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Are mothers less likely to breastfeed in harsh environments? Physical environmental quality and breastfeeding in the Born in Bradford Study

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Abstract

We use the UK's Born in Bradford study to investigate whether women in lower-quality environments are less likely to breastfeed. We use measures of physical environmental quality (water disinfectant by-products (DBPs), air pollution, passive cigarette smoke, and household condition) alongside socioeconomic indicators, to explore in detail how different exposures influence breastfeeding. Drawing on evolutionary life history theory, we predict that lower environmental quality will be associated with lower odds of initiating, and higher hazards of stopping, breastfeeding. As low physical environmental quality may increase the risk of adverse birth outcomes, which may in turn affect breastfeeding chances, we also test for mediation by gestational age, birthweight, baby's head circumference and abdominal circumference. Our sample is comprised of mothers who gave birth at the Bradford Royal Infirmary in West Yorkshire between March 2007 and December 2010 for whom breastfeeding initiation data was available. Analyses were stratified by the two largest ethnic groups: White British (n=3,951) and Pakistani-origin (n=4,411) mothers. After controlling for socioeconomic position, Pakistani-origin mothers had lower chances of initiating, and higher chances of stopping breastfeeding with increased water DBP exposure (e.g. OR for 0.03-0.61 vs <0.02μg/day dibromochloromethane exposure 0.70 [0.58-0.83], HR 1.16 [0.99-1.36]; greater air pollution exposure predicted lower chances of initiation for both ethnic groups (e.g. OR for 10μg/m³ increase in nitrogen dioxide 0.81 [0.66-0.99] for White British mothers and 0.79 [0.67-0.94] for Pakistani-origin mothers) but also a *reduced* hazard of stopping breastfeeding for White British mothers (HR 0.65 [0.52-0.80]); and exposure to household damp/mould predicted *higher* chances of breastfeeding initiation amongst White British mothers (OR 1.66 [1.11-2.47]). We found no evidence that physical environmental quality effects on breastfeeding were mediated through birth outcomes amongst Pakistani-origin mothers, and only weak evidence (p<0.10) amongst White British mothers (exposure to passive cigarette smoke was associated with having lower birthweight infants who were in turn less likely to be breastfed whereas greater air pollution exposure was associated with *longer* gestations and in turn *reduced* hazards of stopping breastfeeding). Overall, our findings suggest that there is differential susceptibility to environmental exposures according to ethnicity. Whilst the water DBP results for Pakistani-origin mothers and air pollution-initiation results for both ethnic groups support our hypothesis that mothers exhibit reduced breastfeeding in poorer-quality environments, several physical environmental quality indicators showed null or positive associations with breastfeeding outcomes. We consider physiological explanations for our findings, and their implications for life history theory and public health policy.

Key words: breastfeeding, trihalomethanes, pollution, smoke, socioeconomic position, Born in Bradford

Key messages

- The association between physical environment quality and breastfeeding varies by type of exposure, outcome and ethnicity.
- There is some evidence that water disinfectant by-products and air pollution reduce breastfeeding, particularly for initiating breastfeeding and for Pakistani-origin mothers, but some null and some positive associations between physical environmental quality and breastfeeding were also found.
- Evolutionary life history theory serves as a useful framework for understanding human reproductive behaviour. It emphasises the importance of environmental quality

in predicting behaviours such as parental investment, and thereby shifts focus away from individual factors and towards modifiable aspects of the environment.

Introduction

There are many factors which impact a woman's infant feeding journey. Here, we contribute to the developing field of evolutionary public health by using evolutionary life history theory to inform an analysis of breastfeeding behaviour risk (Wells, Nesse, Sear, Johnstone, & Stearns, 2017). Life history theory predicts that environmental quality may pattern reproductive behaviour and decision-making, because low-quality environments correlate with lower access to resources and higher morbidity and mortality risk (Dickins, Johns, & Chipman, 2012; Kaplan & Gangestad, 2012; Nettle, 2010b; Quinlan, 2007; Voland, 1998; but see Baldini, 2015). Under certain assumptions, this relatively high environmental risk is thought to trigger behavioural and physiological responses which prioritise having children relatively early, having more of them, and investing relatively less in each i.e. favouring a quantity over quality reproductive strategy in order to ensure successful reproduction despite high mortality risk (Caudell & Quinlan, 2012; Nettle, 2010a). Empirical studies have consistently shown that women in harsher environments have earlier first births, more births, and a greater risk of preterm delivery and lower birthweight and/or smaller infants. This is the case in both cross-population (Bulley & Pepper, 2017; Caudell & Quinlan, 2012; Low, Hazel, Parker, & Welch, 2008) and within-population studies, including high-income populations such as the UK, where overall mortality risk is relatively low but there is still considerable within-population variation in mortality and morbidity (Agyemang et al., 2009; Auger, Park, Gamache, Pampalon, & Daniel, 2012; Clemens & Dibben, 2017; Luo, Wilkins, & Kramer, 2006; Pearl, Braveman, & Abrams, 2001; Schempf, Strobino, & O'Campo, 2009; Virgo & Sear, 2016).

There is less evidence that harsh environments are associated with post-natal parental investment, but reduced breastfeeding is potentially one mechanism which could have evolved to decrease parental investment in lower-quality environments; as well as being a mechanism through which women could achieve higher fertility in such environments (throughout most of human history, at least, when shortened breastfeeding durations would have been associated with shorter birth intervals) (Caudell & Quinlan, 2012; Chisholm, 1993; Nettle, 2010a; Pepper & Nettle, 2014; Quinlan, 2007). Breastfeeding may be partly influenced by unconscious responses to environmental cues, in an evolved, (previously) adaptive response. In contemporary high-income contexts, breastfeeding is of course just one of several ways in which mothers can invest in their children and we make no judgement of women's different infant feeding choices here. Many mothers who do not breastfeed opt to formula feed instead, which can also be considered as maternal investment, but in an economic rather than a physiological sense, especially for socioeconomically-disadvantaged mothers for whom formula incurs a higher financial cost (Raisler, 2000; UNICEF, 2002). There are also many other non-feeding related investments parents can make, like those made in other aspects of infant care such as protection and education (Shenk, 2011). Our study focuses on breastfeeding however, an important influence on maternal and infant health (Ip et al., 2007; Victora et al., 2016); we test the impact of physical environmental conditions thereby contributing a valuable hypothesis to public health interventions.

Human environments are both physical and social and it is important to account for both factors when understanding environmental influences on health and behaviour. In the UK, the link between the social environment, as measured by socioeconomic position (SEP), and breastfeeding is well-established (McAndrew et al., 2012). Disadvantaged women with lower incomes, lower status jobs and/or lower educational attainment are less likely to intend to breastfeed, less likely to initiate it and if they do, they tend to breastfeed for shorter durations. Current UK policy entitles women to 12 months of maternity leave with the first 6 weeks paid at average weekly earnings, then £145.18 per week thereafter (GOV.UK, 2019). The UK Equality Act 2010 defines treating a woman unfavourably because she is breastfeeding as discrimination (Maternity Action, 2014) but the law does not currently allow a simple straightforward right to breastfeeding breaks at work, although employers do have to consider health and safety issues (Health and Safety Executive, 2019; Maternity Action, 2018). With barriers to providing lactation breaks evident in large public sector organisations (Fraser, 2016), it is likely that the smaller and less formal organisations that more socioeconomically-disadvantaged mothers often work for, will be even less supportive in this regard (Heinig et al., 2006).

Socioeconomic position is not the only way that large societies are stratified. The UK is home to great diversity, with people of various ethnic backgrounds and immigration histories calling this country home (Office for National Statistics, 2012). Ethnicity and socioeconomic status can be intertwined, with some ethnic minorities also being socioeconomically disadvantaged. For example, ethnic minorities may be more likely to live in deprived areas of the UK than their White counterparts (McAndrew et al., 2012). Socioeconomic position and ethnicity do however impart different influences on breastfeeding, and socioeconomic position may have more of a beneficial effect in some ethnic groups than others. For example Kelly et al. found that higher income levels were associated with increased odds of initiating breastfeeding amongst White and Asian mothers, but that it had less of a consistent effect amongst Black mothers (2006). Ethnicity can be considered a proxy for differing immigration histories and cultural influences and as such is an important factor to explore in relationships between environmental conditions and breastfeeding outcomes. While socioeconomic position and ethnicity may capture women's social, cultural and economic constraints and opportunities, there are physical aspects of environmental quality which may also influence reproduction and parenting, either because they directly influence physiology, or because they act as cues to environmental quality to which women respond by changing their reproductive behaviour (not necessarily consciously).

By virtue of different environmental exposures, socioeconomic circumstances and cultural influences, the impact of physical environmental quality on breastfeeding is likely to vary between populations. Life history theory predicts that parental investment will be reduced in harsher environmental conditions and/or when resources are scarce. However, low- and middle-income countries generally have higher breastfeeding rates than high-income countries (Victora et al., 2016) even though the environments in these contexts are in many ways "harsher". Analyses focusing on pre-industrial societies have however shown that even in these harsher contexts, there is *within*-population variation in parental investment whereby breastfeeding tracks ecological stress, with mothers terminating breastfeeding sooner under conditions of warfare and famine and weaning showing a quadratic relationship with pathogen stress (Quinlan, 2007).

We have previously shown a positive association between environmental quality and breastfeeding in the UK, both when environmental quality was measured using aggregated data at Primary Care Trust level (Brown, 2014) and with individual data at the home, street and neighbourhood level (Brown & Sear, 2017). We looked at environmental effects on breastfeeding initiation and duration of any breastfeeding in the Millennium Cohort Study (Brown & Sear, 2017), using a broad definition of environmental quality encompassing both sociocultural and physical aspects, such as how supportive and friendly people were and whether there were signs of crime and antisocial behaviour; as well as the built environment and perceptions of cleanliness and general environmental pollution. We found that for every one-unit increase in objectively-assessed local environmental quality, mothers were 54% more likely to initiate breastfeeding (CI 1.23-1.92) and 14% less likely to stop breastfeeding (CI 0.77-0.97), even after controlling for socioeconomic position. We also found significant effect modification with more advantaged SEP having a 'buffering' effect, reducing the magnitude of the consequences of adverse environmental quality. Women from high-income households had relatively high breastfeeding initiation rates and those with high status jobs were more likely to maintain breastfeeding even in harsh environmental conditions. Here we focus more narrowly on physical aspects of the environment, such as water disinfectant by-products (DBPs) and air pollution, to test the prediction that a poor-quality (harsher) physical environment will negatively impact breastfeeding, alongside an assessment of the association between SEP and breastfeeding.

Physical environmental quality and breastfeeding: proximate mechanisms and ultimate perspectives

An integrative evolutionary approach requires both proximate explanations of how a behaviour works, and also an 'ultimate' explanation as to why it exists (Nettle, 2011). Ultimate explanations centre on fitness consequences of a behaviour, explain why it is favoured (or not) in certain contexts and address its evolutionary function (Scott-Phillips, Dickins, & West, 2011). So far we have proposed an ultimate explanation for reduced breastfeeding in lower quality environments: lower parental investment and higher fertility are adaptive in harsh environments. But what are the proximate (i.e. immediate physiological or behavioural) mechanisms which explain the relationship between harsh environments and breastfeeding? Physical aspects of the environment may directly influence maternal and child physiology, which then influences reproductive and parenting behaviours. We acknowledge that a complication is that breastfeeding is a dyadic process influenced by the infant too (Tully & Ball, 2013). There has been relatively little research explicitly linking environmental pollutant exposure with breastfeeding outcomes, but chemical compounds have been detected in breastmilk (Stefanidou, Maravelias, & Spiliopoulou, 2009), some of which are likely to have endocrine disrupting capabilities (Pedersen et al., 2013, p. 72). Hormonal disruption or toxicity can impact mammary gland development during pregnancy (Rosen-Carole et al., 2017) and also the lactation process itself. This is certainly the case for maternal smoking which has been shown to interfere with the milk ejection reflex, reduce milk output, alter the taste and composition of breastmilk, as well as suppress infant appetite and increase irritability (Amir, 2001). It is possible that exposure to passive cigarette smoke and other pollutants such as those from vehicle exhaust fumes, chlorinated water and damp and mould will have some of the same effects, albeit that the level of toxin exposure may be substantially less.

