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Do changing levels of maternal exercise during pregnancy affect neonatal adiposity? Secondary analysis of the babies after SCOPE: evaluating the longitudinal impact using neurological and nutritional endpoints (BASELINE) birth cohort (Cork, Ireland)

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ABSTRACT

Objective To investigate whether changing levels of exercise during pregnancy are related to altered neonatal adiposity.

Design Secondary analysis of data from a prospective cohort study.

Setting Cork, Ireland.

Participants 1200 mother–infant pairs recruited as part of a prospective birth cohort, Babies After SCOPE: Evaluating the Longitudinal Impact Using Neurological and Nutritional Endpoints (BASELINE).

Main outcome measures Neonatal adiposity was assessed within several days of birth using air displacement plethysmography (PEAPOD). Per cent body fat (BF%) as a continuous outcome and a pair of dichotomous variables; high or low adiposity, representing BF% >90th or <10th centile, respectively. Multivariable linear and logistic regression models were used to investigate the relationship between exercise and the respective outcomes.

Results Crude analysis revealed no association between a changing level of exercise (since becoming pregnant) at 15 weeks' gestation and any of the outcomes (BF%, low adiposity and high adiposity). At 20 weeks' gestation, analyses revealed that relative to women who do not change their exercise level up to 20 weeks, those women who decreased their exercise level were more likely to give birth to a neonate with adiposity above the 90th centile (OR 1.62, 95% CI 1.07 to 2.46). This association was maintained after adjustment for putative confounders (OR 1.62, 95% CI 1.06 to 2.47).

Conclusions We observed a possible critical period for the association between changing exercise levels and neonatal adiposity, with no association observed with exercise recall for the first 15 weeks of gestation, but an association with a decreasing level of exercise between 15 and 20 weeks. These results should be interpreted in line with the limitations of the study and further studies utilising objectively measured estimates of exercise are required in order to replicate these findings.

Trial registration number NCT01498965.

Strengths and limitations of this study

- Air displacement plethysmography was used to measure neonatal body composition
- Directed acyclic graphs, based on an understanding of the causal network linking the variables in the analysis, were used to identify putative confounding variables.
- Exercise variables were based on maternal self-report and therefore subject to error.
- Pre-pregnancy exercise data were not available, meaning we were unable to ascertain what pre-pregnancy exercise level women had changed from.

INTRODUCTION

In their 2006 guideline, the Royal College of Obstetricians and Gynaecologists (RCOG) concluded that pregnant women should be 'encouraged to initiate or continue exercise to derive the health benefits associated with such activities'.[1]

The benefits of physical activity during pregnancy are likely to operate through an increased blood flow and oxygenation to the fetus.[2 3] It has also been proposed that the impact of exercise on fetal growth is mediated by its association with maternal insulin sensitivity, glucose metabolism and gestational weight gain.[4 5] Another mechanism by which exercise may be implicated is via the functioning of the uteroplacental unit, for example by affecting placental function, volume and growth rates.[6–8] However, the apparent beneficial associations of exercise appear to be dependent on the timing of when exercise is undertaken. For example, Clapp *et al*[7] demonstrated that women who performed a high quantity of moderate exercise in early pregnancy and then cut back in late pregnancy (hi-lo) delivered offspring who were heavier and longer at birth, compared with offspring of women who either did moderate volumes in both early and late pregnancy or a low volume followed by a high volume (lo-hi). The hi-lo exercise regimen was also associated with a greater placental volume at delivery, relative to the other two groups, presumably as a result of faster placental growth in early gestation. Those who either maintained moderate exercise or increased to a high volume of exercise in late gestation (relative to the hi-lo group) did not exhibit this increased placental volume at birth, suggesting that early gestation is a critical period for any influence of exercise on placental development to be enacted, with a potentially suppressive association in late gestation.[2] Furthermore, it has been reported that the transient changes in glucose regulation observed after bouts of exercise differ depending on when in pregnancy the exercise load is occurring, with increases in blood glucose observed after exercise early in pregnancy, but decreases in later pregnancy.[9] These fluctuations in nutrient supply, depending on the timing of exercise, could also contribute to differential associations with fetal growth.

