Effects of antenatal exercise in overweight & obese pregnant women on maternal and perinatal outcomes: a randomised controlled trial

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ABSTRACT

Objective: To assess whether antenatal exercise in overweight/obese women would improve maternal and perinatal outcomes.

Design: Two-arm parallel randomised controlled trial

Setting: Home-based intervention in Auckland, New Zealand

Population and sample: Pregnant women of body mass index ≥25 kg/m^2.

Methods: Participants were randomised to a 16-week moderate-intensity stationary cycling programme from 20 weeks of gestation, or to a control group with no exercise intervention**.**

Main outcome measures: Primary outcome was offspring birth weight. Perinatal and maternal outcomes were assessed, with the latter including weight gain, aerobic fitness, quality of life, pregnancy outcomes, and postnatal body composition. Exercise compliance was recorded with heart rate monitors.

Results: 75 participants were randomised in the study (intervention 38, control 37). Offspring birth weight (adjusted mean difference 104 g; p=0.35) and perinatal outcomes were similar between groups. Aerobic fitness improved in the intervention group compared to controls (48.0 sec improvement in test time to target heart rate; p=0.019). There was no difference in weight gain, quality of life, pregnancy outcomes, or postnatal maternal body composition between groups. However, compliance with exercise protocol was poor, with an average of 33% of exercise sessions completed. Sensitivity analyses showed that greater compliance was associated with improved fitness [increased test time (p=0.002), greater VO_2 peak (p=0.015), and lower resting heart rate (p=0.014)], reduced postnatal adiposity [reduced fat mass (p=0.007) and body mass index (p=0.035)], and better physical quality of life (p=0.034).

Conclusions: Maternal non-weight-bearing moderate-intensity exercise in pregnancy improved fitness but did not affect birth weight or clinical outcomes.
Tweetable abstract: Moderate-intensity exercise in overweight/obese pregnant women improved fitness but had no clinical effects.

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INTRODUCTION

There has been a global increase in rates of overweight and obesity among women of reproductive age. The number of women entering pregnancy in an overweight or obese state has nearly doubled over the last three decades, now affecting more than a third of pregnancies in some nations[1-4].

Overweight and obesity are associated with many pregnancy complications, including a 2- to 3-fold increase in the risk of gestational diabetes, pregnancy-induced hypertension, and pre-eclampsia, as well as increased risk of caesarean section, induction of labour, and longer hospital stay[5]. Importantly, offspring born to overweight/obese women tend to be heavier and fatter at birth, and also are at higher risk of perinatal complications[6,7]. Further, they are at increased risk of obesity, metabolic complications, and cardiovascular events in later life, as well as premature mortality[8-11]. Studies on bariatric surgery prior to pregnancy suggest that interventions targeting maternal obesity can potentially improve short- and long-term offspring health[12,13]. Further, there is expert consensus that physical activity before and/or during pregnancy can improve long-term offspring health[14]. A recent meta-analysis reported that antenatal physical activity in women of any body mass index (BMI) led to a small reduction in offspring birth weight[15]. It is possible that this modest reduction in birth weight in offspring of overweight/obese women may be beneficial in the long-term, for example reducing obesity risk[5,16].

Meta-analysis and systematic reviews focussing on antenatal physical activity interventions in overweight/obese women have reported only a modest reduction in gestational weight gain, and minimal impact on other clinical outcomes[17,18]. However, regular moderate-intensity physical activity of 30 minutes or more during pregnancy is advocated by at least 11 guidelines worldwide [19,20]

Home-based exercise in particular, may be more acceptable than exercising in groups for these women (who often have poor body image), while non-weight-bearing exercise is likely to cause less strain on ligaments and joints[5,21].Thus, the aims of this randomised controlled trial were to assess the effects of a home-based antenatal stationary cycling exercise intervention on maternal and offspring health[22]. We hypothesised that the exercise intervention would lead to a reduction in maternal weight gain, birth weight, perinatal complications, as well as improvements in other maternal health outcomes (fitness, quality of life, body composition, and pregnancy outcomes).

METHODS

Study design

The IMPROVE (Improving Maternal and Progeny Obesity Via Exercise) study was a parallel two-arm randomised controlled trial on antenatal exercise, with 1:1 allocation ratio to intervention or control group[22]. It was conducted in Auckland (New Zealand) between March 2013 and October 2014. Ethics approval for the trial was obtained from the Health and Disability Ethics Committee, Ministry of Health, New Zealand. Written and verbal informed consent was obtained from all participants. The trial protocol has been published previously[22].

Participants

Participants were women aged 18–40 years with a body mass index (BMI) ≥25 kg/m^2 and a singleton pregnancy <20 weeks of gestation. Exclusion criteria were ongoing smoking, multiple pregnancy, pre-existing contraindications to antenatal exercise, or living outside the Auckland Region[20].

Randomisation

Participants were randomly allocated into intervention or control groups in variable block sizes, stratified on ethnicity (Maori/Pacific Islander/New Zealand European/Other) and parity (nulliparous/parous). Randomization sequences were generated by a biostatistician with no clinical involvement in the trial, and used sequentially according to enrolment order. Randomisation sequences were stored securely with password protection, and group allocation revealed to participants only after completion of baseline assessments. The recruitment coordinator (responsible for order of enrolment) did not have access to the randomisation tables at any time, maintaining allocation concealment.