Adverse birth outcomes as a mediating factor

Physical aspects of the environment may also influence reproductive and parenting behaviours through indirect links. For example, an association between environmental pollutants and breastfeeding may be mediated by adverse birth outcomes. Evidence for the relationship between pollutants and adverse birth outcomes is mixed, possibly due to varying methodology, differing levels of exposure and misclassification (Poirier et al., 2015), though there does seem to be consensus that pollution can harm the developing foetus. Pollutant exposure may be linked with an increased risk of spontaneous abortion and stillbirth (Faiz et al., 2012; Waller, Swan, Delorenze, & Hopkins, 1998), but it may also increase the risk of prematurity or having a low birth weight or small for gestational age baby (Dadvand et al., 2013; Nieuwenhuijsen, Dadvand, Grellier, Martinez, & Vrijheid, 2013).

Prematurity and low birthweight can affect an infant's ability to suckle, swallow and breathe, increasing vulnerability to feeding problems (Wambach & Riordan, 2016). Affected babies are also more likely to be separated from their mothers at birth, for example by being moved to incubators, depriving dyads of skin-to-skin and making establishing breastfeeding more difficult. In addition to these proximate explanations, evolutionary theory predicts that parental investment is lower when offspring chances of reproducing themselves appear diminished (Heijkoop, 2010; Mann, 1995). Therefore an ultimate perspective predicts that in order to adjust lactational investment optimally, mothers must evaluate infant health status and reproductive value (not necessarily consciously). Several studies have provided support for this hypothesis, for example: mothers of twins have been shown to bias investment towards the healthier twin (Mann, 1995); interbirth intervals are shorter following the birth of a child with a long-term health problem (Waynforth, 2015); and mothers of low birthweight infants have been shown to wean earlier (Bereczkei, 2001).

Our predictions

The aim of this study is to test whether mothers are less likely to breastfeed in harsh environments, a prediction derived from the evolutionary framework of life history theory. We look specifically at one region in North England to answer this question and focus on small-scale within-population heterogeneity in physical environmental quality. In particular we hypothesise that worse household condition (i.e. having no central heating and being exposed to damp/mould) and greater exposure to water disinfectant by-products, air pollution, and passive cigarette smoke will negatively impact women’s breastfeeding chances by reducing their odds of initiating breastfeeding and increasing their hazards of stopping breastfeeding. We further hypothesise that these aspects of the physical environment may also have indirect effects on the same breastfeeding outcomes through potentially harming foetal development resulting in mothers having smaller neonates whom they are less likely to breastfeed.

Methods

Dataset

The Born in Bradford cohort study (BiB) follows the health and wellbeing of over 13,500 children born at the Bradford Royal Infirmary, West Yorkshire, England between March 2007 and December 2010. Pregnant women were primarily recruited at 26-28 weeks gestation when attending the hospital for routine tests. There have been several waves of data collection to date. Of relevance to this study, a baseline interviewer-administered questionnaire was completed shortly after recruitment which captured sociodemographic data; details of delivery, birthweight and antenatal information were obtained from maternity and radiology information systems; babies had abdominal and head circumferences measured before discharge; and breastfeeding information was recorded during health worker visits and linked back to the main dataset. Further follow-up occurred for two sub-cohorts – BiB1000 and ALLIN (ALLergy and INfection) – over the first 4 and 2 years of life respectively, from which we obtained information on breastfeeding duration. An additional sub-sample took part in the MeDALL (MEchanism of the Development of ALLergy) study, for whom we have additional information on household condition and breastfeeding at age 4 years. We use air pollution measures collected as part of the multi-site European Study of Cohorts for Air Pollution Effects (ESCAPE) project (Pedersen et al., 2013). Routine water quality monitoring data were provided by Yorkshire Water for the eight water supply zones covering the study area from January 2006 to March 2011 and exposure levels were derived by Mireille Toledano and Imperial College of Science Technology and Medicine (Smith et al., 2016). More details on the cohort, sub-cohorts and data collection is available elsewhere (Smith et al., 2016; Wright et al., 2013).

We only included mothers with live births (excluding 72 mothers), and where mothers had twins or triplets, we randomly chose one child for inclusion (excluding 182 babies). For mothers with repeated pregnancies during the data collection period (2007-2010), we randomly selected one pregnancy (excluding a further 1,286 babies). These restrictions to one mother-one child data points were to ensure each mother just contributed one case to the dataset to avoid issues of clustering at the mother level. Our sample includes mothers of varying parity, not just first time mothers as some women will have given birth prior to inclusion in the study. This gave us an initial maximum usable sample size of 12,318 mother-infant dyads.

Variables

Ethnicity

Given that breastfeeding practices and environmental exposure may differ by ethnicity (a proxy for differing immigration histories and cultural influences), we present stratified results, focusing on the two main ethnic groups in Bradford - White British (n=4,031) and Pakistani-origin (n=4,448) mothers. We also present model results for the total sample), but do not attempt to interpret results for the rest of the sample, since it comprised a heterogeneous "other" ethnicity category (n=1,541) and women who did not provide their ethnicity (n=2,298).

Breastfeeding outcomes

We used two outcomes: 1) breastfeeding initiation and 2) duration of any (rather than exclusive) breastfeeding. We combined breastfeeding initiation data from health visitor records and sub-cohort follow-up. This gave us initiation data for 98% of the women in our sample (n=12,087, missing=231).

3,737 women took part in at least one of the sub-cohort surveys in which duration questions were asked, of which 80% had initiated breastfeeding (n=2,979). We were able to derive duration for 95% of these women (n=2,827). Duration was replaced with the baby's age for the 407 mothers who were still breastfeeding at the time of their last survey (167 of whom were White British and 159 of whom were Pakistani-origin). Where mothers stopped breastfeeding between surveys, duration was coded as the age of the child in the last survey where breastfeeding was recorded as still happening (likely underestimating durations for some mothers). Mothers who initiated breastfeeding but who recorded duration as 0 days were recoded as half a day (0.02months) to acknowledge that some transfer of breastmilk may have occurred and to differentiate these mothers from those who did not attempt breastfeeding at all.

Physical environmental quality indicators

All measures were coded so that higher values represented greater exposure and poorer environmental quality. Where possible we have used data on exposure during pregnancy but have had to use later exposure as proxies for some indicators.

Water disinfectant by-products (DBPs)

We used five water DBP indicators: total trihalomethanes, brominated trihalomethanes (subdivided into bromodichloromethane and dibromochloromethane) and chloroform. Modelled trihalomethane concentrations encompassing residential (and workplace, if relevant) address were assigned and time-weighted average concentrations were calculated for each mother in the study. The time-weighting was based on the proportion of the whole pregnancy falling into each month. These time-weighted average concentrations were then adjusted for individual water use including consumption, showering, bathing and swimming (Smith et al., 2016) to create a personalised measure of whole pregnancy average integrated uptake (µg/day). All five indicators had positively skewed distributions and so we created tertiles of exposure based on the full sample of women.

Air pollution

As part of the ESCAPE project, 20 European study areas collected measurements of particulate matter (e.g. $PM_{2.5}$ and PM_{10}) and nitrogen oxides (NO_2 and NO_x). We used nitrogen oxide measures as our indicators of air pollution, as Bradford was one of the 16 ESCAPE sites that did not collect particulate matter measures (Beelen et al., 2013). In addition, the evidence is less consistent for links between nitrogen oxides and infant health outcomes (Shah & Balkhair, 2011), and as such our paper makes an important contribution to the evidence base. Furthermore, Bradford is one of the UK's nitrogen oxide pollution hotspots (Google My Maps, 2019): nitrogen oxide levels were relatively high in Bradford between 2007 and 2010, surpassing the annual average air quality objective level of $40µg/m^3$ (Maybury, 2016) and levels have remained high in recent years (Department for Environment Food and Rural Affairs, 2019). As part of the ESCAPE project, exposure estimates were personalised with land use regression models to take into account each mother's proximity to traffic and buildings and their load and density at different time points during pregnancy (Beelen et al., 2013). We selected whole pregnancy average exposure levels of nitrogen oxides ($20µg/m^3$) and nitrogen dioxide (10µg/m³) for use in the present study. The nitrogen oxides indicator encompasses nitrogen dioxide as well as nitric oxide. We used continuous indicators in the main models (but created tertiles when testing for interactions with ethnicity) as both measures were normally distributed.

Passive cigarette smoke

Mothers were asked in the baseline questionnaire if they were exposed to cigarette smoke at work or at home and we collapsed *Yes* and *Less than an hour* into *Yes* to make this a binary variable.

Household condition

We used two binary variables for household condition based on maternal reporting of damp and/or mould and lack of central heating, derived from the ALLIN and MeDALL sub-cohorts at 12 months, 24 months and/or 4 years.

Socioeconomic position (SEP)

A wide range of socioeconomic position (SEP) indicators have been shown to be associated with both adverse birth outcomes (Erickson & Arbour, 2014) and breastfeeding (McAndrew et al., 2012). As a proxy for individual resources and to some extent, social environmental quality, we wanted to capture the multifactorial nature of socioeconomic position so used five indicator variables (all taken from the baseline questionnaire) to construct a latent variable: mother's education, her partner's occupation, financial difficulties, means-tested benefits and food insecurity. This allocated everyone a disadvantage score which we then standardised to aid interpretation of model results. We also included the IMD (Index of Multiple Deprivation) 2010 score (McLennan, Barnes, Noble, Davies, & Garratt, 2011) as a measure of neighbourhood deprivation in descriptive analyses. Higher values represented more disadvantage for both SEP measures.

Covariates

We adjusted for key maternal and infant characteristics known to influence breastfeeding and/or birth outcomes: maternal age, immigration status, smoking during pregnancy, BMI, parity, infant sex, singleton/multiple birth and cohabitation status. This reduced our maximum sample size down to 8,993 mothers (3,615 White British and 3,982 Pakistani-origin).

Birth outcomes

Birthweight in kilograms, head and abdominal circumferences in centimetres and gestational age in weeks were used as continuous measures in our mediation models.

Statistical Methods

We first explored the data by using t-tests and chi-squared tests to compare White British and Pakistani-origin mothers in terms of their sociodemographic characteristics, birth outcomes, environmental exposures and breastfeeding outcomes. We also compared those with missing initiation data to the rest of the sample in the same way. We assessed associations between physical environmental quality indicators using polychoric, polyserial and Pearson's correlations as appropriate. Unadjusted associations between our two measures of SEP (socioeconomic disadvantage and neighbourhood deprivation) and physical environmental quality were assessed using linear and logistic regression models as appropriate. To test our hypothesis about the association between physical environmental quality and breastfeeding, we ran separate statistical models for each of the ten physical environmental quality indicators and breastfeeding outcomes i.e. only including one indicator at a time. Our first set of models adjusted for the key maternal and infant covariates listed above, and our second set of models additionally adjusted for the standardised socioeconomic disadvantage score. This allowed us to see whether any association persisted above and beyond the effect of individual socioeconomic position (we also ran models to test the association between socioeconomic position and breastfeeding outcomes). Logistic regression models were used to assess relationships with breastfeeding initiation, whilst we used event history analysis to take account of the right-censored breastfeeding duration data (using the Weibull distribution to reflect the diminishing probability of breastfeeding over time). Breastfeeding duration results are therefore presented as hazard ratios reflecting the risk of stopping breastfeeding for different environmental exposures. . As well as running analyses separately by ethnicity, we also ran the two sets of models on White British and Pakistani-origin mothers combined, adding in an *environmental quality X ethnicity* interaction to test for ethnic differences in the effect of physical environmental quality on breastfeeding outcomes. We plotted predicted probabilities of initiating and maintaining breastfeeding based on these interaction models to visually compare associations amongst the two groups. The probability of maintaining breastfeeding is presented as a survival curve where the "failure" variable is stopping breastfeeding and "surviving" is maintaining breastfeeding at a given time point.

We tested for mediation using structural equation modelling adding pathways through birth outcomes to the fully adjusted models and examining indirect effects. We ran models for birthweight, head circumference and abdominal circumference (all simultaneously adjusted for gestational age) and for gestational age separately (with all environmental quality indicators treated as continuous to allow for estimation of indirect effects).