The number of studies investigating the associations between physical activity and neonatal body composition (as opposed to size) from large scale observational studies is small. Data from a limited number of relatively small randomised controlled trials report either a null or reducing association between physical activity and neonatal adiposity,[7 8 10] with potentially stronger associations if the exercise intervention is administered at later gestations. Findings from a recent observational study, the Healthy Start cohort (n=826), also suggested that increasing physical activity levels in later pregnancy could be associated with a reduction in neonatal adiposity, even after adjusting for putative confounders (eg, maternal age, race or ethnicity, educational status, household income, pre-pregnancy body mass index (BMI) and prenatal smoking status).[11]

It is now well established that the in utero milieu experienced by the developing fetus could influence long-term risk for the development of obesity and obesity-related non-communicable diseases (OR-NCDs).[12–14] Maternal behaviour during this critical period of developmental plasticity has the potential to permanently alter susceptibility to later chronic disease via alterations in the offspring's metabolic and endocrinological phenotype.[15–17] Consequently, we hypothesise that maternal exercise in pregnancy will be associated with altered neonatal adiposity, such that an increasing/decreasing exercise level in pregnancy will be associated with a reduction/increase in adiposity, respectively. Any changes in neonatal adiposity could be indicative of an altered phenotypic profile in the offspring, which may increase susceptibility to later chronic disease.

The objective of this study was to investigate whether changes in maternal exercise during pregnancy were associated with offspring adiposity in the neonatal period, measured using PEAPOD in a large homogeneous population.

METHODS

Neonatal participants were recruited as part of the Cork BASELINE birth cohort study (ClinicalTrials.gov NCT: 01498965 www.birthcohorts.net)[18] between August 2008 and August 2011 from women who had participated in Screening for Pregnancy Endpoints (SCOPE) Ireland. SCOPE was a multicentre prospective cohort study with the aim of developing screening tests to predict various complications of pregnancy (eg, pre-eclampsia, small for gestational age (SGA) infants and spontaneous preterm birth) (ACTRN12607000551493).[19] Methods are described in detail elsewhere.[19 20] In brief, participants were healthy nulliparous women with singleton pregnancies recruited antenatally between February 2007 and February 2011 in Cork, Ireland. Women were recruited, interviewed and all measurements obtained at 15±1 and 20±1 weeks' gestation.[19 21] Exclusion criteria included: a high risk for pre-eclampsia/delivery of a SGA neonate/spontaneous preterm birth because of underlying medical conditions, three or more previous miscarriages, three or more terminations of pregnancy or having received interventions such as aspirin that might modify pregnancy outcome. At the time of interview, data were entered into an internet-accessed central database with a complete audit trail designed and hosted by MedSciNet, Sweden. Participants were followed-up prospectively, with pregnancy outcome data collected by trained research midwives.

Neonatal adiposity was assessed in the majority of neonates within 72 hours of birth by calculating neonatal BF% using the PEAPOD. The mean time of measuring BF% in those infants born over 37 weeks' gestation was 1.8 days (SD 0.97 days). Of those infants born <37 weeks' gestation, the mean time of testing was 2.4 days (SD 1.2 days). Measurement of neonatal BF% involves direct measurement of body mass using precise scale and body volume in an airtight, enclosed chamber. Body composition assessment by densitometry involves the measurement of the density of the whole body. Body density is then used in a two-compartment model to calculate the percentage of fat, fat mass and fat-free mass.[22] The PEAPOD has excellent test-to-test reproducibility and is safe, non-invasive and fast.[23 24]

Exercise data were collected at both the 15-week and 20-week visits in a standardised manner. At both time points, women were asked how many times per week they engaged in vigorous activity (which made the woman breathe harder or puff or pant),[25] moderate activity (did not breathe harder or puff or pant) or walking for recreation or exercise. At 15 weeks, women were asked: 'Has your level of exercise (physical activity) changed since you've been pregnant?', to which they could respond 'decreased', 'unchanged' or 'increased'. At 20 weeks, women were then asked: 'Has your level of exercise changed since last SCOPE visit?', with the same possible response options.