Intervention

The intervention group participated in a structured home-based moderate-intensity antenatal exercise programme utilising magnetic stationary bicycles (Sportop NB600/NB800) from 20 to 35 weeks of gestation. Participants received a written programme prescribing frequency and duration of weekly exercises. Participants were also provided with heart rate monitors (Polar S625/Polar RS800, Polar Electro Oy, Kempele, Finland) to wear during all cycling sessions, and given target heart rates to maintain exercise sessions at moderate intensity (40-59% VO_2 reserve)[22,23]. Each exercise session included a 5-minute warm-up and cool-down period at low intensity. A total of 67 sessions were prescribed (frequency varying between 3 to 5 sessions per week, and duration of moderate-intensity exercise between 15-30 minutes per session, according to stage of pregnancy). Each participant was visited at home at the beginning of the intervention by an exercise physiologist, who was available for help with exercise-related problems. The number of sessions completed and duration and intensity of cycling undertaken was obtained by downloading heart rate monitor data (using Polar Pro Trainer 5 software, Polar Electro Oy). The control group was neither prescribed an exercise intervention nor provided with heart rate monitors.

Due to the nature of the intervention, participants were un-blinded to group allocation after completion of baseline assessments. They continued routine antenatal and delivery care with their chosen maternity carers. Participants in both groups were able to continue their routine physical activity and diet without restriction.

Outcomes

The primary outcome was offspring birth weight. Secondary outcomes included, pre-specified maternal and perinatal outcomes.

Birth weight and other perinatal outcomes were obtained from clinical records. Placental weight was measured untrimmed by delivery staff. Perinatal outcomes were defined as follows: large for gestational age (LGA) – birth weight >90th centile; small for gestational age (SGA) – birth weight <10th centile for gestational age [24]; perinatal asphyxia – 5-minute Apgar score <7; hypoglycaemia – blood glucose less than 2.5 mmol/l, requiring therapy other than supplemental feeding; respiratory distress – any non-specific respiratory distress needing respiratory support/oxygen therapy. Length of postnatal hospital stay was defined the time between delivery and home discharge. Other parameters calculated were standardized birth weight z-score (adjusting for gestational age and gender) [25], offspring BMI and ponderal index. Customised birth weight centiles (adjusting for maternal ethnicity, parity, height, weight and offspring gender and gestational age using New Zealand population data) [26] were also obtained.

Gestation at delivery was based on an early dating scan at <16 weeks of gestation (or on the last menstrual period where a scan was not available). Total gestational weight gain was obtained by subtracting the weight at the booking antenatal clinic visit from the last antenatal weight (measured after 36 weeks of gestation). Duration of hospital stay for childbirth was recorded as the time between admission to maternity unit for childbirth and discharge home following delivery. Gestational diabetes mellitus was diagnosed by a standard 75 g oral glucose tolerance, based on a fasting plasma glucose ≥5.5 mmol/l and/or a 2-hour post-test plasma glucose ≥9.0 mmol/l. Pregnancy-induced hypertension was defined as a systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg, on at least two occasions after 20 weeks of gestation without proteinuria; pre-eclampsia as pregnancy-induced hypertension with proteinuria; preterm delivery as childbirth <37 weeks of gestation; severe post-partum haemorrhage as blood loss >1000 ml following delivery; perineal tears as spontaneous lacerations of any degree occurring during labour; and early initiation of breast feeding as new born put to the breast within one hour of birth.

To determine maternal physical health outcomes, participants underwent three assessments at the Maurice and Agnes Paykel Clinical Research Unit (Liggins Institute): 1) at baseline (19 weeks of gestation), 2) at the end of the intervention (36 weeks of gestation), and 3) post-natally (approximately 2 weeks after delivery). Socio-demographic and past medical/obstetric data were collected at the first assessment. Height was measured to the nearest millimetre using a Harpenden Stadiometer (Holtain Ltd., Crymych, UK), while weight was measured to the nearest 0.1 kg using the same calibrated electronic scale (Model 1582, Tanita, USA) during all assessments. BMI was consequently calculated as per standard formula. Difference in weight between assessments 1 and 2 was taken as weight change during intervention, and between assessments 2 and 3 as weight loss at follow-up.

Maternal and paternal socio–demographic data were also obtained. At baseline and mid-intervention (32 weeks of gestation), maternal habitual physical activity was assessed by the Pregnancy Physical Activity Questionnaire (PPAQ) [27], while dietary intake was evaluated at using 3-day food intake records, and analysed using Foodworks software (Xyris Software Pvt Ltd, Australia).

Aerobic capacity was assessed on all participants by a single investigator using a sub-maximal graded exercise test on an electronically-braked cycle ergometer (Schiller, Baar, Switzerland), with simultaneous breath-by-breath measurement of expired and inspired O_2 and CO_2 volumes (ParvoMedics TrueOne 2400, Parvomedics, Sandy, Utah, USA)[28]. Tests were performed as previously described[22]. Parameters of interest were the time taken to reach the target heart rate of 150 bpm, workload when reaching target heart rate, and submaximal peak VO_2 achieved. An increase in test time to reach the target heart rate and the work load tolerated would indicate an improvement in fitness. Resting heart rate and resting blood pressure (seated position) were measured prior to the fitness test by an automated blood pressure measuring device (Dinamap Pro Care 100, GE Healthcare, UK) using an appropriately-sized cuff.

Maternal post-natal body composition was assessed by whole-body dual-energy absorptiometry (Lunar Prodigy 2000, General Electric, Maddison, Wisconsin, USA) approximately two weeks after delivery. Total body fat mass, lean mass, percentage body fat, and bone mineral density were obtained using Encore 2007 software v.11.40.004 (General Electric). Maternal fat mass index was subsequently calculated.