We conducted complete case analyses and so sample sizes varied depending on the outcome and indicator included in the model.

Ethics

BiB and its sub-studies have been approved by the Bradford Research Ethics Committee (Wright et al., 2013). The current study received ethics approval from the London School of Hygiene & Tropical Medicine's Research Ethics Committee (9398-01).

Results

Sample characteristics

White British and Pakistani-origin mothers significantly differed in most characteristics (Table 1). Pakistani-origin mothers had higher levels of initiation (57% versus 42%) but duration was similar at 8-9 months for both groups. Pakistani-origin mothers had lower exposure to water DBPs and were less likely to be exposed to passive smoke, but had higher exposure to air pollution. There were no ethnic differences in either indicator of household condition. Pakistani-origin mothers had higher SEP scores indicating greater socioeconomic disadvantage. On average, they had less education, greater neighbourhood deprivation, were more likely to be on means-tested benefits and experience financial difficulties, but were less likely to experience food insecurity. Pakistani-origin women's partners were less likely to be non-manual workers and more likely to be manual workers or self-employed compared to White British women's partners. The immigration statuses of the two groups significantly varied; the majority of White British mothers were born in the UK whilst almost all of the Pakistani-origin mothers were first or second generation immigrants. Pakistani-origin mothers had lower BMIs and higher parity but were just as likely to have a female infant or multiple birth. Fewer Pakistani-origin mothers were living without a partner. In terms of birth outcomes, Pakistani-origin infants tended to be born earlier and were lighter, with smaller head and abdominal circumferences.

Although mothers with missing initiation data (n=231) significantly differed from the rest of the sample in terms of some of the environmental exposures, SEP and other sociodemographic factors (Table 1), their small numbers means that these differences are unlikely to affect the interpretation of our results.

Associations between physical environmental quality indicators

In our descriptive analyses, several environmental quality indicators were positively associated with one another in both ethnic groups, although the correlations varied in strength and significance. Focusing just on significant correlations (at $p<0.05$), the strongest positive correlations were between the different water DBPs (r=0.914 to 1) and between the different air pollution indicators (r=0.820 and 0.826). Passive smoke exposure was more weakly positively associated with water DBPs in both ethnic groups (r=0.077 to 0.153), and also with air pollution (r=0.057 and 0.103) and damp/mould amongst White British mothers (r=0.125). Household condition only correlated with other environmental quality exposures amongst Pakistani-origin mothers; both indicators were weakly positively correlated with exposure to nitrogen dioxide (r=0.184 and r=0.132) and having no central heating was also weakly positively correlated with nitrogen oxide exposure (r=0.242). However, several water DBPs were *negatively*, albeit weakly, associated with air pollution amongst Pakistani-origin mothers (r=-0.034 to -0.079). These correlations suggest that exposures broadly cluster together, perhaps indicating a 'harsh' physical environment, particularly for White British mothers, but the separate indicators measure slightly different aspects of the environment. Correlations between the environmental quality indicators are shown in SM Table 1.

Socioeconomic position and physical environmental quality

Disadvantaged socioeconomic position (SEP) was generally associated with poorer physical environmental quality, with for example, both greater individual socioeconomic disadvantage and neighbourhood deprivation (IMD) being positively associated with greater air pollution exposure (Table 2). There were some differences by ethnicity for the other exposures though. Most notably, although White British mothers who were more socioeconomically disadvantaged and who lived in more deprived neighbourhoods had higher levels of water DBP exposure, there was no association amongst Pakistani-origin mothers (except for between IMD and dibromochloromethane exposure). Passive smoke exposure was positively associated with socioeconomic disadvantage in both ethnic groups, but with neighbourhood deprivation only amongst White British mothers. Damp/mould exposure was more likely for socioeconomically disadvantaged White British mothers and for mothers of either ethnicity living in more deprived neighbourhoods. Only Pakistani-origin mothers living in more deprived neighbourhoods were less likely to have access to central heating. This suggests that a lower quality physical environment is broadly associated with a lower quality socioeconomic environment, though again this relationship is stronger for White British mothers.

Socioeconomic position and breastfeeding

The first lines of Tables 3 and 4 show the relationship between socioeconomic position and breastfeeding initiation and the hazard of stopping breastfeeding after controlling for maternal and infant characteristics. Although not shown for brevity, the SEP-breastfeeding associations in the M2 environmental quality models were very similar to the M1 associations presented, suggesting that socioeconomic disadvantage influences breastfeeding separately from these aspects of the environment.

Breastfeeding initiation

More socioeconomically disadvantaged mothers had lower odds of initiating breastfeeding. The odds of initiating breastfeeding decreased by 23% and 20% for each standard deviation increase in socioeconomic disadvantage for White British and Pakistani-origin mothers, respectively.

Breastfeeding duration

Mothers with greater socioeconomic disadvantage had increased hazards of stopping breastfeeding. The hazard of stopping breastfeeding increased by 11% and 13% for each standard deviation increase in socioeconomic disadvantage for White British and Pakistani-origin mothers respectively.

Physical environmental quality and breastfeeding

The remaining rows of Tables 3 and 4 present results of our analyses of the relationships between the environmental quality indicators and breastfeeding initiation and duration (hazard of stopping). M1 models are adjusted for maternal and infant characteristics and M2 models are additionally adjusted for SEP. Note that each row in the tables refers to a separate model, as we ran individual models for each environmental quality indicator. The last column shows the results of the significance tests for the interactions between ethnic group and environmental quality from models controlling for maternal and infant characteristics and SEP and including White British and Pakistani-origin mothers, but excluding other ethnicities. The corresponding predicted probabilities based are presented in Figure 1.

Breastfeeding initiation

Results of our initiation analyses broadly suggest support for our predictions, with the exception of the damp/mould indicator, though not all environmental indicators were significantly associated with initiation and there were some differences between ethnic groups.

Water DBPs

Whilst there were no significant relationships between DBPs and initiation amongst White British mothers, all DBP measures were significant negative predictors amongst Pakistani-origin mothers. All five DBP measures showed a dose-response relationship whereby Pakistani-origin mothers in the mid- and high-exposure tertiles both had reduced odds compared to the low-exposure tertiles. For example, Pakistani-origin mothers exposed to mid-levels of dibromochloromethane (0.02-0.03µg/day) were 28% less likely to initiate breastfeeding compared to those exposed to low levels (<0.02µg/day), whilst those exposed to high levels (0.03-0.61µg/day) were 30% less likely. Adjusting for SEP had little effect on the associations between water DBPs and breastfeeding amongst Pakistani-origin mothers; adjusted effect sizes ranged between a 22-31% reduction in the odds of initiation. The significant interaction between dibromochloromethane exposure and ethnicity (p=0.018) is shown in Figure 1a: Pakistani-origin mothers with low exposure have a 55% probability of initiating breastfeeding whilst those with mid and high exposure have similarly lower chances at just 47%. White British mothers show a U-shaped relationship, with the lowest probability occurring at mid-exposure levels (47%), and low and high levels conferring probabilities of 50% and 52%, respectively.

Air pollution

Whilst both air pollution measures were significantly negatively associated with breastfeeding initiation amongst Pakistani-origin mothers, only nitrogen dioxide exposure showed a significant association amongst White British mothers. These associations persisted after adjusting for SEP, with significant effect sizes varying from a 19-27% reduction in odds of initiation. Ethnicity did not interact with air pollution to predict breastfeeding initiation (Figure 1c).

Passive cigarette smoke

Passive smoke exposure was not significantly associated with breastfeeding initiation, although relationships were in the predicted direction, with exposure to smoke at work or home conferring lower odds in both ethnic groups (Figure 1e).

Household condition

Central heating access showed no significant association in either group, although relationships were all in the predicted direction, whereby no access conferred lower odds of initiating breastfeeding (Figure 1g). Contrary to our predictions, damp/mould exposure showed a positive association with initiation in both groups, though this relationship was only significant in White British mothers, and became stronger once SEP was controlled for, with exposed White British mothers being 66% more likely to initiate breastfeeding than those with no damp/mould exposure (Figure 1i).

Breastfeeding duration

In contrast to the breastfeeding initiation results, results for breastfeeding duration (hazard of stopping breastfeeding) were more mixed and did not offer strong support for our predictions.

Water DBPs

Water DBP exposure did not significantly predict hazards of stopping breastfeeding amongst White British mothers and associations were mostly going against the predicted direction (with greater exposure predicting *reduced* hazards of stopping breastfeeding). Water DBP associations were however in the predicted direction for Pakistani-origin mothers, but only dibromochloromethane was a significant predictor of the hazard of stopping breastfeeding and only at mid, not high, exposure levels. The effect became marginally stronger after controlling for SEP, with Pakistani-origin mothers exposed to 0.02-0.03µg/day of dibromochloromethane having a 21% higher hazard of stopping compared to those with low exposure (<0.02μg/day). These results hint at the predicted association between higher water DBP exposure and increased hazards of stopping breastfeeding in Pakistani-origin mothers only, and suggest that dibromochloromethane may be a particular chemical of interest. Although none of the water DBPs interacted with ethnicity to predict breastfeeding duration, Figure 1b illustrates the differential impact of exposure on the two main ethnic groups clearly. Pakistani-origin mothers with high exposure levels have lower probabilities of breastfeeding than those with low levels from about 1 month onwards, whilst the converse is true for White British mothers.

Air pollution

Contrary to our predictions, greater air pollution exposure was associated with a significant *reduction* in the hazard of stopping breastfeeding amongst White British mothers Nitrogen dioxide exposure showed the same direction of association amongst Pakistani-origin mothers, albeit non-significantly. Effect sizes also increased after controlling for SEP, with each 20μg/m³ increase of nitrogen oxides and each 10μg/m³ increase of nitrogen dioxide conferring a 23% and 35% reduction in the hazard of stopping breastfeeding, respectively. The interaction between ethnicity and nitrogen dioxide exposure (p=0.034) is clear in Figure 1d. The survival curve for nitrogen dioxide exposure shows that there while there was no difference in the probability of maintaining breastfeeding according to exposure level for Pakistani-origin mothers, White British mothers exposed to high levels of nitrogen dioxide (2.29-3.10 10μg/m³) had much higher chances of maintaining breastfeeding than those exposed to low levels (<1.94 10μg/m³), particularly after the first month or so. For example, White British mothers with high levels of nitrogen dioxide exposure have a 60% chance of breastfeeding until 6 months whereas those with low levels of exposure have just a 45% chance (Figure 1d).

Passive cigarette smoke

Passive smoke exposure did not significantly predict the hazard of stopping breastfeeding, whether or not SEP was controlled for, although associations were in the predicted direction in both ethnic groups with mothers exposed to smoke at work or at home having greater hazards of stopping breastfeeding than those unexposed. We found no significant interaction between ethnicity and passive smoke but the corresponding survival curve suggests that smoke exposure had more of a detrimental impact on maintaining breastfeeding for Pakistani-origin mothers than White British mothers (Figure 1f).

Household condition

Neither of the household condition indicators significantly predicted the hazard of stopping breastfeeding, before or after controlling for SEP. Relationships for central heating were in the opposite direction to that predicted with mothers without household heating having *lower* hazards of stopping breastfeeding compared to those with heating in both ethnic groups Household damp/mould exposure was also non-significantly associated with a *reduced* hazard of stopping breastfeeding in the models controlling for SEP. Neither household indicator significantly interacted with ethnicity but the survival curves in Figures 1h and 1j suggest that worse household condition appears to confer higher probabilities of maintaining breastfeeding amongst the White British mothers only.

Mediation by birth outcomes

We found some weak evidence for mediation amongst White British mothers, with indirect effects only significant at the 10% level, but no evidence for mediation amongst Pakistani-origin mothers.

Although there was no direct effect on breastfeeding, our mediation analyses showed that amongst White British mothers, passive smoke exposure had an indirect effect on breastfeeding initiation through birthweight: mothers exposed to passive cigarette smoke at home or at work had lower birthweight infants who were in turn less likely to be breastfed. Whilst this indirect effect was in the predicted direction, greater air pollution exposure (as indexed by both nitrogen oxides and nitrogen dioxides) was associated with *longer* gestations and in turn reduced hazards of stopping breastfeeding (i.e. longer durations), which goes against our prediction that increased exposure leads to smaller neonates and reduced breastfeeding.

