saving option.

Promote healthy, well-cooked food within schools which help to address parents' anxiety over what and how much their children eat at school.

Key to supporting teachable moments, pregnant women, parents of children aged 6-12 months and children aged 4-7 should feel supported and not judged during their interactions with health professionals or care providers.

7.12~~1~~ Future research

Pregnancy, the complementary feeding period and when children start school offer teachable moments which may influence the long-term health outcomes of both women and children. Studies which explore the long-term impact of healthy dietary advice during pregnancy are limited. One key area for future research is for long-term studies which explore long-term health outcomes, beyond the immediate clinical outcomes of pregnancy or growth of children during the first year.

It is also a major priority, to explore the barriers which prevent women from taking up referrals to a dietitian as part of their antenatal care, where issues around weight might be better addressed. Women in our study did not mind talking about their weight with their midwife, but often weight concerns were ignored, and midwives suffer from a lack of time, training, and

resources. Understanding the barriers which currently exist is a critical first step to designing effective programmes for mass introduction, which have the capacity to minimise the impact of overweight on pregnancy outcomes.

There are key gaps in the evidence base in the UK as a result of the UK Infant Feeding Survey having been abandoned, after 2010, ~~in 2015~~ and responsibility for monitoring rates of breastfeeding moved to the devolved governments. Re-introducing the UK Infant feeding survey would help to: 1) Establish whether the age at first introduction to solid food continues to get closer to 6 months or whether stronger, clearer messaging is necessary; 2) Determine the prevalence and adherence to BLW; 3) Explore the complementary feeding practices of low-income families, who are underrepresented in most surveys.

A large, long-term cohort study exploring the impact of BLW on longer-term health outcomes would help to strengthen the evidence base of small studies that currently exists. Recruitment of more lower income and ethnic minority families and families ~~who feed~~using infant formula would also broaden the range of experiences from those of White British, well-educated, breastfeeding women in higher managerial or professional occupations, and determine whether differences in intake between babies following BLW and TW are actually, due to differences in the weaning style, income or breastfeeding.

The development of a simple tool which measures more aspects of BLW, before classifying parents as following BLW or TW would be useful, to achieve a stronger consensus and less reductive definition amongst researchers. Many parents described following BLW as their baby did not take to food (Pearce and Rundle, n.d). An exploration of weaning intention would capture the experiences of parents who start with one weaning method (TW or BLW) and then change when their baby does not eat as they intended. A larger study (than Rowan & Harris, 2012) of the impact of household diet on dietary intake during BLW (or the impact of BLW on the family diet) would help to demonstrate whether BLW is suitable in households where diet is poor, or whether BLW encourages the rest of the family to eat more healthily.

7.13~~2~~ Conclusion

There are teachable moments throughout pregnancy and early childhood, which offer an opportunity to improve the diets of women and shape the development of healthier eating habits in infants and young children. Despite awareness of these teachable moments, they are often lost due to a lack of time, training, understanding or evidence base. This results in failure to convert the teachable moment into a learnable moment. It is time to shift the focus away from

the problematisation of weight and diet during pregnancy and of diet in early childhood. Instead, health promotion should be reframed to focus on the promotion of long-term healthy eating habits of women as the gatekeepers of the family diet. Empowering women and families to support better adherence to dietary recommendations during pregnancy, the timely introduction of appropriate and varied complementary foods and encourage the take up of school meals.

8.0 References

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