To determine maternal quality of life, participants completed a self-administered generic health-related quality of life assessment questionnaire (WHO QOL-BREF)[29] at baseline and at the end of the intervention period. The questionnaire consists of 26 questions in four domains (physical health, psychological, social relationships, environmental) with scores on a 0–100 scale (higher values indicating better quality of life). An overall score was obtained by averaging individual domain scores. A generic quality of life questionnaire was used due to lack of pre-validated questionnaires specific to pregnancy[30].

Statistical analysis

Sample size calculation is provided in the published trial protocol[22]. Treatment evaluation was performed on the principle of intention to treat. Analysis of covariance regression models were used to evaluate the main treatment effect on the primary outcome and other birth measures between the two treatment groups, adjusting for maternal BMI at study entry, maternal ethnicity and parity (i.e. stratification factors), gestational age at birth and offspring gender. Treatment effects on continuous maternal outcomes were assessed adjusting for the two stratification factors and the baseline value (except for postnatal body composition and pregnancy outcomes, for which baseline BMI was used as a proxy measure instead). Logistic regression models were used for the analysis of binary outcomes, with associated odds ratios and 95% confidence intervals. Possible associations between compliance with study protocol (expressed as percentage of prescribed exercise sessions completed) and outcomes in the intervention group were assessed using Spearman's rank correlations; sensitivity analyses were carried out with regression models as described above, treating compliance as a linear predictor. Statistical analyses were performed in SAS v9.4 (SAS Institute Inc., Cary, NC, USA). Statistical tests were two-tailed and significance maintained at 5%, without adjustment for multiple testing. Missing data were not imputed.

RESULTS

Between March 2013 and April 2014, a total of 195 women were assessed for eligibility, and 75 participants were enrolled in the trial (intervention n=38, control n=37) (Figure S1). As rate of recruitment was slower than anticipated, the recruitment period was extended from the original 12 month period, by 2 months. Baseline characteristics in intervention and control groups were similar (Table S1), as were baseline fitness levels and quality of life scores (data not shown). Follow up of trial participants continued until October 2014, when all predetermined assessments were completed. Three participants developed medical contraindications to antenatal exercise and discontinued the intervention, but outcome data were collected, and included in the intention-to-treat analysis (Figure S1). One participant (intervention group) withdrew from the study during the intervention period, and outcome data were not collected at her request (Figure S1). A total of 37 participants per group were included in the outcome analysis, in accordance to their original group assignment.

Birth outcomes

Offspring birth weight was similar in the intervention and control groups (p=0.35), as were other parameters measured at birth (Table 1). Customised birth weight centiles between intervention and control groups were also similar (52 ± 33% vs 43 ± 26%, respectively; p=0.12). There were no group differences for other birth outcomes and perinatal complications (Table 1). The total number of male (n=38) and female (n=36) offspring were similar, but there was unequal gender distribution between groups, with fewer male offspring in the intervention group (n=13, 34%), compared to control group (n=25, 68%). There was one perinatal death in each group due to reasons unrelated to the exercise intervention (cord tightly wrapped around neck at birth and listeriosis diagnosed on histology).

Pregnancy outcomes

There were no differences in gestational weight gain between intervention and control groups (p=0.397; Table 2). Further, there were no observed effects on other pregnancy outcomes, except for a trend towards a reduction in perineal tears during labour in the intervention group (Table 2).

Physical health outcomes

Women in the intervention group improved their aerobic fitness with intervention, increasing the test time taken to reach the target heart rate of 150 bpm in comparison to controls (+48.0 sec; p=0.019) (Table 2; Figure 1). Women who exercised also increased their peak work load compared to control women (+8.8 W; p=0.019) (Table 2). There were no differences in other physical health outcomes between groups, including weight gain over the intervention period, postpartum weight and adiposity (Table 2).

Quality of life

There were no differences in post-intervention quality of life scores between groups (Table 2).

Exercise and compliance

Compliance with the cycling intervention (as objectively measured by heart rate monitor data) was highly variable, with an average of 33% of exercise sessions completed (range 0–85%). Only a third of participants in the intervention group completed more than 30 of the 67 prescribed sessions. Notably, there was a steady decline in compliance with the exercise protocol as pregnancies progressed (Figure S2A). Total duration of cycling throughout the intervention was on average 572 minutes per participant, with 40% at low intensity, 52% at moderate intensity, and 8% at high intensity (Figure S2B).

Effects of compliance

Compliance with study protocol was correlated with changes in test time (ρ=0.49; p=0.013), work load (ρ=0.64; p=0.001), resting heart rate (ρ=-0.49; p=0.008), and in weight gain over the intervention period (ρ=-0.48; p=0.010). Improved compliance was also correlated with lower postnatal fat mass (ρ=-0.53; p=0.002), lower total body fat percentage (ρ=-0.40; p=0.030), and lower BMI (ρ=-0.43; p=0.015).

As a result, sensitivity analyses were conducted, showing that greater compliance was associated with increased fitness and reduced postnatal adiposity (Table 3). Specifically, greater compliance was associated with increased test time, greater VO_2 peak, increased work load, and lower resting heart rate, reduced fat mass and lower postnatal BMI (Table 3). Further, compliance was associated with better post-intervention physical quality of life (β=0.265; p=0.034).

Adverse events

There were no adverse effects reported in association with the exercise intervention.