Discussion

We predicted that mothers with poorer environmental quality i.e. greater exposure to environmental pollutants and worse household condition would be less likely to initiate breastfeeding and have higher hazards of stopping breastfeeding. We found mixed associations between physical environmental quality indicators and breastfeeding outcomes, with the direction and strength of relationship varying by indicator and ethnicity; broadly, though, the relationships between environmental quality and breastfeeding initiation showed stronger support for our hypothesis than those between environmental quality and breastfeeding duration (the hazard of stopping breastfeeding). Relationships were, perhaps surprisingly, little affected by the inclusion of socioeconomic position in models. This suggests that physical environmental quality and socioeconomic position may be separate axes of influence on breastfeeding, with some aspects of physical environmental quality impacting breastfeeding above and beyond the well-established social and economic barriers.

Ethnic differences in breastfeeding outcomes

Pakistani-origin mothers had higher breastfeeding initiation rates and longer average breastfeeding durations than White-British mothers in our sample. It could be that varying cultural influences contribute to this difference, with for example protective Islamic beliefs (Williamson & Sacranie, 2012; Zaidi, 2014), South Asian cultural teachings (Choudhry & Wallace, 2012) and more extensive support networks (GOV.UK, 2018) amongst Pakistani-origin mothers playing a key role. In addition, as Table 1 shows, only a small proportion of Pakistani-origin mothers in our sample were born in the UK; our measures of physical environmental quality and socioeconomic disadvantage do not capture earlier life exposure and it may be that Pakistani-origin mothers' breastfeeding outcomes would be better predicted by earlier exposure in Pakistan than by contemporary exposure in the UK.

Acculturation also influences breastfeeding practices; it can be thought of as the extent to which people from one culture adapt their behaviour to reflect the norms of another cultural group. This may explain the relatively similar breastfeeding durations between the two ethnic groups in our study. The detrimental influence of UK societal norms on immigrant breastfeeding chances have been reported quantitatively for immigrants generally (Hawkins, Lamb, Cole, & Law, 2008) and qualitatively for those immigrating from South Asian countries specifically

(Choudhry & Wallace, 2012). For example, previous analyses using the Millennium Cohort Study have shown that whilst babies of South Asian descent had similar odds of being breastfed to White babies, immigrant mothers were less likely to initiate breastfeeding the longer they lived in the UK (Brown & Sear, 2017 [Supplementary material]; Hawkins et al., 2008).

Reduced breastfeeding in harsh environments

The water DBP results for both breastfeeding outcomes for Pakistani-origin mothers and the air pollution breastfeeding initiation results for both ethnic groups support our hypothesis that mothers are less likely to breastfeed in poorer-quality environments. Although we did not find associations between passive smoke exposure and breastfeeding in our study (in part likely due to controlling for maternal smoking), links between smoking and breastfeeding in the literature may provide clues as to how air pollution could directly impact breastfeeding initiation. For example, air pollution may have a similar negative impact on milk ejection, output, taste and composition as well as on infant irritability and appetite (Amir, 2001). Our water DBP findings are in line with previous BiB research that found trihalomethane exposure was negatively associated with birthweight but only in Pakistani-origin infants (Smith et al., 2016). Whilst we found no evidence for mediation by birthweight, together Smith's study and ours suggest that Pakistani-origin mothers are particularly vulnerable to DBPs even though their exposure is lower. DBPs concentrate in fatty tissues, accumulating over the life course and mobilising during gestation and lactation (Colborn, Vom Saal, & Soto, 1993; Freire et al., 2011). The rate of elimination depends on the amount of fat a person has (World Health Organization, 2005) and, as South Asian populations have more fat mass than Europeans (Deurenberg, Deurenberg-Yap, & Guiricci, 2002; Stanfield, Wells, Fewtrell, Frost, & Leon, 2012), the Pakistani-origin mothers in our sample may have retained DBPs in their bodies for longer, resulting in greater physiological impact. The compounds may impact breast development and lactation (Bielmeier, Best, & Narotsky, 2004; Rosen-Carole, Auinger, Howard, Brownell, & Lanphear, 2017) and may transfer from mother to infant (Batterman, Zhang, Wang, & Franzblau, 2002), potentially altering the taste and acceptability of breastmilk (Office of Environmental Health Hazard Assessment California Environmental Protection Agency, 2010). Alternatively, rather than being driven by physiological variation, the observed ethnic differences could be explained by social factors not controlled for e.g. diet and stress (Smith et al., 2016), or even fertility (although further data exploration shows this to be unlikely (results available on request)). Differences in childhood experiences (Belsky, 2012; Hartman, Li, Nettle, & Belsky, 2017) may also account for the ethnic differences in our results to some extent.

Breastfeeding as protection from environmental harm?

Our finding that White British mothers had reduced hazards of stopping breastfeeding (i.e. longer durations) when exposed to more air pollution is contrary to our prediction, but could perhaps reflect mothers using breastfeeding to protect their infants from environmental harm. Breastfeeding provides greater antioxidative protection than formula feeding (Shoji & Koletzko, 2007) and may counteract some of the detrimental health impacts of prenatal exposure to environmental contaminants (Guxens et al., 2012), such as respiratory problems (Naz, Page, & Agho, 2016) and impaired motor and cognitive development (Lertxundi et al., 2015). Similarly, the positive damp/mould-initiation relationship could also be explained by the protective effect of breastfeeding against the associated risks of asthma and allergies (Flohr et al., 2018; Klopp et al., 2017; Lodge et al., 2015; Silvers et al., 2012; Sonnenschein-van Der Voort et al., 2012; Tischer et al., 2011). It is however not clear why only White British mothers showed these associations.

Mediation by birth outcomes

Whilst we did not find evidence that passive smoke exposure impacts breastfeeding directly, our mediation results suggest that it may restrict foetal growth, manifesting as lower birthweight with the knock-on effect of mothers being less likely to initiate breastfeeding for these smaller infants. Compounds in cigarette smoke may cause oxidative stress to the foetal-placental unit (Erickson & Arbour, 2014) resulting in smaller neonates.

Our finding that some of the association between greater air pollution exposure and *reduced* hazards of stopping breastfeeding was mediated through longer gestational lengths, whilst counter to our prediction of greater exposure, smaller neonates and lower breastfeeding chances, is echoed to some extent by findings from other studies. For example, air pollution studies in Italy (Sabatino et al., 2015) and Australia (Jalaludin et al., 2007) found that greater exposure to air pollutants was associated with a *reduced* risk of having a preterm birth. Looking specifically at exposure to nitrogen oxides in these studies results are however more mixed: greater nitrogen dioxide exposure during the first trimester was associated with *reduced* preterm birth risk in the Australian study but greater exposure in the second trimester was associated with *increased* preterm birth risk in the Italian study. Mixed evidence for associations between nitrogen oxides and birth outcomes notwithstanding (Shah & Balkhair, 2011), it is possible that a longer gestation could serve as mechanism by which to compensate for maternal hypoxemic-hypoxic damage (Sabatino et al., 2015).

Taken together these mediation results suggest that mothers with low birthweight and shorter gestation lengths have reduced breastfeeding chances, a finding corroborated by our previous analyses of the Millennium Cohort Study (Brown & Sear, 2017) which showed that lower birthweight infants had lower initiation rates and average breastfeeding durations (e.g. 67 % and 2.07 months vs 69% and 2.69 months for normal weight, and 74% and 3.11 months for heavy weight). Low birthweight and preterm birth (i.e. when gestational lengths are shorter than 37 weeks) may negatively impact breastfeeding in several ways. Mothers of low birthweight infants often experience difficulties that are not common to women giving birth to healthy full-term infants. For example, some of the underlying causes of preterm birth (hypertension, diabetes and maternal obesity) negatively influence breastmilk production (De Freitas, Lima, Carlos, Priore, & Do Carmo Castro Franceschini, 2016). Recovering from a complicated pregnancy or delivery, feeling tired of depressed after prolonged hospitalisation, or feeling anxious due to the baby's real or apprehended condition and mourning a twin are also additional risk factors (Lefebvre, 1990; Tommy's, 2019). The baby may be more likely to be separated from the mother to be taken to the intensive care unit or to have various tests and treatments (Adamkin, 2006; De Freitas et al., 2016; Dodrill, 2011; Lefebvre, 1990). In terms of infant factors, low birthweight or preterm babies are more likely to be part of a twin or triplet set, to be sleepier and have less stamina, and exhibit signs of weakness including extreme immaturity and thermal instability and illness (including critical conditions on respirators) (Adamkin, 2006; Lefebvre, 1990). These small babies are more likely to suck poorly (with immature or dysfunctional sucking skills and poor suck-swallow-breathe coordination) or to refuse the breast; they are less likely to be discharged exclusively breastfeeding, with mothers more likely to report feeding problems after discharge too (Dodrill, 2011; Lefebvre, 1990; Ross & Browne, 2013; UCSF Children's Hospital, 2004).

Breastfeeding initiation versus breastfeeding duration

Whilst breastfeeding initiation results were broadly in line with our predictions, our breastfeeding duration (hazard of stopping breastfeeding) results were more inconsistent. This could be because duration was measured on a smaller, less representative sample, with less power to detect effects. However, we also found stronger initiation than duration results in our previous study (Brown & Sear, 2017), suggesting that initiation may be genuinely more strongly influenced by environmental quality than duration. It is likely that breastfeeding duration is more influenced by other factors such as women needing to return to work (Andrew & Harvey, 2011; Heck, Braveman, Cubbin, Chávez, & Kiely, 2006; Huang & Yang, 2015; Kimbro, 2006; Rippeyoung & Noonan, 2012). It is also interesting that Pakistani-origin mothers didn't breastfeed for longer than White British mothers in this sample, even though their initiation rates were higher. It could be that associations would be more pronounced or consistent if we had used duration of exclusive breastfeeding rather than of any breastfeeding.

Implications for Life History Theory

While we find some evidence for predicted associations between lower physical environmental quality and reduced breastfeeding, we also find several null associations. Moreover, the air pollution-duration and damp/mould-initiation associations amongst White British mothers suggest that investment may actually be *increased* in response to environmental risk. This could be adaptive in this low infant mortality and fertility context where replacement of infants is unlikely; it may be beneficial to invest at a higher rate and protect infants as much as possible from morbidity risk. We found some evidence for mediation by birth outcomes, suggesting that mothers may be using infant viability cues to tailor investment through breastfeeding.

The different measures of physical environmental quality support interpretations of both greater and lesser lactational investment in response to environmental stressors in our study. These mixed associations might suggest that the Bradford environment is not "harsh" enough to enforce the same maternal investment decisions mothers make in environments with greater extrinsic morbidity and mortality risk. We might expect to see more pronounced and consistent reductions where environmental adversity is greater, both in terms of the measures explored in this study and in terms of other aspects of the physical environment. Quinlan's study exploring aspects such as famine and warfare provides good support for the life history theory prediction of reduced maternal investment in such harsher conditions (Quinlan, 2007). As well as the earlier weaning findings we mentioned in our introduction, his analysis of data from 186 pre-industrialised societies also found that maternal care was reduced in harsher conditions (Quinlan, 2007). It is also possible that forms of parental investment other than (or instead of) breastfeeding may be reduced in poorer-quality environments within high-income contexts too and this could prove a fruitful avenue for further research. Even though we found just limited support for our predictions, by using an evolutionary approach we can recognise that both biology and behaviour respond to environmental cues and that "adverse" outcomes can sometimes be understood as the result of optimising reproductive strategies in a given context. We make a theoretical contribution by showing that how environmental quality is operationalised in life history theory research is important. Our mixed findings suggest that social and economic proxies of environmental quality may be more strongly linked to life history outcomes than physical measures. Even so, associations between SEP and physical environmental quality differ by ethnic group, suggesting that SEP cannot be used as a reliable proxy for environmental exposure. This nuance cautions against using socioeconomic position, environmental quality and ethnicity interchangeably when assessing the association between environmental harshness and reproductive outcomes.

