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RESEARCH

Maternal Physical Activity and Neonatal Cord Blood pH: Findings from the Born in Bradford Pregnancy Cohort

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Objective: Evidence suggests that physical activity whilst pregnant is beneficially associated with maternal cardiometabolic health and perinatal outcomes. It is unknown if benefits extend to objective markers of the neonate condition at birth. This study investigated associations of maternal pregnancy physical activity with cord blood pH.

Methods: Cord blood pH was measured when clinically indicated in a subgroup of Born in Bradford birth cohort participants (n = 1,467). Pregnant women were grouped into one of four activity categories (inactive/somewhat active/moderately active/active) based on their self-reported physical activity at 26–28 weeks gestation. Linear regression was used to calculate adjusted mean differences in cord blood pH, and Poisson regression was used to quantify relative risks for moderate cord blood acidaemia (pH < 7.10), across physical activity groups.

Results: More than half of pregnant women (52.0%) were inactive, one-fifth were somewhat active (21.7%), fewer were moderately active (14.6%) and active (11.7%), respectively. Pregnancy physical activity was favourably associated with higher cord blood pH. Compared to neonates of inactive women, there was some evidence that neonates of women who were at least somewhat active in pregnancy had lower relative risk of moderate cord blood acidaemia (for arterial blood: relative risk = 0.70 (95% confidence interval 0.48–1.03)).

Conclusions: Modest volumes of mid-pregnancy maternal physical activity do not appear to adversely influence cord blood pH and may enhance the neonate condition at birth.

Keywords: Exercise; Fetal Blood; Acidosis; Fetal Development

Introduction

Safety concerns are cited by pregnant women as a barrier to physical activity (Coll *et al.*, 2017). This may have originated from cultural beliefs that women should 'rest' in pregnancy (Coll *et al.*, 2017) alongside former recommendations that physical activity should be limited because of concerns for mother and offspring welfare, including risk of impaired oxygen supply to the fetus during supine exercise (American College of Obstetricians and Gynecologists (ACOG), 1985; Pivarnik and Mudd, 2009).

It is still good practice to avoid supine exercise, particularly late in pregnancy, but otherwise physical activity can enhance transportation of oxygenated blood to the developing fetus, via physiological adaptations such as increased placental surface area, and enhanced blood flow and perfusion balance between maternal and fetal circulations (Melzer *et al.*, 2010; Ferraro, Gaudet and Adamo, 2012). Physical activity can also aid regulation of circulating blood glucose levels (Collings *et al.*, 2020a) which could help to reduce the risk of placental dysfunction and fetal hyperinsulinemia, thereby impacting fetal metabolism, oxygen demand and lactate accumulation (Jarmuzek, Wielgos and Bomba-Opon, 2015). As well as acute neonatal stress, each of these factors can have implications for the cord blood pH, levels of which provide an objective marker of the neonate condition immediately prior to birth and closely relate to Apgar scores (Victory *et al.*, 2004). Low cord blood pH has been shown to predict neonate morbidity and mortality and longer term neurodevelopmental impairment (Malin, Morris and Khan, 2010; Yeh, Emary and Impey, 2012; Kelly *et al.*, 2018; Vesoulis *et al.*, 2018). There is currently limited support for an association between pregnancy physical

activity with cord blood pH, but the evidence-base is low quality, characterised by small studies that were likely underpowered to detect associations (Davenport *et al.*, 2018).

The objective of this study was to investigate associations of maternal pregnancy physical activity with cord blood pH measured in neonates who were born in poor condition, or for whom there was a concern during labour or immediately following birth. Evidence for a positive association with cord blood pH could strengthen the case that physical activity is safe and potentially beneficial for healthy pregnant women and their neonates.