Routine physical activity and dietary intake

Based on the PPAQ data, energy expenditure in household, caregiving, and occupational activities was similar in both groups at baseline and mid-intervention Total dietary energy intake at baseline and mid-intervention was also similar between groups (Table S2), as were the percentages of energy intake from carbohydrate, fat, and protein (Table S3).

DISCUSSION

Main findings

This study showed that a 16-week programme of moderate-intensity non-weight-bearing antenatal exercise in overweight/obese women did not alter offspring birth weight, maternal weight gain, pregnancy outcomes, or perinatal complication rates. However, the exercise intervention led to an improvement in aerobic fitness in the mothers in the second half of pregnancy.

Strengths and limitations

One of the study limitations was the small sample size involving 75 participants. The pre-specified sample size of 50 participants per group was not achieved as the recruitment rate was slower than anticipated. However, this issue was counter-balanced by a high follow-up rate, with birth outcomes available on 99% of participants. As the sample size was determined by the primary trial outcome (birth weight)[22], our trial could have low power to detect differences in maternal pregnancy outcomes between groups. Despite its relatively small sample size however, this study is still one of the largest randomised controlled trials on a home-based antenatal exercise intervention in overweight/obese women conducted to date[17,18]. While there are several recent larger trials in overweight/obese women such as the LIMIT and UPBEAT trials[41,42], their interventions include a major dietary component and exercise prescription is less specific, making it very difficult to discern the effects of antenatal exercise *per se* on outcomes. For instance, a greater reduction in weight gain is observed with interventions including a dietary component in addition to exercise[15,17].

Another limitation of this trial was low compliance with the exercise protocol. Poor compliance has been a problem common to other studies, especially those involving overweight and obese pregnant subjects[43]. Although this intervention incorporated several measures to improve exercise compliance, including the use of a home based intervention, non-weight bearing type of exercise and guidance from an exercise physiologist, compliance was still unsatisfactory. The same intervention previously reached higher compliance rates (75%) in leaner (BMI 25.5 kg/m^2) women[28], emphasizing the difficulty in motivating heavier women to exercise. However, unlike many other studies, we have quantified compliance objectively with heart rate monitoring throughout the intervention period[15]. We believe the detailed objective data on the amount of exercise actually completed by the intervention group (Figure S2) would be valuable for designing more achievable exercise interventions for this group. While sensitivity analysis showed that within the intervention group, increased compliance was associated with improved fitness, reduced postnatal adiposity, and better physical quality of life, this *post hoc* analysis was on a smaller cohort (n=37). Nevertheless, despite this caveat, these data suggest that women who exercised more, where able to achieve benefits on physical health.

This study included a multi ethnic group of healthy non-smoking overweight and obese pregnant women from the Auckland region. Generalizability of results to the community, were improved by not limiting participation to women attending a single maternity care institution, as has been the case in some previous trials. However, it is possible that the women opting to participate in this trial were more motivated to undergo antenatal lifestyle modification than the general population.

Interpretation

There is a paucity of data on the effects of antenatal exercise on offspring of overweight/obese women [18]. Excluding studies with concomitant dietary interventions, only a few clinical trials in overweight/obese women have examined the effects of antenatal exercise on offspring health [31-33]. These trials also reported low compliance with the intervention, and similarly reported no changes in birth weight or perinatal outcomes [31-33]. Nonetheless, our results align with a Cochrane review showing improvement in fitness but lack of evidence of other benefits or risks to pregnant women of any BMI with aerobic antenatal exercise[34]. Similar results with improvement in aerobic fitness, but no effect on maternal pregnancy outcomes, were demonstrated with the same intervention, in leaner nulliparous pregnant women, by our research unit previously[28]. The trend towards reduced perineal tears in the intervention group is consistent with a report of reduction in perineal lacerations with increased physical activity during pregnancy in a prospective cohort[35]. Meta-analysis of antenatal exercise trials in pregnant women of any BMI[15,36] and specific to overweight/obese pregnant women[17,18] have also demonstrated a lack of benefit on pregnancy outcomes other than a modest (0.4-0.9 kg) reduction in gestational weight gain. There is no compelling data to confirm that a reduction in gestational weight gain will benefit pregnancy and labour complications[37].

Data on quality of life during pregnancy in relation to exercise are limited. A lack of effect of exercise on quality of life in advanced pregnancy was previously reported in obese women following a light to moderate intensity exercise program (group sessions and walking at home), utilising the WHOQOL- BREF questionnaire[33]. Other trials of antenatal exercise, not specifically targeting overweight/obese women, and using a variety of generic questionnaires, have reported conflicting results[38-40]. The unavailability of a validated questionnaire specific to pregnancy[30] and the timing of the evaluation in relation to childbirth, could contribute to differences between studies. However, most studies have shown a reduction in physical quality of life with advancing pregnancy, and the association between increased compliance and improved physical quality of life shown in this trial suggests that regular exercise maybe beneficial in improving this component.

The positive impact of antenatal exercise on maternal fitness in overweight and obese women was demonstrated by this trial. As long-term data on the effects/benefits of improved fitness in pregnant overweight/obese women is lacking, it is not possible to ascertain whether there will be health benefits later in life for the participants from our exercise group. One follow-up study reported that lean women who voluntarily continued to exercise throughout pregnancy remained active in the long term, displaying more favourable cardiovascular risk profiles and improved fitness at peri-menopausal age, in comparison to women who did not continue to exercise in pregnancy[44]. Improved fitness, while not appearing to benefit pregnancy and postnatal outcomes, could have long-term beneficial effects if maintained, including lower risk of obesity-related complications such as diabetes, hypertension and dyslipidaemia[45]. Improvement in cardiorespiratory fitness is also associated with a lower risk of mortality from all-causes and cardiovascular deaths in women, and appears to attenuate the higher risk of death associated with obesity[46]. Follow-up of study participants is planned to look at the impact on long-term health.