Statistical analysis

Differences in maternal characteristics and birth outcomes, stratified by change in exercise level, were explored using one-way analysis of variance for continuous variables (with scheffe test for post-hoc pairwise comparisons) and χ^2 test for categorical variables (table 1). Descriptive statistics (frequencies and percentages) of the different levels of exercise were summarised and are shown in table 2. We generated a 'no exercise' binary variable with a value of 1 indicating women who were reported doing no vigorous, moderate and recreational walking activity per week.

We used linear regression models to investigate the associations between changing levels of self-reported maternal exercise during pregnancy and birth weight (g) and BF% measured as continuous variables. Change in exercise

Table 1 Descriptive statistics in those with changing levels of physical activity during pregnancy

	Change in exercise level in pregnancy to 15 weeks (n=1200)		
	Decreased (n=813 (67.8%))	**Unchanged (n=346 (28.8%))**	**Increased (n=41 (3.4%))**
Maternal characteristics			
Maternal age, mean (SD)	30.51 (4.17)*	28.89 (4.74)	28.88 (5.19)
Maternal BMI at 15 weeks, mean (SD)	25.02 (4.12)	24.49 (4.21)	24.18 (3.85)
Maternal years schooling, mean (SD)	13.27 (0.83)	13.18 (0.81)	13.15 (0.73)
Maternal socioeconomic status, mean (SD)	44.33 (16.15)*	39.10 (15.40)	43.51 (16.35)
Maternal household income <€21 000, n (%)	47 (5.80)*†	45 (13.16)	7 (17.07)
Maternal smoking in first trimester, n (%)	49 (6.03)*	55 (15.90)	5 (12.20)
Maternal alcohol intake in first trimester (units/week)	4.61 (5.76)	5.39 (6.97)	5.99 (8.10)
Birth outcomes			
Gestational age (weeks), mean (SD)	40 (1.16)	40 (1.24)	40 (1.00)
Birth weight (g), mean (SD)	3525 (460)	3471 (478)	3541 (449)
Neonatal adiposity (%), mean (SD)	11.06 (4.15)	11.03 (4.06)	11.22 (4.13)
Adiposity <10th centile (yes), n (%)	68 (8.36)	26 (7.51)	3 (7.32)
Adiposity >90th centile (yes), n (%)	86 (10.58)	39 (11.27)	7 (17.07)
	Change in exercise level in pregnancy: 15–20 weeks (n=1200)		
	Decreased (n=263 (21.9%))	**Unchanged (n=665 (55.4%))**	**Increased (n=272 (22.7%))**
Maternal characteristics			
Maternal age, mean (SD)	30.74 (4.13)*	29.52 (4.58)†	30.39 (4.25)
Maternal BMI at 15 weeks, mean (SD)	25.07 (4.06)	24.60 (4.01)	25.20 (4.52)
Maternal years schooling	13.28 (0.72)	13.23 (0.86)	13.22 (0.82)
Maternal socioeconomic status	44.33 (15.49)*	40.96 (16.08)†	45.79 (16.21)
Maternal household income <€21 000, n (%)	15 (5.70)*	66 (10.03)	18 (6.62)
Maternal smoking in first trimester, n (%)	23 (8.75)	73 (10.98)†	13 (4.78)
Maternal alcohol intake in first trimester (units/week)	4.91 (5.79)	5.24 (6.82)†	3.98 (5.01)
Birth outcomes			
Gestational age (weeks), mean (SD)	40 (1.20)	40 (1.19)	40 (1.14)
Birth weight (g), mean (SD)	3541 (498)	3487 (458)	3537 (448)
Neonatal adiposity (%), mean (SD)	11.44 (4.66)	10.90 (4.02)	11.08 (3.79)
Adiposity<10th centile (yes), n (%)	22 (8.37)	58 (8.87)	16 (5.88)
Adiposity>90th centile (yes), n (%)	41 (15.59)	68 (10.23)	23 (8.46)

*Different to 'unchanged'.
†Different to 'increased'.
BMI, body mass index.