Limitations

We had to use data from time points as late as 4 years after birth for the two household condition indicators and to derive some breastfeeding information. For most women this would have been well after they stopped breastfeeding. We have had to assume that this exposure was the same as during pregnancy but this may not be the case for all participants. Additionally, for some indicators we only had data available for sub-cohorts, reducing our sample size for analysis but also the representativeness of our findings. For example, damp/mould exposure and lack of central heating access were both measured at least 12 months after birth and only for mothers in the ALLIN and MeDALL sub-cohorts; this might partially explain their protective and null effects, respectively, as household condition may have changed over time and the relatively smaller sample sizes may have skewed associations. A further limitation was our restricted exploration of other ethnicities due to small numbers and heterogeneity in the "other" category.

Whilst we were able to demonstrate some associations between physical environmental quality and breastfeeding outcomes, an understanding of the proximate mechanisms which drive these associations is needed to determine whether breastfeeding is causally associated with environmental quality. Data on potential physiological mechanisms would be particularly helpful, for example, measuring uptake and lactational transfer of pollutants. Whilst water DBPs have been shown to transfer to breastmilk, the amount of these chemical compounds that an infant digests will vary according to the timing of maternal exposure as well as the timing of feeds (Batterman et al., 2002), with different concentrations in the breastmilk likely affecting taste and acceptability to the infant to varying extents. Air pollution exposure may similarly alter the composition of breastmilk (Cinar, Ozdemir, Yucel, & Ucar, 2011). It is possible that some aspects of the physical environment are more perceivable than others, with for example air pollution being more detectable than the concentrations of DBPs in water. The extent to which mothers consciously detect these exposures and the extent to which they consciously adjust their breastfeeding behaviour accordingly remains to be investigated.

Conclusion

We hypothesised that poor physical environmental quality would either directly or indirectly negatively impact the breastfeeding chances of mothers in Bradford. Our predictions were only partially supported with the size and direction of associations varying according to environmental exposure, ethnicity and breastfeeding outcome, with little evidence for an indirect effect through neonate size. From a policy perspective, in order to improve the health of the population it is important to understand how individual attributes interact with environmental exposure to produce synergistic and modifiable effects (Erickson & Arbour, 2014). The results of our study suggest that environmental hazard exposure is not always synonymous with socioeconomic disadvantage, and that whilst the latter may be a robust predictor of lower breastfeeding chances, poor physical environmental quality has less of a consistent effect, though we did find some associations. White British and Pakistani-origin mothers had different breastfeeding and environmental experiences even though they lived in the same geographical area, additionally highlighting the importance of ethnicity, immigration and sociocultural influences. The impact of water DBP exposure on breastfeeding was particularly pronounced for the Pakistani-origin mothers in our sample and we suggest that focusing on reducing the amount of chemical compounds in water (and more research into the physiological impacts of dibromochloromethane in particular) should be a public health concern. Despite the possibility of harm from environmental contaminants in breastmilk, breastfeeding is still recommended as the safest and healthiest infant feeding method. Whilst women should be provided with personalised infant feeding support, we suggest that it is also important to focus on tackling environmental inequities in order to facilitate successful breastfeeding.

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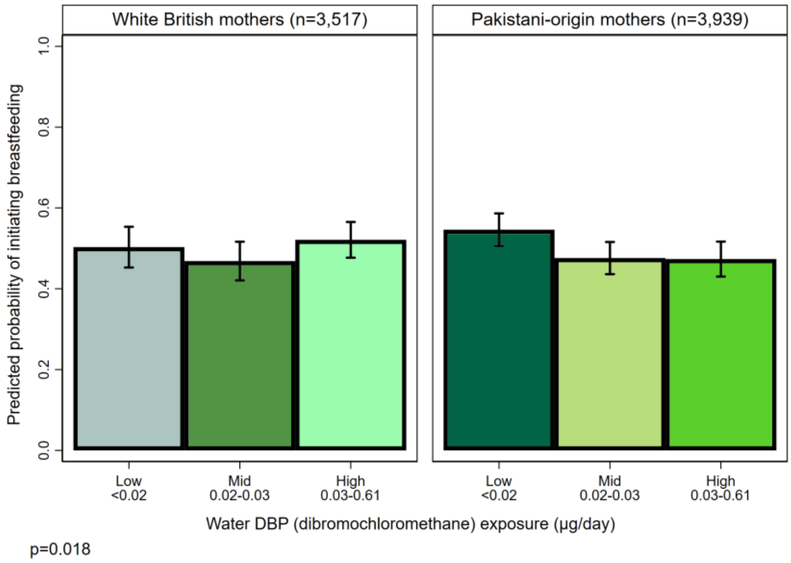

Figure 1a. Predicted probability of initiating breastfeeding by dibromochloromethane (water disinfectant byproduct) exposure and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

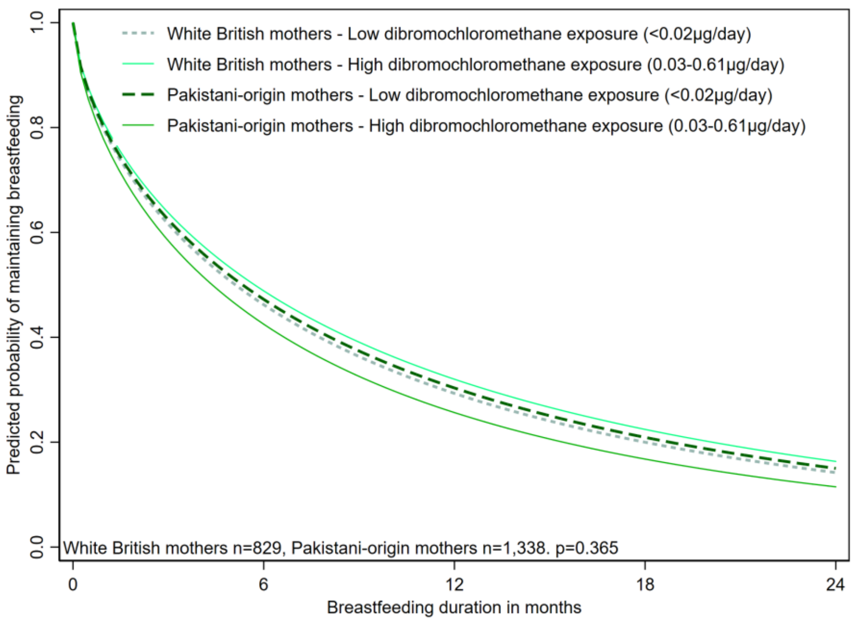

Figure 1b. Predicted probability of maintaining breastfeeding by dibromochloromethane (water disinfectant by-product) exposure and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

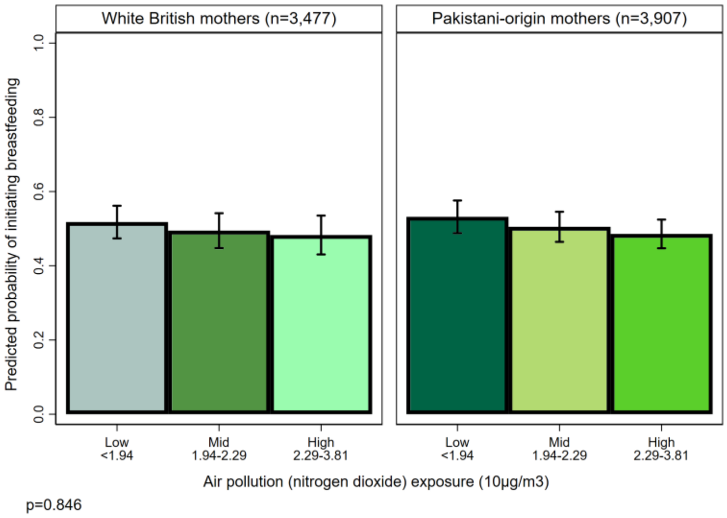

Figure 1c. Predicted probability of initiating breastfeeding by nitrogen dioxide (air pollution) exposure and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

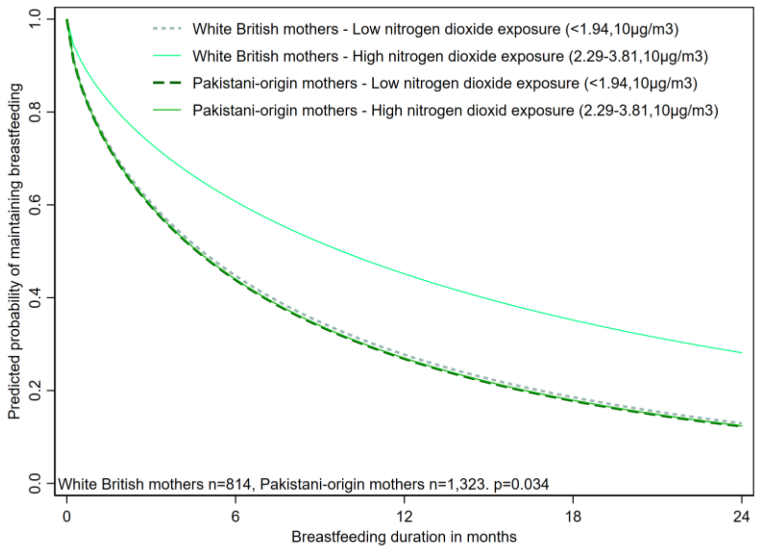

Figure 1d. Predicted probability of maintaining breastfeeding by nitrogen dioxide (air pollution) exposure and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

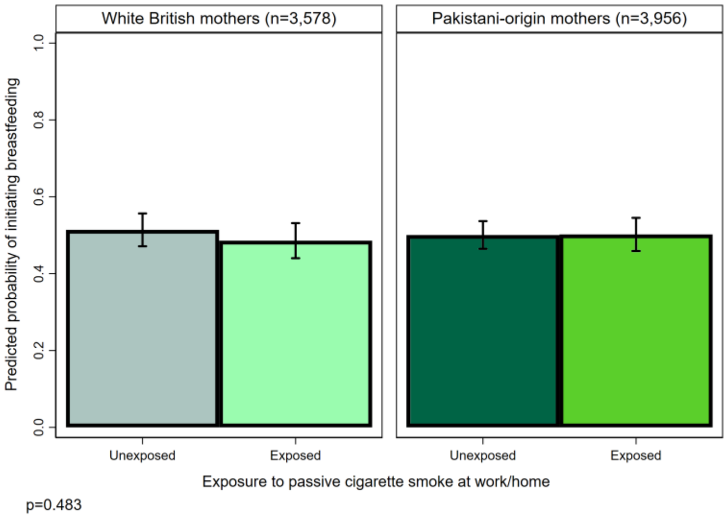

Figure 1e. Predicted probability of initiating breastfeeding by passive smoke exposure and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

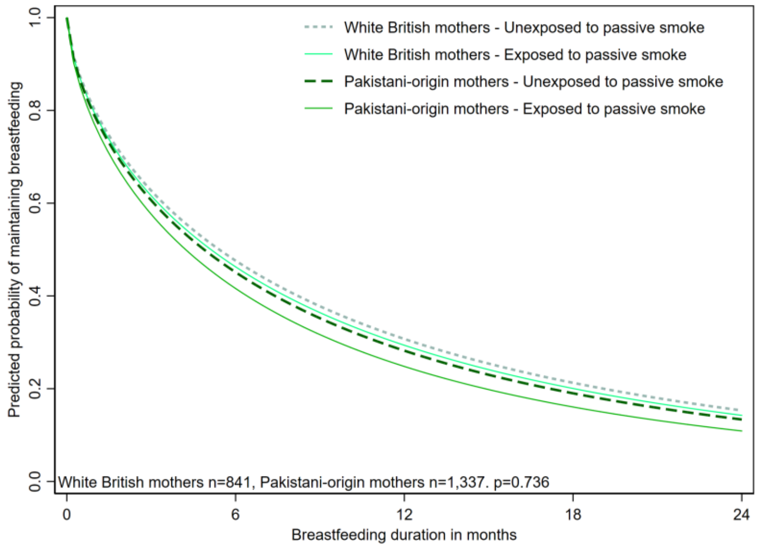

Figure 1f. Predicted probability of maintaining breastfeeding by passive smoke exposure and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