The objective of this study was to demonstrate proof of concept that non-weight-bearing exercise could improve pregnancy outcomes, enabling the provision of evidence-based advice to overweight/obese pregnant women, rather than to incorporate this intervention directly to clinical practice. The participants reported that a home-based programme made it easier to incorporate exercise to their daily routine, but as pregnancy advanced it became more uncomfortable to exercise (due to, for example, pelvic discomfort and increased fatigue). The service providers felt that overweight/obese pregnant women would feel more comfortable with a home-based programme. Although church- and gym-based programmes were also discussed initially, these were logistically difficult to implement within a research context, but could be helpful for community implementation.

CONCLUSIONS

Overall, the potential beneficial effects of non-weight bearing antenatal exercise in overweight and obese women on maternal and neonatal health outcomes, other than improved maternal fitness, remain unproven. However, data from this study indicate that low exercise compliance could potentially account for the lack of demonstrable effects on pregnancy outcomes. Novel strategies to improve exercise compliance may need to be considered in this group who appear relatively resistant to complying with prescribed antenatal exercise in the second half of pregnancy. There may also be greater benefit by starting in early pregnancy or prior to conception. Nonetheless, further studies are needed to determine if such an approach is feasible and of greater benefit.

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Author contributions: SNS, YJ, LMEMC, GKP, SG, AE, WSC, GP, and PLH were involved in study conception and design; SNS coordinated the trial and collected data with assistance from GP, JBB, SC, and ROR; YJ and JGBD analysed the data; SNS, PLH, and JGBD wrote the manuscript with input from all other authors.

Ethics statement: This study was approved by the Health and Disability Ethics Committees (Ministry of Health, New Zealand; 12/NTB/24). Locality approvals were obtained from the research offices at Auckland, Counties Manukau, and Waitemata District Health Boards, as well as relevant Māori research committees within the Auckland region. Written and verbal informed consent was obtained from all participants.

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Table 1. Birth outcomes in the intervention (n=37) and control (n=37) groups. Continuous variables are summarised as means ± SD, and categorical variables as n (%). The estimated differences in means are provided for continuous variables and in odds ratios for categorical variables, as well as the associated 95% confidence intervals (CI). Data are adjusted for maternal ethnicity, parity, and baseline BMI; continuous birth parameters (except birth weight z-score) are also adjusted for gestational age and gender.

	Intervention	Control	Estimated Difference	95% CI	P-value
Gestational age (d)	274 ± 12	278 ± 10	-3.28	-8.30, 1.73	0.196
Birth weight (g)	3578 ± 630	3594 ± 469	104	-116, 324	0.347
Birth weight z-score	0.65 ± 1.12	0.38 ± 0.86	0.21	-0.26, 0.68	0.380
Birth length (cm)	51.2 ± 2.6	51.8 ± 2.5	0.06	-0.99, 1.09	0.923
Occipito-frontal circumference (cm)	35.1 ± 1.6	35.1 ± 1.4	0.28	-0.40, 0.95	0.416
Ponderal index (g/cm^3)	26.5 ± 2.8	25.8 ± 2.4	0.53	-0.70, 1.76	0.392
BMI at birth (kg/m^2)	13.6 ± 1.6	13.4 ± 1.2	0.31	-0.30, 0.92	0.318
Placental weight (g)	665 ± 192	670 ± 135	-2.77	-96, 91	0.953
Apgar score at 1 min	8.3 ± 1.6	8.0 ± 2.3	0.35	-0.61, 1.32	0.465
Apgar score at 5 min	9.2 ± 1.7	9.1 ± 2.1	0.08	-0.85, 1.01	0.869
Length of hospital stay (h)	61 ± 41	80 ± 107	-20	-61, 21	0.329
LGA	9 (24%)	4 (11%)	2.52	0.67, 9.38	0.170
SGA	4 (11%)	3 (8%)	1.34	0.23, 7.96	0.745
Birth weight >4 kg	10 (26%)	7 (19%)	1.59	0.50, 5.04	0.429
Birth weight <2.5 kg	1 (3%)	1 (3%)	0.75	0.03, 17.71	0.860
Fetal death *in utero*	1 (3%)	1(3%)	0.93	0.05, 17.23	0.959
Admission to HDU/ICU	3 (8%)	3 (8%)	0.91	0.16, 5.28	0.915
Perinatal asphyxia	1 (3%)	2 (5%)	0.44	0.04, 5.41	0.521
Hypoglycaemia	4 (11%)	3 (8%)	1.31	0.26, 6.63	0.743
Respiratory distress	5 (13%)	2 (5%)	2.62	0.45, 15.32	0.284

Table 2. Study outcomes in participants in the intervention (n=37) and control (n=37) groups. The difference in means is provided for continuous variables and in odds ratios for categorical variables, as well as the associated 95% confidence intervals (CI). Data are adjusted for maternal ethnicity, parity, and baseline value (except for postnatal body composition and pregnancy outcomes, for which baseline BMI was used as a proxy measure instead). P-values statistically significant at p<0.05 are shown in bold.