Table 2 Descriptive statistics of self-reported activity levels at 15 and 20 weeks

	Exercise level at 15 weeks (n=1200)	Exercise level at 20 weeks (n=1200)
Vigorous at least once per week (yes), n (%)	327 (27.25)	377 (31.42)
Moderate at least once per week (yes), n (%)	892 (74.33)	908 (75.67)
Recreational at least once per week (yes), n (%)	1040 (86.67)	1057 (88.08)
No exercise per week, n (%)	104 (8.67)	100 (8.33)

	Change in exercise level between 15 and 20 weeks		
	Decreased (n=263)	Unchanged (n=665)	Increased (n=272)
Any exercise per week at 15 weeks			
No, n (%)	7 (2.66)	72 (10.83)	25 (9.19)
Yes, n (%)	256 (97.34)	593 (89.17)	247 (90.81)

levels was coded as a categorical variable: no change (reference group) versus decreased versus increased. Regression diagnostics did not reveal any violations to linear regression assumptions (ie, normally distributed residuals and homogeneity of variance). We subsequently generated separate binary variables (0=no; 1=yes) indicating the presence of either low or high adiposity. Low and high adiposity was defined as below/above the gestational age-specific and sex-specific 10th/90th adiposity centiles, respectively, according to the centiles produced by Hawkes *et al*.[26] The associations between changes in physical activity and these dichotomous variables were investigated using logistic regression models.

We performed sensitivity analyses limiting the sample to only those born at term (n=1180) and separately, to those born non-low birth weight (>2500 g) (n=1180), but estimates did not markedly change and thus these infants were retained in the analysis. Furthermore, as the analysis sample was based on those that had complete data for the exposure, outcome and covariates, we also investigated whether we had introduced a selection bias by only including those with complete data (see online supplementary file 1).

To identify less biased associations between our exposures and outcome, we produced a directed acyclic graph (DAG) using Daggity.[27] DAGs provide a method for formalising and clarifying the causal hypothesised assumptions a researcher may make regarding the variables they wish to analyse[28] and thus justify modelling choices.[29 30] These graphs are especially useful for identifying variables which potentially confound the relationship between two variables, thus providing researchers with sets of variables for which adjustment (and importantly non-adjustment) is necessary, in order to obtain unbiased estimates of the relationship between a set of variables. For a more detailed discussion on the use of these graphs in epidemiology, refer the study by Greenland *et al*.[31] Daggity is a web-based interface that allows researchers to construct and edit a DAG, with the ultimate aim of identifying sufficient sets of variables for adjustment which will minimise bias when estimating the association between an exposure and outcome. The set of variables identified by Daggity as necessary for adjustment were socioeconomic status (SES), maternal employment, smoking status, alcohol intake, BMI, level of education, maternal age and whether the mother's job was physically active (see online supplementary figure 1 for analysis DAG). These variables were then incorporated into multivariable regression models. All analyses were conducted in Stata/IC V.14.1.

RESULTS

Descriptive statistics of the sample (and those omitted)

Compared with all of those enrolled without a PEADOD measurement (n=513) cohort, those enrolled in Cork with a PEAPOD measurement taken (n=1258) were approximately 130 g (95% CI 80% to 190%) heavier and born approximately 2 days later (95% CI 1.05% to 3.01%), but with no differences in any maternal biological or demographic data (see online supplementary table 1). Although 1258 had PEAPOD measurements taken, 58 infants were not included in the final analysis due to all PEAPOD data being lost/mis-entered (n=16), being born too early or late for adiposity centiles to be generated (n=23) and having incomplete exposure and covariate data (n=19), leaving a final analysis sample of 1200. Compared with those with PEAPOD measurements, but not in the final analysis sample, those who were in the final analysis had higher birth weight (187.81; 95% CI 64.45% to 311.17%), but with no differences in gestational age or any maternal biological or demographic data (see online supplementary table 2).