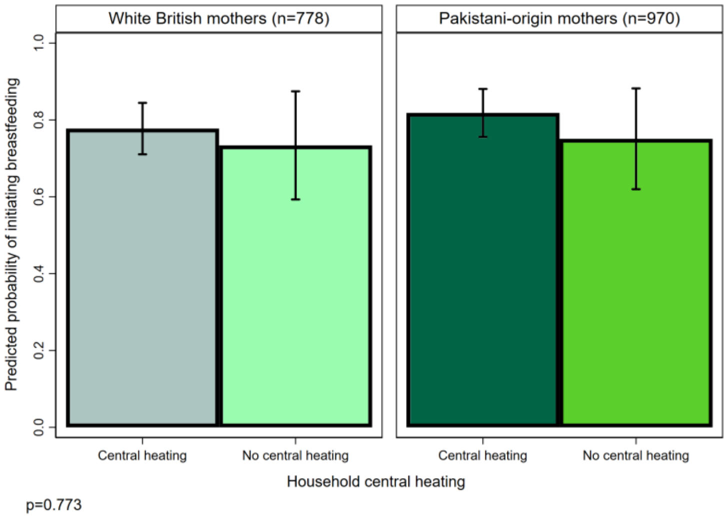

Figure 1g. Predicted probability of initiating breastfeeding by household central heating and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

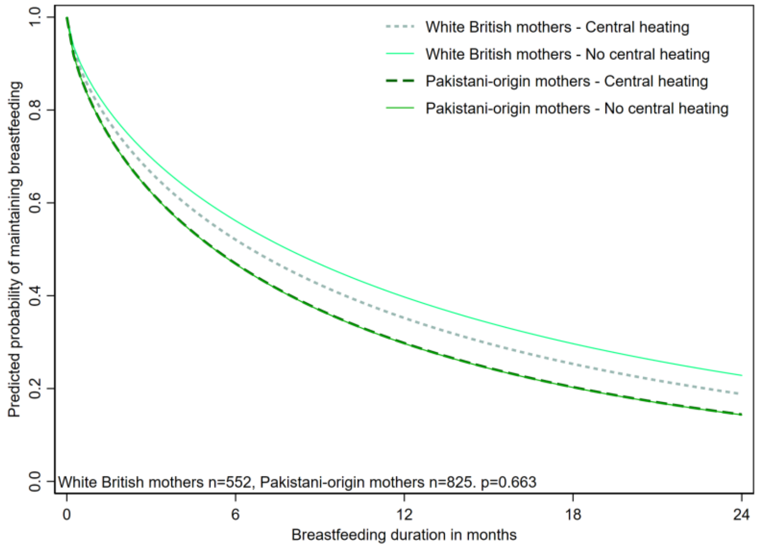

Figure 1h. Predicted probability of maintaining breastfeeding by household central heating and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

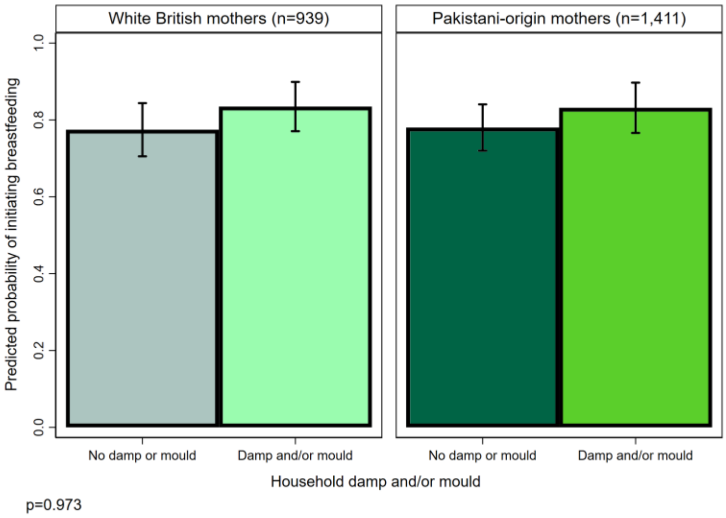

Figure 1i. Predicted probability of initiating breastfeeding by household damp and/or mould exposure and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

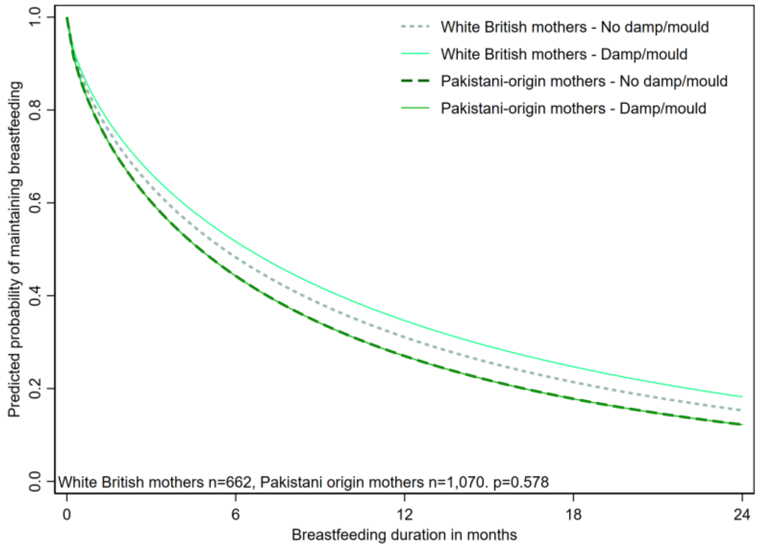

Figure 1j. Predicted probability of maintaining breastfeeding by household damp and/or mould exposure and ethnicity. Models restricted to just White British and Pakistani-origin mothers and including ethnicity x exposure interaction, adjusted for maternal and infant characteristics and socioeconomic position.

Table 1: Characteristics of study population. MeDALL = Mechanisms of the Development of ALLergy sub-cohort. ALLIN = ALLergy and INfection sub-cohort. BiB1000 = BiB1000 sub-cohort. ESCAPE = European Study of Cohorts for Air Pollution Effects. eClipse = maternity information system a Breastfeeding duration questions only asked of those in sub-cohorts; 117 women with "Don't knows" and 35 provided no answers to duration questions. b P-values for t-tests and X2 comparing White British and Pakistani-origin mothers. c P-values for t-tests and X2 comparing mothers with and without missing breastfeeding initiation data. d Standardised factor score where higher scores indicate greater socioeconomic disadvantage. e IMD = 2010 Index of Multiple Deprivation score where higher scores indicate greater deprivation.

		Total (n=12,318)									
		Mothers with initiation data (n=12,087)							Mothers missing initiation data (n=231)		
				Main ethnic groups							
		All ethnic groups (n=12,087)		White British mothers (n=3,951)		Pakistani-origin mothers (n=4,411)		P-value [b]	All ethnicities		P-value [c]
	Data source (time point)	n	n(%) or mean ± SD	n	n(%) or mean ± SD	n	n(%) or mean ± SD		n	n(%) or mean ± SD	
Breastfeeding											
Initiation	Child health records, MeDALL (4yrs), ALLIN (24m, 12m), BiB1000 (36m, 24m, 12m, 6m)	12,087	5,982 (49.49%)	3,951	1,645 (41.64%)	4,411	2,507 (56.84%)	**<0.001**	.	.	1.365
Duration (months) a		2,827	8.84 ± 8.96	902	8.21 ± 9.09	1,437	8.63 ± 8.86	0.271	.	.	
Physical environmental quality											
Water disinfectant by-products	Yorkshire Water routine monitoring data (pregnancy)										
Total trihalomethanes		9,714	1.85 ± 1.63	3,863	2.27 ± 1.97	4,341	1.50 ± 1.21	**<0.001**	135	2.05 ± 1.92	0.145
<1.05µg/day			3,244 (33.40%)		917 (23.74%)		1,850 (42.62%)	**<0.001**		39 (28.89%)	0.310
1.05-1.82µg/day			3,240 (33.35%)		1,228 (31.79%)		1,470 (33.86%)			43 (31.85%)	
1.82-23.96µg/day			3,230 (33.25%)		1,718 (44.47%)		1,021 (23.52%)			53 (39.26%)	
Brominated trihalomethanes		9,714	0.25 ± 0.21	3,863	0.30 ± 0.24	4,341	0.20 ± 0.17	**<0.001**	135	0.29 ± 0.27	**0.016**
<0.14µg/day			3,244 (33.40%)		841 (21.77%)		1,938 (44.64%)	**<0.001**		39 (28.89%)	**0.036**
0.14-0.26µg/day			3,246 (33.42%)		1,278 (33.08%)		1,415 (32.60%)			37 (27.41%)	
0.26-3.34µg/day			3,224 (33.19%)		1,744 (45.15%)		988 (22.76%)			59 (43.70%)	
Bromodichloromethane		9,714	0.20 ± 0.16	3,863	0.24 ± 0.18	4,341	0.16 ± 0.13	**<0.001**	135	0.23 ± 0.21	**0.014**
<0.12µg/day			3,244 (33.40%)		852 (22.06%)		1,929 (44.44%)	**<0.001**		39 (28.89%)	***0.057***
0.12-0.21µg/day			3,245 (33.41%)		1,285 (33.26%)		1,407 (32.41%)			38 (28.15%)	
0.21-2.61µg/day			3,225 (33.20%)		1,726 (44.68%)		1,005 (23.15%)			58 (42.96%)	
Dibromochloromethane		9,714	0.03 ± 0.03	3,863	0.04 ± 0.04	4,341	0.02 ± 0.02	**<0.001**	135	0.04 ± 0.04	***0.075***
<0.02µg/day			3,245 (33.41%)		900 (23.30%)		1,862 (42.89%)	**<0.001**		38 (28.15%)	***0.057***
0.02-0.03µg/day			3,244 (33.40%)		1,215 (31.45%)		1,500 (34.55%)			39 (28.89%)	