	Intervention	Control	Estimated difference	95% CI	P-value
Pregnancy and birth outcomes					
Gestation at delivery (d)	274 ± 12	278 ± 10	-3.3	-8.3, 1.7	0.196
Gestational weight gain (kg)	12.0 ± 5.3	13.2 ± 5.8	-1.2	-3.9, 1.6	0.397
Length of hospital stay (h)	61 ± 41	80 ± 107	-20.2	-61.3, 20.9	0.329
Gestational diabetes mellitus	4 (11%)	2 (5%)	2.1	0.3, 12.8	0.432
Gestational hypertension	1 (3%)	0	-	-	-
Pre-eclampsia	1 (3%)	1 (3%)	1.8	0.1, 40.1	0.726
Preterm birth	2 (5%)	1 (3%)	2.3	0.2, 29.6	0.511
Induction of labour*	5 (19%)	8 (28%)	0.9	0.2, 3.9	0.935
Augmentation of labour*	7 (26%)	10 (35%)	0.9	0.2, 3.4	0.846
Caesarean section	18 (47%)	13 (35%)	1.7	0.6, 4.5	0.293
Severe postpartum haemorrhage	3 (8%)	5 (14%)	0.6	0.1, 2.9	0.509
Perineal tears*	6 (22%)	10 (35%)	0.2	0.1, 1.1	0.061
Early initiation of lactation	25 (66%)	28 (76%)	0.8	0.2, 3.2	0.796
Antenatal physical outcomes					
Δ fitness test time (sec)	31.6 ± 88.4	-12.6 ± 69.1	48.0	8.3, 87.6	**0.019**
Δ test work load (W)	4.6 ± 15.3	-3.6 ± 12.2	8.8	1.5, 16.0	**0.019**
Δ peak VO_2 (ml/kg/min)	0.24 ± 2.1	-0.71 ± 2.6	0.67	-0.5, 1.88	0.267
Δ weight over intervention period (kg)	8.3 ± 3.7	8.8 ± 4.0	-0.6	-2.3, 1.2	0.512
Resting systolic blood pressure (mmHg)	113.2 ± 12.2	118.5 ± 9.8	-3.1	-8.6, 2.3	0.249
Resting diastolic blood pressure (mmHg)	67.8 ± 8.3	70.0 ± 8.7	-0.8	-4.8, 3.1	0.675
Resting heart rate (bpm)	82.0 ± 8.4	85.0 ± 11.3	-3.7	-8.9, 1.4	0.151
Postnatal physical outcomes					
Weight loss at follow-up (kg)	8.1 ± 2.6	7.5 ± 2.5	0.8	-0.5, 2.2	0.234
Body mass index (kg/m^2)	32.4 ± 4.6	34.5 ± 6.2	-0.3	-1.2, 0.5	0.410
Lean mass (kg)	46.0 ± 7.0	47.1 ± 6.9	0.3	-2.3, 2.9	0.836
Fat mass (kg)	38.7 ± 9.1	43.1 ± 11.7	-1.5	-4.2, 1.2	0.277
Total body fat (%)	45.3 ± 4.8	47.3 ± 4.6	-1.0	-2.9, 1.0	0.304
Fat mass index	14.1 ± 3.2	15.8 ± 4.1	-0.5	-1.3, 0.2	0.163
Post-intervention quality of life					
Physical	61.0 ± 18.0	64.1 ± 14.1	-2.4	-12.0, 7.2	0.617
Psychological	72.6 ± 13.7	71.6 ± 9.5	1.6	-4.6, 7.8	0.599
Social	69.0 ± 15.9	74.2 ± 16.2	-5.2	-13.5, 3.2	0.221
Environmental	78.8 ± 10.1	78.2 ± 9.3	-0.6	-6.2, 5.0	0.839
Overall	70.2 ± 10.7	72.2 ± 9.3	-1.8	-7.7, 4.2	0.545

* Only including participants without pre-labour caesarean section (intervention n=27, control n=29)

Table 3. The association between compliance with study protocol and maternal physical health outcomes at antenatal (36 weeks of gestation) and post-natal (approximately 2 weeks after delivery) assessments among the intervention group (n=37). Compliance was defined as the percentage of prescribed exercised session completed. Statistical models have adjusted for ethnicity, parity, and baseline value (or baseline BMI for postnatal body composition). P-values statistically significant at p<0.05 are shown in bold.

		β	95% CI	P-value
Antenatal	Δ fitness test time (sec)	1.534	0.628, 2.441	**0.002**
	Δ test work load (W)	0.336	0.172, 0.501	**0.0004**
	Δ peak VO_2 (ml/kg/min)	0.044	0.010, 0.079	**0.015**
	Δ resting systolic blood pressure (mmHg)	-0.020	-0.219, 0.179	0.838
	Δ resting diastolic blood pressure (mmHg)	0.006	-0.121, 0.133	0.927
	Δ resting heart rate (bpm)	-0.169	-0.301, -0.038	**0.014**
	Δ weight over intervention period (kg)	-0.041	-0.099, 0.018	0.161
Post-natal	Body mass index (kg/m^2)	-0.031	-0.059, -0.002	**0.035**
	Fat mass (g)	-125	-213, -38	**0.007**
	Total body fat (%)	-0.067	-0.137, 0.004	0.065

Figure 1. Aerobic fitness expressed as the time taken to reach the target heart rate of 150 bpm in intervention (red) and control (blue) groups. Higher values represent greater fitness. Data are means ± SEM. *p=0.019 for the comparison between groups post-intervention.