Methods

Study design

Born in Bradford (BiB) is a prospective birth cohort study of 12,453 pregnant women who were recruited between 2007–10 whilst attending routine antenatal appointments at Bradford Royal Infirmary, the only maternity unit serving the city. Bradford is the sixth largest metropolitan borough in England and is one of the most deprived and ethnically diverse cities in the country (Wright *et al.*, 2013). In a subsample of BiB participants, cord blood samples were taken and pH was analysed on the labour ward. This occurred when there was 'concern about the baby during labour or immediately following birth' or if the baby was born in poor condition (National Institute for Health and Care Excellence, 2007). The final sample comprised 1,467 mother-neonate pairs. As cord blood pH was measured only when clinically indicated the pH subgroup was skewed toward greater representation of nulliparous women (who are higher risk for pregnancy complications (Bai *et al.*, 2002)) and more caesarean section deliveries. The characteristics of the included subgroup were otherwise similar to all other BiB participants (n = 12,391 mother-neonate pairs; see *Supplementary Table S1*) who were broadly representative of the obstetric population in Bradford at the time of recruitment (Wright *et al.*, 2013). The BiB study was approved by the Bradford Research Ethics Committee (ref 07/H1302/112) and all mothers provided written informed consent.

Maternal physical activity was assessed at 26–28 weeks gestation using the General Practice Physical Activity Questionnaire (GPPAQ) which has been validated against accelerometry and exhibits face validity in the BiB pregnancy cohort (National Health Service, 2009; Collings *et al.*, 2020a, 2020b). Mothers were grouped into one of four activity levels (inactive/somewhat active/moderately active/active) based on their self-reported occupational physical activity level, physical exercise and walking. The active category is consistent with meeting the recommended minimum of 150 minutes per week of moderate intensity physical activity (Department of Health and Social Care, 2019). Full details of the GPPAQ including the scoring system used to derive activity categories are shown in *Supplementary Figure S1*.

Following clinical guidelines that were in operation at the time, in the event there was 'concern about the baby either in labour or immediately following birth', or if the baby was born in poor condition with a 1-minute Apgar score of 5 or less, the umbilical cord was double-clamped and venous and arterial blood samples were taken for gas analysis by clinical staff (Thorp, Dildy and Yeomans, 1996; National Institute for Health and Care Excellence, 2007). The data were retrieved from obstetric records and were used to derive a third variable that represented the lowest cord blood pH recorded from either umbilical sample (Kelly *et al.*, 2018).

Women consented to the abstraction and use of their data from obstetric medical records and at recruitment completed an interviewer administered questionnaire. Full details of all covariables have previously been described (Collings *et al.*, 2020a).

Statistical analysis

Linear regression models were used to calculate differences in cord blood pH levels between the four groups of maternal physical activity (reference group: inactive); p-values from trend tests across physical activity categories are also presented. Models were initially adjusted for maternal age, ethnicity, early-pregnancy body mass index (measured at ~12 weeks gestation), socioeconomic status, parity, season of physical activity assessment, and neonate sex. Adjustments for maternal smoking, delivery mode, gestational age, birth weight, and neonate abdominal circumference were subsequently included because they changed β-coefficients between exposures and outcomes by ≥10% (Maldonado and Greenland, 1993). All dependent variables (arterial, venous and the lowest cord blood pH) were approximately normally distributed and results from the linear regression analysis are presented as marginal means with 95% confidence intervals. Adjusted for the same covariates, Poisson regression was used to quantify the relative risk of moderate cord blood acidaemia (pH < 7.10 (Yeh, Emary and Impey, 2012; Vesoulis *et al.*, 2018)) between neonates of inactive women compared to women who were at least somewhat active in pregnancy (somewhat active, moderately active, and active groups combined). All analyses were performed in Stata/SE version 15.0 software and $p <$ 0.05 was deemed statistically significant.

Results

Participant characteristics

Descriptive statistics for the study sample are presented in **Table 1**. More than half of women (52.0%) were inactive in pregnancy, one-fifth were somewhat active (21.7%) and fewer were moderately active (14.6%) and active (11.7%), respectively. Inactive women were more frequently of Pakistani-origin, multiparous and were from moderately or the most deprived socioeconomic strata. Nearly one-tenth (8.5%) of the lowest recorded cord blood pH samples were moderately acidaemic (*Supplementary Table S2* shows the number of cases of acidaemia stratified by cord blood source and physical activity level). Cord blood pH was positively related to Apgar scores (*Supplementary Figures S2 and S3*).