0.03-0.61μg/day			3,225 (33.20%)		1,748 (45.25%)		979 (22.55%)			58 (42.96%)	
Chloroform		9,714	1.60 ± 1.44	3,863	1.96 ± 1.75	4,341	1.29 ± 1.05	**<0.001**	135	1.77 ± 1.67	0.191
<0.91μg/day			3,243 (33.38%)		933 (24.15%)		1,831 (42.18%)	**<0.001**		40 (29.63%)	0.332
0.91-1.56μg/day			3,241 (33.36%)		1,216 (31.48%)		1,484 (34.19%)			42 (31.11%)	
1.56-20.94μg/day			3,230 (33.25%)		1,714 (44.37%)		1,026 (23.64%)			53 (39.26%)	
Air pollution	ESCAPE (pregnancy)										
Nitrogen oxides (20μg/m^3)		9,629	1.80 ± 0.42	3,809	1.67 ± 0.38	4,313	1.91 ± 0.41	**<0.001**	128	1.80 ± 0.43	0.944
<1.60μg/m^3			3,215 (33.39%)		1,754 (46.05%)		979 (22.70%)	**<0.001**		38 (29.69%)	0.374
1.60-1.95μg/m^3			3,212 (33.36%)		1,308 (34.34%)		1,432 (33.20%)			40 (31.25%)	
1.95-3.81μg/m^3			3,202 (33.25%)		747 (19.61%)		1,902 (44.10%)			50 (39.06%)	
Nitrogen dioxide (10μg/m^3)		9,629	2.14 ± 0.39	3,809	2.01 ± 0.36	4,313	2.22 ± 0.38	**<0.001**	128	2.14 ± 0.40	0.841
<1.94μg/m^3			3,213 (33.37%)		1,748 (45.89%)		1,017 (23.58%)	**<0.001**		40 (31.25%)	0.880
1.94-2.29μg/m^3			3,208 (33.32%)		1,299 (34.10%)		1,448 (33.57%)			44 (34.38%)	
2.29-3.81μg/m^3			3,208 (33.32%)		762 (20.01%)		1,848 (42.85%)			44 (34.38%)	
Passive cigarette smoke	Baseline (26-28wks gestation)	9,839	3,169 (32.21%)	3,936	1,697 (43.11%)	4,377	1,064 (24.31%)	**<0.001**	140	61 (43.57%)	**0.004**
Household condition											
No central heating	ALLIN (24m, 12m)	2,198	123 (5.60%)	834	41 (4.92%)	1,046	58 (5.54%)	0.544	.	.	
Damp and/or mould	MeDALL (4yrs), ALLIN (24m, 12m)	2,932	598 (20.40%)	1,013	211 (20.83%)	1,519	304 (20.01%)	0.617	.	.	
Socioeconomic position											
Socioeconomic disadvantage dSocioeconomic disadvantage d	BiB1000 (12m), Baseline (26-28wks gestation)	12,087	-0.003 ± 0.999	3,951	-0.057 ± 1.146	4,411	0.146 ± 1.036	**<0.001**	231	0.160 ± 1.027	**0.014**
Food insecure	BiB1000 (12m)	1,186	249 (20.99%)	443	128 (28.89%)	564	73 (12.94%)	**<0.001**	.	.	
Financial difficulties	Baseline (26-28wks gestation)	10,022	779 (7.77%)	3,936	271 (6.88%)	4,383	345 (7.88%)	**0.027**	174	18 (10.34%)	0.376
Means tested benefits	Baseline (26-28wks gestation)	9,863	3,884 (39.38%)	3,936	1,431 (36.36%)	4,398	2,005 (45.59%)	**<0.001**	139	64 (46.04%)	0.110
Partner's employment status	Baseline (26-28wks gestation)	9,369		3,960		4,214		**<0.001**	129		**0.037**
Employed-Non-Manual			3,831 (40.89%)		1,892 (51.27%)		1,307 (31.02%)			44 (34.11%)	
Employed-Manual			3,220 (34.37%)		1,028 (27.86%)		1,721 (40.84%)			43 (33.33%)	
Self-employed			1,394 (14.88%)		376 (10.19%)		835 (19.81%)			19 (14.73%)	
Student			166 (1.77%)		53 (1.44%)		53 (1.26%)			3 (2.33%)	
Unemployed			758 (8.09%)		341 (9.24%)		298 (7.07%)			20 (15.50%)	
Education: <5 GCSE equivalent	Baseline (26-28wks gestation)	9,266	2,127 (22.95%)	3,556	766 (21.54%)	4,198	1,133 (26.99%)	**<0.001**	160	62 (38.75%)	**<0.001**
Neighbourhood deprivation (IMD) e	Baseline (26-28wks gestation)	9,895	42.09 ± 17.81	3,949	36.25 ± 19.08	4,410	46.56 ± 14.79	**<0.001**	143	41.80 ± 18.31	0.843
Ethnicity		9,879		3,951		4,410			141		**<0.001**
White British			3,951 (39.99%)		3,951 (100.00%)		0 (0.00%)			80 (56.74%)	
Pakistani-origin			4,411 (44.65%)		0 (0.00%)		4,411 (100.00%)			37 (26.24%)	

Other			1,517 (15.36%)		0 (0.00%)		0 (0.00%)			24 (17.02%)	
Covariates											
Immigration status	Baseline (26-28wks gestation)	12,050		3,924		4,409			231		**<0.001**
Born in the UK and both parents born in the UK			3,893 (32.31%)		3,746 (95.46%)		25 (0.57%)	**<0.001**		82 (35.50%)	
2nd generation (at least one parent born outside UK)			2,378 (19.73%)		112 (2.85%)		1,850 (41.96%)			24 (10.39%)	
1st generation (arrived to UK as a child)			842 (6.99%)		46 (1.17%)		619 (14.04%)			7 (3.03%)	
1st generation (arrived to UK as an adult)			4,937 (40.97%)		20 (0.51%)		1,915 (43.43%)			118 (51.08%)	
Age (years)	Baseline (26-28wks gestation)	9,898	27.31 ± 5.63	3,951	26.67 ± 6.08	4,411	27.70 ± 5.21	**<0.001**	143	26.48 ± 6.48	***0.078***
BMI	Baseline (26-28wks gestation)	9,399	25.97 ± 5.68	3,744	26.67 ± 5.97	4,188	25.56 ± 5.42	**<0.001**	131	26.27 ± 5.55	0.548
Smoked during pregnancy	Baseline (26-28wks gestation)	9,811	1,644 (16.64%)	3,948	1,330 (33.69%)	4,400	153 (3.48%)	**<0.001**	141	44 (31.21%)	**<0.001**
Parity	eClipse (birth)	11,381	1.08 ± 1.29	3,807	0.77 ± 1.03	4,199	1.37 ± 1.42	**<0.001**	181	1.13 ± 1.55	0.656
0			4,979 (43.75%)		1,996 (52.43%)		1,521 (36.22%)	**<0.001**		87 (48.07%)	**0.002**
1			3,000 (26.36%)		1,092 (28.68%)		996 (23.72%)			45 (24.86%)	
2			1,850 (16.26%)		465 (12.21%)		826 (19.67%)			23 (12.71%)	
3			930 (8.17%)		158 (4.15%)		518 (12.34%)			7 (3.87%)	
4			397 (3.49%)		64 (1.68%)		211 (5.03%)			9 (4.97%)	
5+			225 (1.98%)		32 (0.84%)		127 (3.02%)			10 (5.52%)	
Female infant	eClipse (birth)	11,830	5,731 (48.44%)	3,942	1,904 (48.30%)	4,396	2,142 (48.73%)	0.698	191	90 (47.12%)	0.717
Twins or triplets	eClipse (birth)	11,831	149 (1.26%)	3,942	53 (1.34%)	4,396	66 (1.50%)	0.558	191	2 (1.05%)	0.950
Not living with partner	MeDALL (4yrs), ALLIN (12m), BiB1000 (12m, 6m), Baseline (26-28wks gestation)	9,891	1,664 (16.82%)	3,946	1,128 (28.59%)	4,404	305 (6.93%)	**<0.001**	141	40 (28.37%)	**<0.001**
Birth outcomes	eClipse (birth)										
Gestational age (weeks)		11,831	39.13 ± 1.79	3,942	39.26 ± 1.84	4,396	39.07 ± 1.73	**<0.001**	191	37.76 ± 3.81	**<0.001**
Birthweight (kgs)		11,830	3.22 ± 0.55	3,941	3.35 ± 0.56	4,396	3.13 ± 0.53	**<0.001**	191	2.95 ± 0.86	**<0.001**
Head circumference (cms)		10,962	34.22 ± 1.62	3,632	34.52 ± 1.60	4,061	34.01 ± 1.58	**<0.001**	138	34.01 ± 2.33	0.128
Abdominal circumference (cms)		10,409	31.21 ± 2.66	3,447	31.95 ± 2.63	3,866	30.65 ± 2.59	**<0.001**	128	31.53 ± 2.51	0.173

Table 2: Unadjusted associations between socioeconomic position and environmental quality indicators. Each row refers to a separate model, as we ran individual models for each physical environmental quality indicator. Linear regression used for all indicators except for passive cigarette smoke, no central heating and damp and/or mould associations which were tested with logistic regression. Excludes mothers missing breastfeeding initiation data. Neighbourhood deprivation measured by the 2010 index of multiple deprivation score and socioeconomic disadvantage measured by our standardised socioeconomic position score (higher scores correspond to greater disadvantage for both measures). Positive coefficients represent predicted direction of association, whereby greater disadvantage is associated with greater environmental exposure.

	All mothers (n=12,087)								**White British mothers (n=3,951)**								**Pakistani-origin mothers (n=4,411)**							
	Socioeconomic disadvantage				**Neighbourhood deprivation**				**Socioeconomic disadvantage**				**Neighbourhood deprivation**				**Socioeconomic disadvantage**				**Neighbourhood deprivation**			
Physical environmental quality	**n**	**Coef.**	**95% CI**	**P-value**	**n**	**Coef.**	**95% CI**	**P-value**	**n**	**Coef.**	**95% CI**	**P-value**	**n**	**Coef.**	**95% CI**	**P-value**	**n**	**Coef.**	**95% CI**	**P-value**	**n**	**Coef.**	**95% CI**	**P-value**
Water disinfectant by-products																								
Total trihalomethanes	9,714	0.038	0.008-0.067	**0.012**	9,712	-0.002	-0.004--0.000	**0.030**	3,863	0.137	0.083-0.191	**<0.001**	3,861	0.008	0.005-0.011	**<0.001**	4,341	-0.027	-0.061-0.008	0.134	4,341	-0.001	-0.004-0.001	0.228
Brominated trihalomethanes	9,714	0.010	0.006-0.013	**<0.001**	9,712	-0.000	-0.000-0.000	0.156	3,863	0.026	0.019-0.032	**<0.001**	3,861	0.001	0.001-0.002	**<0.001**	4,341	-0.001	-0.005-0.004	0.807	4,341	-0.000	-0.000-0.000	0.378
Bromodichloromethane	9,714	0.008	0.005-0.011	**<0.001**	9,712	0.000	0.000-0.000	0.429	3,863	0.021	0.016-0.026	**<0.001**	3,861	0.001	0.001-0.001	**<0.001**	4,341	-0.001	0.005-0.003	0.691	4,341	-0.000	-0.000-0.000	0.463
Dibromochloromethane	9,714	0.001	0.000-0.001	***0.053***	9,712	0.000	0.000-0.000	**<0.001**	3,863	0.002	0.001-0.003	**<0.001**	3,861	0.000	0.000-0.000	**0.021**	4,341	0.000	-0.001-0.000	0.315	4,341	0.000	0.000-0.000	**0.008**
Chloroform	9,714	0.028	0.002-0.054	**0.035**	9,712	-0.002	-0.003-0.000	**0.024**	3,863	0.112	0.064-0.160	**<0.001**	3,861	0.007	0.004-0.010	**<0.001**	4,341	-0.026	-0.056-0.004	***0.092***	4,341	-0.001	-0.003-0.001	0.212
Air pollution																								
Nitrogen oxides	9,629	0.035	0.028-0.043	**<0.001**	9,626	0.006	0.005-0.006	**<0.001**	3,809	0.012	0.002-0.023	**0.025**	3,807	0.001	0.001-0.002	**<0.001**	4,312	0.041	0.029-0.053	**<0.001**	4,312	0.008	0.007-0.009	**<0.001**
Nitrogen dioxide	9,629	0.038	0.031-0.045	**<0.001**	9,626	0.007	0.006-0.007	**<0.001**	3,809	0.025	0.016-0.035	**<0.001**	3,807	0.003	0.002-0.004	**<0.001**	4,312	0.039	0.028-0.050	**<0.001**	4,312	0.009	0.008-0.010	**<0.001**
Passive cigarette smoke	9,839	0.352	0.312-0.392	**<0.001**	9,836	0.010	0.008-0.013	**<0.001**	3,936	0.618	0.556-0.679	**<0.001**	3,934	0.029	0.026-0.033	**<0.001**	4,377	0.122	0.055-0.189	**<0.001**	4,376	0.000	-0.004-0.005	0.866
Household condition																								
No central heating	2,198	0.128	-0.039-0.296	0.134	2,197	0.014	0.004-0.025	**0.007**	834	0.255	-0.019-0.528	***0.068***	833	0.001	-0.016-0.017	0.919	1,046	-0.032	-0.288-0.224	0.808	1,046	0.038	0.019-0.058	**<0.001**
Damp and/or mould	2,932	0.169	0.086-0.253	**<0.001**	2,931	0.011	0.006-0.016	**<0.001**	1,013	0.235	0.101-0.370	**0.001**	1,012	0.011	0.003-0.019	**0.007**	1,519	0.114	-0.009-0.237	***0.069***	1,519	0.017	0.009-0.026	**<0.001**

Table 3: Associations between physical environmental quality and breastfeeding initiation. Models adjusted for cohabitation status, immigration status, BMI, age, parity, smoking during pregnancy, the sex of the infant and whether it was a multiple birth (M1) and additionally socioeconomic position (M2). OR=odds ratio. CI=confidence interval. Each row in the table refers to a separate model, as we ran individual models for each physical environmental quality indicator. a Odds for one standard deviation increase in socioeconomic disadvantage. b P-value for exposureXethnicity interaction term in model including White British and Pakistani-origin mothers, but excluding other ethnicities.