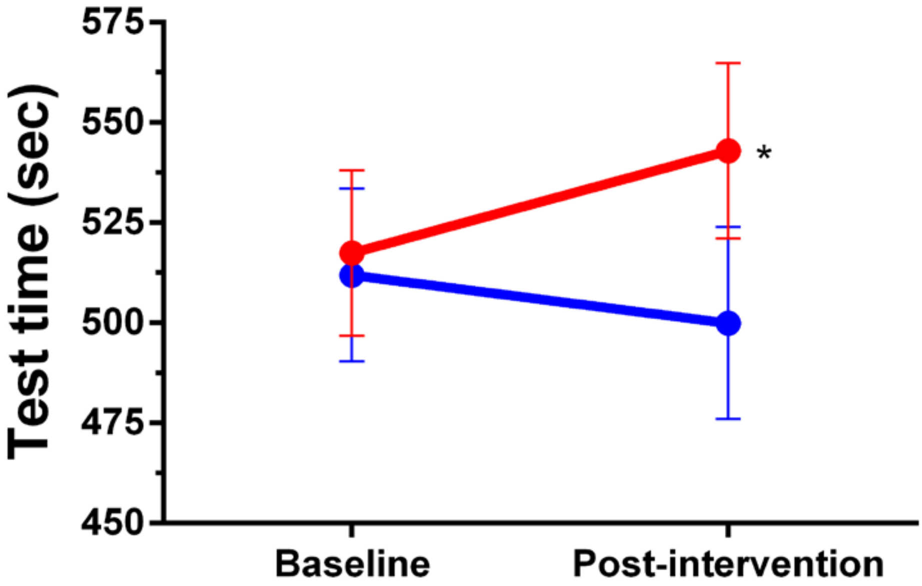


Table S1. Characteristics of study participants at baseline (19 weeks of gestation). Continuous variables are summarised as means ± standard deviations, and categorical variables as n (%). Note that there were no statistically significant differences between groups.

	Intervention	**Control**
n	38	37
Age (years)	31.6 ± 4.6	31.1 ± 5.2
Weight (kg)	88.7 ± 14.1	93.6 ± 17.6
Height (cm)	166.0 ± 6.7	165.5 ±5.3
BMI (kg/m^2)	32.1 ± 4.4	34.1 ± 5.9
Nulliparous	9 (24%)	10 (27%)
Ethnicity		
Pacific Islander	11 (29%)	11 (29%)
Maori	5 (13%)	5 (14%)
New Zealand European or other	22 (58%)	21 (57%)
Employment		
Full-time	26 (68%)	17 (46%)
Part-time	5 (13%)	6 (16%)
Not employed	7 (19 %)	14 (38%)
Annual household income		
NZ$ 50,000 or less	8 (21%)	10 (27%)
Greater than NZ$ 50,000	25 (66%)	19 (51%)
Declined to answer/did not know	5 (13%)	8 (22%)
Time spent in education (years)	15.1 ± 2.9	14.8 ± 2.2
Pregnancy data		
Availability of dating scan	36 (95%)	36 (97%)
Previous gestational diabetes	3 (8%)	2 (5%)
Previous gestational hypertension/pre-eclampsia	0	1 (3%)
Previous caesarean section	9 (24%)	7 (19%)

Table S2. Average weekly energy expenditure (MET-h/week) among trial participants at baseline (19 weeks of gestation) and mid-intervention (32 weeks of gestation). Data were self-reported by participants based on pregnancy physical activity questionnaires (PPAQ), and are expressed as means ± standard deviations. P-values are for group differences based on two-sample t-tests.

		Intervention	**Control**	**P-value**
n		38	37	
Baseline	Total physical activity	292 ± 164	281 ± 167	0.77
	Household/caregiving activity	108 ± 69	125 ± 97	0.41
	Occupational activity	102 ± 96	72 ± 94	0.17
Mid-intervention	Total physical activity	261 ± 101	259 ± 140	0.96
	Household/caregiving activity	103 ± 64	110 ± 76	0.69
	Occupational activity	83 ± 77	77 ± 92	0.80

Table S3. Average daily dietary energy intake in trial participants at baseline (19 weeks of gestation) and mid-intervention (32 weeks of gestation). Data were based on self-reported 3-day dietary records, and are expressed as means ± standard deviations. P-values are for group differences based on two-sample t-tests.

		Intervention	**Control**	**P-value**
n		38	37	
Baseline	Daily energy intake (kcal)	2113 ± 570	2005 ± 525	0.40
	% energy from carbohydrates	46 ± 7	46 ± 7	0.92
	% energy from fat	35 ± 7	35 ± 8	0.77
	% energy from protein	17 ± 3	17 ± 4	0.32
Mid-intervention	Daily energy intake (kcal)	1998 ± 661	2106 ± 634	0.52
	% energy from carbohydrates	44 ± 6	45 ± 6	0.87
	% energy from fat	36 ± 6	35 ± 6	0.73
	% energy from protein	18 ± 5	19 ± 5	0.46

Figure S1

CONSORT diagram describing flow of participants in the IMPROVE study.