Associations of pregnancy physical activity with cord blood pH

Table 2 shows cord blood pH levels stratified by maternal pregnancy physical activity. There was no evidence for effect modification by ethnicity ($p \geq 0.42$) hence results are presented for the whole sample combined, adjusted for ethnic group. Significantly higher cord blood pH was observed in neonates of women who were somewhat active and moderately active in pregnancy compared to neonates of women who were inactive. The Poisson regression analysis provided some indication that, compared to neonates of inactive women, neonates of women who were at least somewhat active in pregnancy had lower risk of moderate cord blood

Table 1: Maternal and neonatal characteristics, overall and stratified by pregnancy physical activity level.

	Overall (*n* = 1,467)	**Inactive (*n* = 763)**	**Somewhat active (*n* = 319)**	**Moderately active (*n* = 214)**	**Active (*n* = 171)**	***p*-difference**
Maternal age (y)	27.1 ± 5.5	27.1 ± 5.7	26.7 ± 5.5	26.9 ± 5.3	27.7 ± 5.2	0.28
Ethnicity (*n* (%))						
White British	623 (42.5)	244 (32.0)	154 (48.3)	120 (56.1)	105 (61.4)	
Pakistani-origin	613 (41.8)	419 (54.9)	105 (32.9)	50 (23.4)	39 (22.8)	
Other/Mixed	231 (15.7)	100 (13.1)	60 (18.8)	44 (20.5)	27 (15.8)	<0.001
Socioeconomic status (*n* (%))						
Least deprived	699 (47.7)	267 (35.0)	195 (61.1)	133 (62.2)	104 (60.8)	
Moderately deprived	571 (38.9)	360 (47.2)	95 (29.8)	64 (29.9)	52 (30.4)	
Most deprived	197 (13.4)	136 (17.8)	29 (9.1)	17 (7.9)	15 (8.8)	<0.001
Parity (*n* (%))						
0	923 (62.9)	431 (56.5)	220 (69.0)	156 (72.9)	116 (67.8)	
1	328 (22.4)	175 (22.9)	72 (22.6)	43 (20.1)	38 (22.2)	
≥2	216 (14.7)	157 (20.6)	27 (8.4)	15 (7.0)	17 (9.9)	<0.001
Early pregnancy BMI (kg/m^2)	25.6 (7.1)	25.6 (7.3)	25.6 (6.3)	25.8 (7.2)	25.1 (7.7)	0.98
Smoked in pregnancy (*n* (%))	252 (17.2)	124 (16.3)	47 (14.7)	41 (19.2)	40 (23.4)	0.071
Delivery mode (*n* (%) vaginal)	747 (50.9)	385 (50.5)	165 (51.7)	114 (53.3)	83 (48.5)	0.80
Offspring sex (*n* (%) male)	807 (55.0)	429 (56.2)	169 (53.0)	116 (54.2)	93 (54.4)	0.78
Gestational age (weeks)	39.7 ± 1.9	39.6 ± 1.9	39.9 ± 1.9	39.7 ± 2.0	40.1 ± 1.5	<0.01
Birthweight (g)	3264 ± 611	3214 ± 627	3279 ± 574	3291 ± 639	3424 ± 539	<0.001[a]
Abdominal circumference (cm)	31.2 ± 3.0	30.9 ± 3.1	31.4 ± 2.7	31.3 ± 3.4	31.9 ± 2.6	<0.001[b]
Moderate cord blood acidaemia[c] (*n* (%))	124 (8.5)	74 (9.7)	23 (7.2)	16 (7.5)	11 (6.4)	0.34

For continuous variables, values are mean ± standard deviation or median (interquartile range) given skewness. Differences between physical activity categories calculated by Chi-square, ANOVA and Kruskal-Wallis tests as appropriate. [a] Significant difference did not persist in ANCOVA including adjustment for ethnicity (*p*-difference = 0.052). [b] Significant difference did not persist in ANCOVA including adjustment for ethnicity (*p*-difference = 0.11). [c] Based on the lowest recorded cord blood pH sample. BMI: Body mass index. PA: Physical activity.