Of the 1200 neonates with complete exposure, outcome and covariate data, 612 (51.00%) were male and 98.25% (n=1 179) were of White European ethnic origin. The mean birth weight was 3510 g (95% CI 3484 to 3537) and the median gestational age was 40 weeks (IQR: 39–41).

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Change in exercise level reported in the first 15 weeks of pregnancy

Table 1 provides descriptive statistics for various maternal characteristics and neonatal outcomes, stratified by type of change of exercise in pregnancy. Compared with women who reported no change in exercise level, those who decreased their level of exercise were older (30.51 years (4.17) vs 28.89 years (4.74)), with a higher level socioeconomic status (44.33 (16.15) vs 39.10 (15.40)), less likely to have a household income below €21 000 (5.80% vs 13.16%) and less likely to have smoked during the first trimester (6.03% vs 15.90%). The small proportion of women who reported increasing their exercise levels from the time they became pregnant to 15 weeks' gestation (<4%) did not differ substantially from the cohort, with the exception of having a higher likelihood of a lower household income (table 1).

It is shown in table 2 that at 15 weeks' gestation, more than a quarter (n=327, 27.25%) of women reported engaging in vigorous exercise at least once per week, with approximately three-quarters reporting doing some form of moderate exercise per week (n=892, 74.33%). About 104 (8.67%) women reported not engaging in any form of exercise per week.

The associations between changing exercise levels and birth weight and neonatal adiposity are shown in table 3. Relative to women who did not change their exercise level in pregnancy up to 15 weeks, there was no difference in any of the outcomes in those women who either increased or decreased their level of exercise, in both crude and adjusted analyses. Changing the reference group in order to compare those who decreased relative to those who increased also revealed no differences in neonatal outcomes.

Change in exercise level between 15 and 20 weeks

Compared with women who reported no change in exercise level between 15 and 20 weeks, those who decreased their level of exercise were older (30.74 years (4.13) vs 29.52 years (4.58)), with a higher level socioeconomic status (44.33 (15.49) vs 40.96 (16.08)) and less likely to have a household income below €21 000 (n=15 (5.70%) vs n=66 (10.03%)). Women who increased their exercise levels between 15 and 20 weeks, relative to those who reported no change, were also older and with a higher SES, with a reduced alcohol intake (3.98 (5.01) units/week vs 5.24 (6.82) units/week) and lower likelihood of smoking during the first trimester (n=13 (4.78%) vs n=73 (10.98%) (table 1).

At 20 weeks, similar levels of exercise were reported, with approximately 30% of women reporting doing vigorous exercise at least once per week, and three-quarters of the sample engaging in some form of moderate exercise. Just over 8% of women reported taking part in no form of exercise at 20 weeks (table 2). Table 2 also reveals that of the 665 women who reported no change in their exercise levels between 15 and 20 weeks, approximately 10% of these (n=72) had engaged in no exercise at

Table 3 Associations between changing exercise levels during pregnancy and birth weight and neonatal adiposity