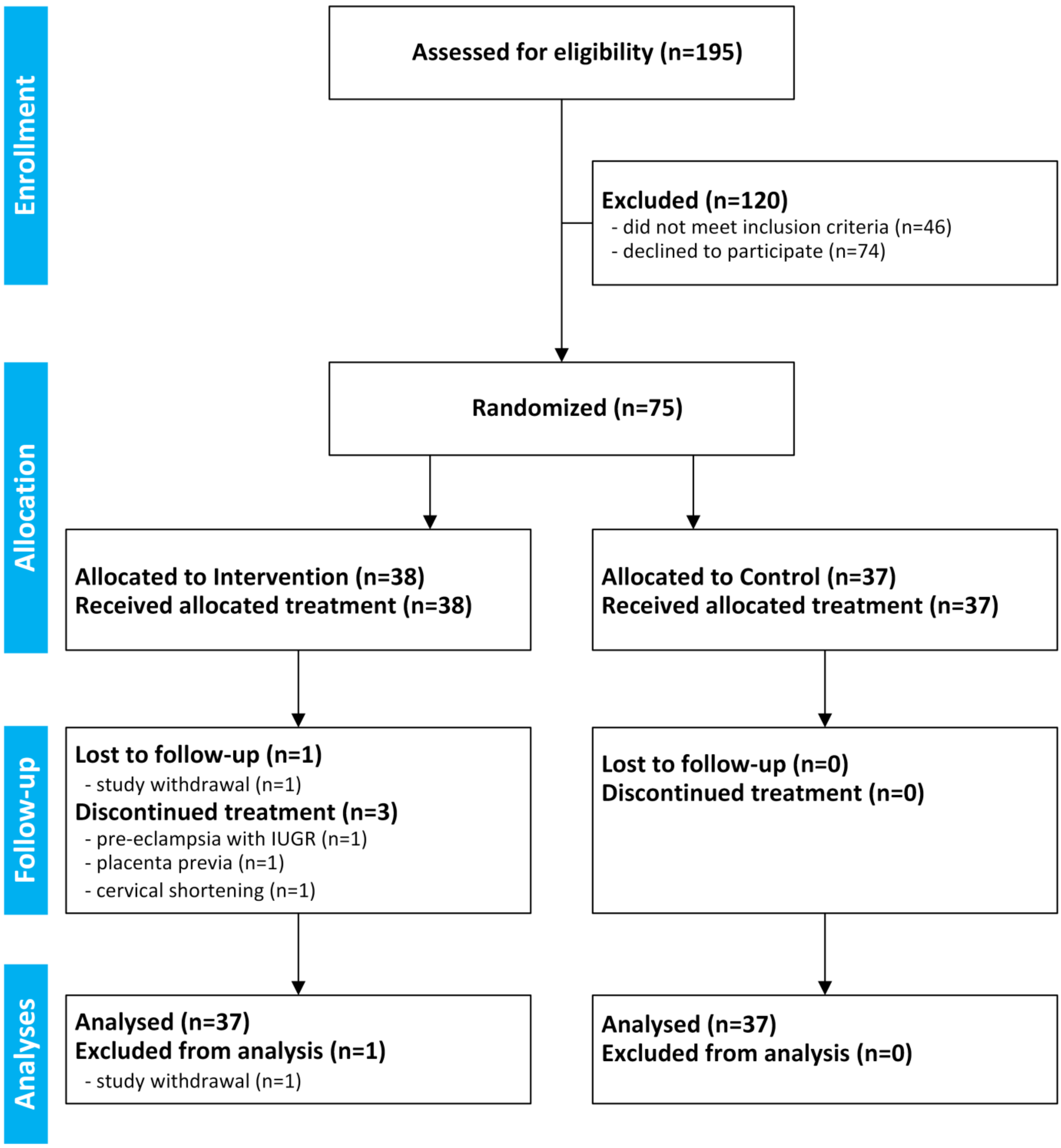


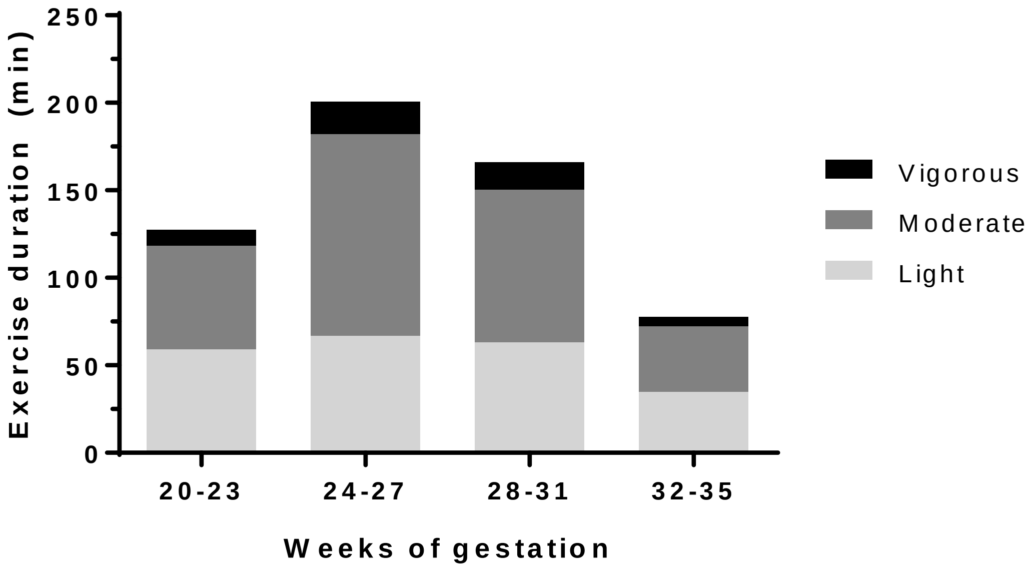
Figure S2

Compliance and amount of stationary cycling undertaken by the exercise group during the 16-week intervention:

A) mean duration of cycling activity according to exercise intensity over the 4-week periods of intervention;

B) box and whisker plots showing the percentage of exercise sessions completed out of the total of 67 prescribed.

A



B