Table 2: Associations of pregnancy physical activity with neonatal cord blood pH.

	Number of participants (*n* in each activity category)	Inactive	Somewhat active	Moderately active	Active	*p*-trend
Arterial pH	1382 (720/300/200/162)	7.22 (7.21–7.22) Reference	**7.23 (7.22–7.24) 0.023**	**7.24 (7.22–7.25) 0.028**	7.23 (7.21–7.24) 0.46	0.11
Venous pH	1427 (742/307/210/168)	7.27 (7.26–7.27) Reference	**7.28 (7.28–7.29) 0.041**	**7.29 (7.27–7.30) 0.049**	7.28 (7.27–7.29) 0.52	0.15
Lowest cord pH	1467 (763/319/214/171)	7.22 (7.21–7.22) Reference	**7.23 (7.22–7.24) 0.016**	**7.23 (7.22–7.24) 0.045**	7.22 (7.21–7.24) 0.53	0.15

Data are estimated marginal means (95% confidence interval) adjusted for maternal age, ethnicity, early-pregnancy BMI, socioeconomic status, parity, season of physical activity assessment, maternal smoking in pregnancy, neonate sex, delivery mode, gestational age, birth weight, and neonate abdominal circumference. Below the estimates are *p*-values. Bold font denotes significantly different values compared to the referent inactive group ($p < 0.05$). Adjusting for other maternal lifestyle factors (alcohol consumption, caffeine intake, sleep problems, use of dietary supplements), pregnancy complications (gestational diabetes, gestational hypertension, gestational weight gain, emergency caesarean and medical or surgical induction), measurement factors related to maternal physical activity (gestational age at the time of reporting, if women were feeling well and were able to enjoy their normal daily activities, if maternal physical activity was reported during Ramadan) and cord blood pH (the time delay from birth to blood sampling (the median (IQR) time delay to arterial and venous cord blood samples was 10 (10) and 12 (10) minutes, respectively) did not appreciably influence associations and so were not retained in models. Models were rerun excluding samples that were missing data for sampling time ($n = 61$) and excluding samples that were delayed by ≥30 minutes following delivery ($n = 82$), the results were substantively unchanged.

acidaemia (arterial pH (relative risk (95% confidence interval): 0.70 (0.48–1.03), $p = 0.071$; venous pH (0.62 (0.34–1.12), $p = 0.11$); lowest pH (0.73 (0.51–1.05), $p = 0.086$).

Discussion

This study found that maternal pregnancy physical activity was favourably associated with higher cord blood pH. The association was modest in size but may be underestimated due to errors in self-reported physical activity (Celis-Morales *et al.*, 2012). It is also conceivable that any positive influence on cord blood pH may be clinically meaningful as lower values are associated with higher risk of serious adverse neonatal outcomes in a dose-dependent manner (Malin, Morris and Khan, 2010; Yeh, Emary and Impey, 2012; Kelly *et al.*, 2018; Vesoulis *et al.*, 2018).

A recent meta-analysis concluded that there was low quality evidence from six randomised trials which together indicated there was no evidence for an association between pregnancy physical activity with cord blood pH (Davenport *et al.*, 2018). However, an observational study reported that arterial cord pH was significantly higher in neonates of women who performed high-intensity exercise throughout pregnancy compared to neonates of women who had discontinued exercising (Clapp *et al.*, 1995). Furthermore, cohort analysis of a controlled trial found that objectively measured physical activity at 16 weeks gestation was associated with higher venous cord blood pH and arterial oxygen saturation (Baena-García *et al.*, 2019). The results provided by Baena-García et al. may be of limited clinical relevance, however, as their analysis was restricted to participants with 'normal' cord blood pH values >7.20 (Baena-García *et al.*, 2019).