	Crude			Multivariable*		
	Decreased	Unchanged	Increased	Decreased	Unchanged	Increased
Change in exercise level in pregnancy to 15 weeks, coefficient (95% CI)						
Birth weight (g)†	54.39 (−4.16 to 112.93)	(reference)	70.24 (−80.40 to 220.89)	22.03 (−37.61 to 81.67)	(reference)	74.40 (−75.84 to 224.64)
Neonatal adiposity (%)†	0.03 (−0.49 to 0.55)	(reference)	0.19 (−1.15 to 1.53)	0.01 (−0.52 to 0.55)	(reference)	0.33 (−1.01 to 1.67)
Adiposity<10th centile‡	1.12 (0.70 to 1.80)	(reference)	0.97 (0.28 to 3.36)	1.20 (0.73 to 1.95)	(reference)	0.82 (0.23 to 2.94)
Adiposity>90th centile‡	0.93 (0.62 to 1.39)	(reference)	1.62 (0.67 to 3.90)	0.96 (0.62 to 1.41)	(reference)	1.75 (0.71 to 4.31)
Change in exercise level in pregnancy: 15–20 weeks, coefficient (95% CI)						
Birth weight (g)†	54.47 (−11.96 to 120.90)	(reference)	50.11 (−15.53 to 115.75)	42.68 (−23.62 to 108.98)	(reference)	22.30 (−43.49 to 88.09)
Neonatal adiposity (%)†	0.54 (−0.05; to 1.13)	(reference)	0.18 (−0.40 to 0.76)	0.56 (−0.03 to 1.15)	(reference)	0.13 (−0.46 to 0.72)
Adiposity<10th centile‡	0.94 (0.56 to 1.56)	(reference)	0.64 (0.36 to 1.14)	0.94 (0.56 to 1.59)	(reference)	0.69 (0.39 to 1.24)
Adiposity>90th centile‡	1.62 (1.07 to 2.46)	(reference)	0.81 (0.49 to 1.33)	1.66 (1.09 to 2.54)	(reference)	0.80 (0.48 to 1.32)

*Adjusted for: socioeconomic status, years of schooling, employment status, maternal body mass index, smoking in first trimester, alcohol intake in first trimester, maternal age and exercise as part of job.
†Linear regression for continuous outcomes (β).
‡Logistic regression for dichotomous outcomes (OR).

15 weeks. Similarly, of those who increased their exercise levels between 15 and 20 weeks, just under 10% (n=25) had reported no exercise at 15 weeks (table 2).

Crude analysis shows that relative to women who do not change their exercise level between 15 and 20 weeks, those women who decreased their exercise level were more likely to give birth to a neonate with adiposity above the 90th centile (OR 1.62, 95% CI 1.07 to 2.46) (table 3). This association was maintained after adjustment for the putative confounders (OR 1.66, 95% CI 1.09 to 2.54). When changing the reference group in order to compare women who decreased exercise levels relative to those who increased exercise, it was observed that those who decreased were twice as likely to give birth to a neonate with an adiposity above the 90th centile (OR 2.00, 95% CI 1.16 to 3.44), which again was also maintained on adjustment (OR 2.09, 95% CI 1.20% to 3.61%). Birth weight was not associated with differences in exercise (table 3).

DISCUSSION

In this cohort of White European mother–offspring pairs, we report the association between changing levels of exercise during pregnancy and neonatal adiposity measured using PEAPOD. We observed that pregnant women who reported a decrease in exercise levels between 15 and 20 weeks had a 60% higher risk of having a baby with adiposity above the 90th centile when compared with women who reported no change. This risk was approximately double when women who reported a decrease in exercise levels between 15 and 20 weeks were compared with women who reported an increase in exercise levels. This association was maintained after adjustment for a set of putative confounders, including maternal education, employment status, smoking, alcohol intake, BMI socioeconomic status, maternal age and whether her occupation was physically active. This positive association between decreased exercise level and adiposity was also observed when adiposity was assessed as a continuous variable, though the 95% CI did include the null. The exercise–adiposity association was only apparent between 15 and 20 weeks and not for changing exercise levels prior to 15 weeks, raising the possibility that there is a potential critical period with regard to the association between changes in exercise level and the development of offspring adiposity.

A major strength of the study is the use of air-displacement plethysmography for the estimates of body composition. This method is a quick, safe and non-invasive technique, which has shown to be a reliable and accurate instrument for determining BF% in infants.[23 32 33] As such, it has been deemed the primary method for measuring body density in paediatric populations.[34] Inter-observer variability was reduced by having a small, highly trained team of midwives and researchers who conducted all of the assessments to strict protocols. However, repeated measurements were not performed and thus we were unable to assess intra-observer variability. The prospective design of the cohort, allowing us to comprehend the temporal relationship between variables and the rich collection of covariates available for adjustment further strengthens the study. Another strength of this study is the use of a DAG which is based on an understanding of the causal network linking the variables in the analysis. As such, the DAG allows for the appropriate adjustment for a set of putative confounders in order to obtain a less biased estimate of the association between changing levels of exercise and neonatal adiposity. We are, however, cautious not to refer to any association as 'causal' as we cannot exclude the possibility of the presence of both residual confounding and, in particular with this subjective measurement of exercise, measurement error.