	Breastfeeding initiation																						
	All mothers							White British mothers							Pakistani-origin mothers							
	M1: Controlling for maternal and infant characteristics				M2: Controlling for maternal and infant characteristics and socioeconomic position			M1: Controlling for maternal and infant characteristics				M2: Controlling for maternal and infant characteristics and socioeconomic position			M1: Controlling for maternal and infant characteristics				M2: Controlling for maternal and infant characteristics and socioeconomic position			
	n	OR	95% CI	P-value	OR	95% CI	P-value	n	OR	95% CI	P-value	OR	95% CI	P-value	n	OR	95% CI	P-value	OR	95% CI	P-value	Interaction P-value bInteraction P-value b
Socioeconomic disadvantage aSocioeconomic disadvantage a	8,955	-	-	-	0.776	0.739-0.814	**<0.001**	3,589	-	-	-	0.772	0.712-0.837	**<0.001**	3,979	-	-	-	0.797	0.743-0.854	**<0.001**	
Physical environmental quality																						
Water disinfectant by-products																						
Total trihalomethanes	8,825							3,517							3,939							0.103
1.05-1.82µg/day vs <1.05µg/day		0.855	0.767-0.954	**0.005**	0.837	0.750-0.933	**0.001**		1.005	0.827-1.221	0.962	1.005	0.826-1.222	0.962		0.792	0.682-0.919	**0.002**	0.774	0.666-0.900	**0.001**	
1.82-23.96µg/day vs <1.05µg/day		0.905	0.807-1.013	***0.083***	0.895	0.798-1.003	***0.056***		1.139	0.946-1.370	0.169	1.150	0.955-1.385	0.141		0.774	0.653-0.919	**0.003**	0.765	0.644-0.908	**0.002**	
Brominated trihalomethanes	8,825							3,517							3,939							0.360
0.14-0.26µg/day vs <0.14µg/day		0.864	0.775-0.963	**0.008**	0.845	0.758-0.943	**0.003**		0.904	0.742-1.101	0.316	0.901	0.739-1.099	0.304		0.756	0.651-0.878	**<0.001**	0.744	0.640-0.865	**<0.001**	
0.26-3.34µg/day vs <0.14µg/day		0.942	0.841-1.054	0.297	0.929	0.829-1.040	0.201		1.031	0.853-1.246	0.753	1.045	0.864-1.264	0.652		0.756	0.637-0.898	**0.001**	0.753	0.633-0.895	**0.001**	
Bromodichloromethane	8,825							3,517							3,939							0.426
0.12-0.21µg/day vs <0.12µg/day		0.860	0.772-0.959	**0.007**	0.841	0.753-0.938	**0.002**		0.897	0.737-1.092	0.279	0.896	0.736-1.092	0.276		0.770	0.663-0.895	**0.001**	0.756	0.651-0.879	**<0.001**	
0.21-2.61µg/day vs <0.12µg/day		0.910	0.813-1.020	0.105	0.900	0.803-1.009	***0.070***		1.041	0.862-1.259	0.675	1.057	0.874-1.279	0.567		0.775	0.653-0.920	**0.004**	0.768	0.646-0.912	**0.003**	
Dibromochloromethane	8,825							3,517							3,939							**0.018**
0.02-0.03µg/day vs <0.02µg/day		0.810	0.727-0.902	**<0.001**	0.800	0.717-0.891	**<0.001**		0.879	0.722-1.069	0.196	0.881	0.724-1.073	0.207		0.721	0.622-0.836	**<0.001**	0.717	0.617-0.832	**<0.001**	
0.03-0.61µg/day vs <0.02µg/day		0.926	0.827-1.036	0.180	0.916	0.818-1.026	0.130		1.140	0.949-1.370	0.162	1.150	0.956-1.383	0.139		0.696	0.586-0.828	**<0.001**	0.695	0.584-0.827	**<0.001**	
Chloroform	8,825							3,517							3,939							***0.073***

0.91-1.56µg/day vs <0.91µg/day		0.872	0.782-0.972	**0.013**	0.853	0.765-0.951	**0.004**		1.020	0.840-1.239	0.840	1.023	0.841-1.244	0.819		0.801	0.690-0.930	**0.004**	0.782	0.673-0.909	**0.001**	
1.56-20.94µg/day vs <0.91µg/day		0.944	0.844-1.057	0.319	0.933	0.833-1.045	0.229		1.150	0.957-1.382	0.137	1.167	0.969-1.404	0.103		0.769	0.648-0.912	**0.003**	0.759	0.639-0.901	**0.002**	
Air pollution																						
Nitrogen oxides (20µg/m^3)	8,751	0.774	0.694-0.865	**<0.001**	0.813	0.727-0.909	**<0.001**	3,477	0.884	0.729-1.073	0.212	0.905	0.745-1.100	0.317	3,907	0.693	0.593-0.810	**<0.001**	0.730	0.623-0.854	**<0.001**	0.441
Nitrogen dioxide (10µg/m^3)	8,751	0.766	0.682-0.861	**<0.001**	0.810	0.720-0.911	**<0.001**	3,477	0.772	0.631-0.945	**0.012**	0.806	0.657-0.988	**0.038**	3,907	0.748	0.633-0.885	**0.001**	0.789	0.666-0.935	**0.006**	0.846
Passive cigarette smoke	8,916	0.910	0.823-1.007	***0.067***	0.966	0.872-1.069	0.501	3,578	0.888	0.757-1.041	0.142	0.961	0.817-1.130	0.629	3,956	0.950	0.817-1.104	0.504	0.992	0.852-1.155	0.919	0.483
Household condition																						
No central heating	2,046	0.736	0.454-1.193	0.214	0.787	0.484-1.281	0.336	778	0.692	0.337-1.419	0.315	0.738	0.359-1.518	0.410	970	0.584	0.287-1.186	0.137	0.624	0.303-1.285	0.200	0.773
Damp and/or mould	2,725	1.448	1.116-1.878	**0.005**	1.524	1.171-1.983	**0.002**	939	1.570	1.058-2.329	**0.025**	1.655	1.109-2.470	**0.014**	1,411	1.344	0.919-1.968	0.128	1.415	0.964-2.076	***0.076***	0.973

Table 4: Associations between physical environmental quality and breastfeeding duration. Models adjusted for cohabitation status, immigration status, BMI, age, parity, smoking during pregnancy, the sex of the infant and whether it was a multiple birth (M1) and additionally socioeconomic position (M2). HR=hazard ratio of stopping breastfeeding. CI=confidence interval. Each row in the table refers to a separate model, as we ran individual models for each physical environmental quality indicator. a Odds for one standard deviation increase in socioeconomic disadvantage. b P-value for exposureXethnicity interaction term in model including White British and Pakistani-origin mothers, but excluding other ethnicities.

	Breastfeeding duration (hazard of stopping breastfeeding)																						
	All mothers							White British mothers							Pakistani-origin mothers							
	M1: Controlling for maternal and infant characteristics				M2: Controlling for maternal and infant characteristics and socioeconomic position			M1: Controlling for maternal and infant characteristics				M2: Controlling for maternal and infant characteristics and socioeconomic position			M1: Controlling for maternal and infant characteristics				M2: Controlling for maternal and infant characteristics and socioeconomic position			
	n	HR	95% CI	P-value	HR	95% CI	P-value	n	HR	95% CI	P-value	HR	95% CI	P-value	n	HR	95% CI	P-value	HR	95% CI	P-value	Interaction P-value b
Socioeconomic disadvantage a	2,635	-	-	-	1.108	1.060-1.159	**<0.001**	843	-	-	-	1.105	1.013-1.204	**0.024**	1,346	-	-	-	1.125	1.058-1.196	**<0.001**	
Physical environmental quality																						
Water disinfectant by-products																						
Total trihalomethanes	2,608							829							1,338							0.471
1.05-1.82µg/day vs <1.05µg/day		0.986	0.892-1.090	0.783	0.996	0.901-1.102	0.942		0.995	0.814-1.216	0.959	0.999	0.818-1.222	0.996		1.046	0.916-1.193	0.507	1.054	0.923-1.202	0.437	
1.82-23.96µg/day vs <1.05µg/day		0.991	0.890-1.104	0.873	0.991	0.890-1.104	0.871		0.934	0.768-1.136	0.497	0.923	0.759-1.123	0.425		1.123	0.962-1.310	0.141	1.130	0.968-1.319	0.122	
Brominated trihalomethanes	2,608							829							1,338							0.350
0.14-0.26µg/day vs <0.14µg/day		0.984	0.889-1.088	0.749	0.996	0.901-1.102	0.945		0.976	0.799-1.192	0.811	0.985	0.806-1.203	0.882		1.093	0.956-1.251	0.193	1.105	0.966-1.264	0.147	
0.26-3.34µg/day vs <0.14µg/day		1.003	0.900-1.117	0.962	1.003	0.901-1.118	0.951		0.910	0.747-1.109	0.352	0.903	0.741-1.101	0.313		1.149	0.984-1.341	***0.078***	1.149	0.984-1.342	***0.079***	
Bromodichloromethane	2,608							829							1,338							0.337
0.12-0.21µg/day vs <0.12µg/day		0.980	0.886-1.084	0.701	0.992	0.897-1.098	0.882		0.964	0.790-1.177	0.720	0.975	0.799-1.189	0.800		1.100	0.961-1.259	0.165	1.110	0.970-1.270	0.130	
0.21-2.61µg/day vs <0.12µg/day		1.000	0.898-1.113	0.994	0.999	0.897-1.113	0.987		0.905	0.743-1.102	0.321	0.895	0.734-1.090	0.271		1.132	0.971-1.321	0.114	1.136	0.974-1.325	0.105	
Dibromochloromethane	2,608							829							1,338							0.365
0.02-0.03µg/day vs <0.02µg/day		1.059	0.958-1.172	0.262	1.068	0.966-1.182	0.200		1.061	0.868-1.298	0.564	1.070	0.875-1.309	0.509		1.203	1.053-1.374	**0.006**	1.210	1.059-1.382	**0.005**	
0.03-0.61µg/day vs <0.02µg/day		1.018	0.915-1.133	0.744	1.016	0.913-1.131	0.773		0.920	0.758-1.117	0.402	0.913	0.751-1.108	0.356		1.165	0.996-1.363	***0.056***	1.162	0.994-1.360	***0.060***	
Chloroform	2,608							829							1,338							0.408

0.91-1.56µg/day vs <0.91µg/day		0.969	0.876-1.071	0.537	0.978	0.884-1.081	0.661		0.959	0.785-1.173	0.686	0.960	0.786-1.173	0.691		1.025	0.899-1.170	0.708	1.033	0.905-1.178	0.631	
1.56-20.94µg/day vs <0.91µg/day		0.981	0.881-1.092	0.724	0.981	0.881-1.092	0.724		0.919	0.756-1.116	0.392	0.906	0.745-1.101	0.321		1.114	0.955-1.300	0.169	1.121	0.961-1.308	0.147	
Air pollution																						
Nitrogen oxides (20µg/m³)	2,580	0.937	0.841-1.043	0.233	0.911	0.817-1.015	***0.092***	814	0.786	0.633-0.976	**0.029**	0.769	0.619-0.955	**0.018**	1,323	1.051	0.910-1.213	0.501	1.019	0.881-1.179	0.799	***0.066***
Nitrogen dioxide (10µg/m³)	2,580	0.833	0.749-0.927	**0.001**	0.805	0.723-0.897	**<0.001**	814	0.671	0.540-0.834	**<0.001**	0.646	0.519-0.804	**<0.001**	1,323	0.953	0.825-1.102	0.517	0.928	0.802-1.074	0.316	**0.034**
Passive cigarette smoke	2,624	1.145	1.040-1.260	**0.006**	1.120	1.017-1.234	**0.021**	841	1.082	0.908-1.290	0.378	1.054	0.883-1.258	0.559	1,337	1.111	0.972-1.270	0.124	1.085	0.948-1.241	0.235	0.736
Household condition																						
No central heating	1,651	0.939	0.742-1.189	0.601	0.930	0.734-1.177	0.546	552	0.903	0.546-1.493	0.691	0.898	0.543-1.484	0.674	825	0.989	0.715-1.367	0.946	0.987	0.714-1.365	0.938	0.663
Damp and/or mould	2,065	0.953	0.851-1.066	0.401	0.935	0.836-1.047	0.245	662	0.924	0.747-1.144	0.469	0.930	0.752-1.151	0.505	1,070	1.028	0.882-1.197	0.725	0.990	0.849-1.154	0.896	0.578