This study is the first to report associations between pregnancy physical activity and the full range of cord blood pH in a large and diverse sample of mother-neonate pairs from a deprived location. Our results appear to provide evidence for a threshold-type effect. Compared to neonates of women who were inactive, only neonates of women who were somewhat and moderately active in pregnancy exhibited higher cord blood pH. This is may be explained by fewer women being categorised as active, and hence insufficient statistical power at the higher end of the activity spectrum to detect what appear to be small associations. To account for this and to help decipher the clinical relevance of associations we calculated relative risks for moderate cord blood acidaemia between neonates of inactive women versus women who were at least somewhat active in pregnancy. We found some evidence that being at least somewhat active was associated with a lower risk of moderate acidaemia. The results only approached statistical significance, but all 95% confidence intervals were largely consistent with a protective effect (confidence limits indicated considerable risk reductions of ~40–50% associated with being at least somewhat active in pregnancy versus comparatively marginal risk increases). It is encouraging that modest volumes of mid-pregnancy physical activity do not appear to be detrimental and seem to be associated with some benefit in terms of higher cord blood pH, and possibly lower risk of moderate acidaemia. This is contrary to the popular belief of many women that physical activity in pregnancy is harmful (Coll *et al.*, 2017). Our results support new UK guidelines which emphasise that 'every activity counts' and that inactive pregnant women should gradually accumulate physical activity throughout the week (Department of Health and Social Care, 2019).

The results of this study add to growing evidence that pregnancy physical activity is not only safe but beneficial for the short and long-term health prospects of both mother and child (Collings *et al.*, 2020a, 2020b). Placental function likely underpins the link between maternal physical activity and higher neonatal cord blood pH. Biological adaptations to regular pregnancy physical activity include increased size and vascularity of the placenta which aids oxygen perfusion to the fetus and removal of deoxygenated lactate filled blood (Melzer *et al.*, 2010; Ferraro, Gaudet and Adamo, 2012). Activity-mediated improvements in maternal adiposity and glucose regulation (which we have previously observed in the BiB pregnancy cohort (Collings *et al.*, 2020a)) may also assist prevention of placental dysfunction and fetal hyperinsulinemia, which could help curb adverse fetal metabolism and cord blood acidosis (Jarmuzek, Wielgos and Bomba-Opon, 2015; Aalipour *et al.*, 2018). As with the results of any observational study, residual confounding by imperfectly measured covariates and unknown or unmeasured confounding cannot be excluded. Additional research is needed to replicate the current findings. Future studies should be carried out in unselected population-based samples of mother-neonate pairs, rather than clinically identified samples, which hinders generalisability of results.

Conclusion

In neonates born in poor condition, or for whom there was concern during labour or immediately following birth, maternal physical activity was favourably associated with slightly higher neonatal cord blood pH. Modest volumes of mid-pregnancy physical activity do not appear to be harmful and may enhance the condition of neonates at birth.

Data Accessibility Statement

Data generated and analysed for the current study are available from the corresponding author on reasonable request.

Additional Files

The additional files for this article can be found as follows:

- **Supplementary Table S1.** Participant characteristics of the cord blood pH subgroup included in this study and all other BiB cohort participants. DOI: https://doi.org/10.5334/paah.66.s1
- **Supplementary Table S2.** Cases of moderate cord blood academia (pH < 7.10) stratified by cord blood sample and pregnancy physical activity level. DOI: https://doi.org/10.5334/paah.66.s2
- **Supplementary Figure S1.** The General Practice Physical Activity Questionnaire (GPPAQ) administered to BiB cohort participants. DOI: https://doi.org/10.5334/paah.66.s3
- **Supplementary Figure S2.** Cord blood pH levels stratified by 1 minute Apgar score. DOI: https://doi.org/10.5334/paah.66.s4
- **Supplementary Figure S3.** Cord blood pH levels stratified by 5 minute Apgar score. DOI: https://doi.org/10.5334/paah.66.s5

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Competing Interests

The authors have no competing interests to declare.

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