Arguably, the greatest limitation is the subjective nature of the exercise data. While the questionnaire regarding physical exercise was not validated for any population, the definition of vigorous exercise (daily exercise leading to heavy breathing or being out of breath) has previously been used in other studies.[25] As the exercise variables were based on maternal report, this introduced a potential error due to women not accurately remembering their exercise levels (eg, due to social desirability of reporting higher levels or age). The recall period was relatively short, considering only the very recent past, and focused on habitual activity, thus reducing the extent of the error introduced. An objectively measured assessment of physical activity (eg, an accelerometer) would have been of benefit to estimate actual activity. Nonetheless, in large-scale cohort studies, a compromise is often sought, with participant burden and cost-effectiveness on the one side and a more precisely measured variable on the other. Furthermore, it has been reported that pregnant women may wear monitors placed at the hip incorrectly due to changes in their girth.[35 36] Accordingly, a recent systematic review found that in epidemiological studies among pregnant women, self-reported physical activity measures were the most common assessment method.[37] Research on agreement between subjective estimates of physical activity and objectives measures has generated mixed results,[38 39] with the same systematic review concluding that the agreement between questionnaires and objective measures of physical activity assessment, ranged from 'poor to substantial'.[37]

A related limitation is that, as recruitment commenced during pregnancy, pre-pregnancy exercise data were not available, and as a result we were unable to determine what pre-pregnancy exercise level women had changed from. It could be speculated that women who reported no change in activity level at 15 weeks did not do any exercise to start with. We have shown that those women whose activity remained unchanged at 15 weeks (compared with those who decreased) were more likely to smoke during the first trimester, be of lower socioeconomic status and more likely to have a lower household income, all of which are associated with reduced levels of exercise and fetal growth. While we adjusted for these confounding factors, the lack of baseline activity limits the interpretability of our findings. For example, it would have been interesting to determine whether the observed association between a decreasing exercise level (vs unchanged level) and neonatal adiposity was the same across differing categories of baseline activity.

We were unable to adjust our estimates for the likely mediating role of gestational hyperglycaemia as these data were not available. Similarly, we did not adjust our estimates for gestational weight gain. In line with the published literature,[4 5 40 41] these variables are likely to operate along the causal pathway between maternal exercise and neonatal adiposity. While adjusting for them may mask part of the association between exercise and adiposity, it would have been of benefit to conduct a priori analysis to examine whether a change exercise was associated with neonatal adiposity independently of pre-pregnancy obesity, gestational weight gain or impaired glycaemic control. Acknowledging these data gaps, the current paper did not aim to elucidate possible mechanisms by which the association between exercise and adiposity is enacted, rather, we aimed to identify whether an association existed at all.

A final limitation is the potential lack of generalisability of our results to other groups. For example, study recruitment was limited to primiparous women with singleton pregnancies and notably, a majority of White European gravidas (approximately 98.25%) were recruited into the study. This predominance of White European gravidas does, however, reflect the demographic profile of females aged 15–44 years in Ireland as a whole (95%).[42] Unfortunately, a number of infants (513/1771) were unable to have a body composition assessment. Possible reasons for this include a lag period between the start of the study and the arrival of the PEAPOD, and admittance of the infant to the neonatal intensive care unit (NICU). We have shown that although these infants differed slightly in terms of birth weight (median difference: 130 g; 95% CI 80 to 190 g) and gestational age (median difference: 0.29 weeks; 95% CI 0.15 to 0.43 weeks), there were no differences in the maternal characteristics of those with and without a PEAPOD measurement (see online supplementary table 1), and thus we are confident that we have not introduced a substantial selection bias into the analysis. The employment of a complete-case analysis could also have introduced a degree of selection bias into the analysis; however, online supplementary table 2 shows that, apart from birth weight, there are no differences in the offspring or maternal characteristics of those with complete versus incomplete data.

To the authors' knowledge, this is the first study looking at the association between changing exercise levels in pregnancy and neonatal adiposity using PEAPOD. Previous studies have either used different measurement techniques (sum of skinfolds[7 8] or dual-energy X-ray absorptiometry[10] or were not looking at changing levels of exercise.[11] A recent large observational study observed that the lowest quartile of late-pregnancy energy expenditure was associated with a substantially higher neonatal fat mass (290.5 g vs 249.4 g, p=0.03) within the first 72 hours, which was not mirrored in neonatal fat-free mass.[11] Unlike our study, however, no differences were observed in either midpregnancy or early pregnancy. However, the aforementioned study was not investigating intra-pregnancy change and also relied on a statistically driven method to identify potential confounders, ignoring the causal framework underpinning any possible associations.

We observed a possible critical period for the association between changing exercise levels and neonatal adiposity, with no association observed with exercise recall for the first 15 weeks of gestation, but an association between a decreasing level of exercise between 15 and 20 weeks. This provides support for the findings of Clapp *et al*,[7] who found that women who performed a high volume of moderate exercise in early pregnancy and then cut back in late pregnancy delivered offspring who were heavier and longer at birth, compared with offspring of women who either did moderate volumes in both early and late pregnancy or a low volume followed by a high volume.[7] Indeed in our study, we observed a markedly increased risk of delivering an infant with neonatal adiposity above the 90th centile in pregnant women who reported having increased their exercise levels up to 15 weeks, but then reported a decrease between 15 and 20 weeks, relative to those who reported no change at both time points (OR 5.87, 95% CI 1.74 to 19.80, data not shown), though the uncertainty of this estimate can be observed in the wide CI, reflecting the small number of women on which this finding was based.

The data presented here suggest that a reduction in exercise levels may lead to less favourable outcomes in terms of neonatal adiposity. As such, and given the evidence of maintaining pre-pregnancy exercise levels,[43 44] we advocate the continuation of prepregnancy and early pregnancy exercise levels into later pregnancy. Further studies using objectively measured estimates of physical activity in a range of different population groups are required in order to replicate this finding. For example, the cohort of women in this analysis exhibited relatively low levels of activity, with almost 75% of women never doing any vigorous activity at 15 weeks and only approximately 50% of the women doing moderate activity more than once a week. If results appear consistent and robust to these differences in methodology and population, then these findings have significant implications, which extend beyond the short term. For example, it has been shown that the associations between maternal pregnancy exercise levels and offspring adiposity present at birth extend into childhood, with children of women who exercised during pregnancy observed to have a reduced fat mass at the age of 5 years (37 mm±1 vs 44 mm±4) compared children whose mothers were inactive.[45] However, the overall lack of follow-up studies with body composition assessment at birth limits our ability to explicitly link increased adiposity in early-life and later risk. Nonetheless, if the effects of a reduced level of exercise are able to manifest in the offspring as an altered adiposity at birth, the wider implication is that, during this critical period of developmental plasticity, some sort of programming has occurred, potentially permanently altering the offspring's metabolic and endocrinological phenotype (13–15),[15–17] and altering its long-term susceptibility to a variety of NCDs. It is hoped that with the increasing incorporation of body composition assessment methods in infancy, particularly air-displacement plethysmography, these questions will be able to be investigated.

CONCLUSION

A decreasing level of maternal reported exercise between 15 and 20 weeks' gestation was associated with an increased risk of delivering an infant with a high adiposity. This association was maintained after appropriate adjustment for confounding variables as identified using knowledge of the causal network. However, these findings need interpreting in line with the limitations of the study. Accordingly, further research using objective measures of physical activity and in different populations needs to be conducted in order to validate results.

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