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Exercise FITT-V during pregnancy: Association with birth outcomes

Alex Claiborne[1,2,3] | **Breanna Wisseman**[1,2,3] | **Kara Kern**[1,2,3] | **Dylan Steen**[1,2,3] | **Filip Jevtovic**[1,2,3] | **Samantha McDonald**[4] | **Cody Strom**[5] | **Edward Newton**[6] | **Christy Isler**[6] | **James Devente**[6] | **Steven Mouro**[6] | **David Collier**[7] | **Devon Kuehn**[7] | **George A. Kelley**[8,9] | **Linda E. May**[1,2,3,6]

[1]Department of Kinesiology, East Carolina University (ECU), North Carolina, USA

[2]Human Performance Laboratory, ECU, Greenville, North Carolina, USA

[3]East Carolina Diabetes and Obesity Institute, ECU, Greenville, North Carolina, USA

[4]School of Kinesiology and Recreation, Illinois State University, Normal, Illinois, USA

[5]Department of Kinesiology and Sport, University of Southern Indiana, Evansville, Indiana, USA

[6]Department of Obstetrics and Gynecology, East Carolina University, Greenville, North Carolina, USA

[7]Department of Pediatrics, East Carolina University, Greenville, North Carolina, USA

[8]Department of Epidemiology and Biostatistics, West Virginia University, Morgantown, West Virginia, USA

[9]School of Public and Population Health, Boise State University, Boise, Idaho, USA

Correspondence

Linda E. May, Department of Kinesiology, East Carolina University, Greenville, NC 27858, USA.
Email: mayl@ecu.edu

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Abstract

Background: Prenatal exercise improves birth outcomes, but research into exercise dose–response effects is limited.

Methods: This study is a retrospective, secondary analysis of pooled data from three blinded, prospective, randomized controlled trials. Prenatal exercise frequency, intensity, type, time, and volume (FITT-V) were assessed in supervised sessions throughout pregnancy. Gestational age (GA), neonatal resting heart rate (rHR), morphometrics (body circumferences, weight-to-length and ponderal index) Apgar and reflex scores, and placental measures were obtained at birth. Stepwise regressions and Pearson correlations determined associations between FITT-V and birth outcomes.

Results: Prenatal exercise frequency reduces ponderal index ($R^2 = 0.15$, $F = 2.76$, $p = .05$) and increased total number of reflexes present at birth ($R^2 = 0.24$, $F = 7.89$, $p < .001$), while exercise intensity was related to greater gestational age and birth length ($R^2 = 0.08$, $F = 3.14$; $R^2 = 0.12$, $F = 3.86$, respectively; both $p = .04$); exercise weekly volume was associated with shorter hospital stay ($R^2 = 0.24$, $F = 4.73$, $p = .01$). Furthermore, exercise type was associated with placenta size ($R^2 = 0.47$, $F = 3.51$, $p = .01$).

Conclusions: Prenatal exercise is positively related to birth and placental outcomes in a dose-dependent manner.

KEYWORDS

Apgar, birthweight, dose, placenta, ponderal index, prenatal exercise

1 | INTRODUCTION

Research suggests that there may be a dose-dependent beneficial effect of prenatal exercise for mothers (Allman et al., 2022; Claiborne, Jevtovic, & May, 2023; Claiborne, Williams, et al., 2023; Jevtovic & May, 2022; Jevtovic, Zheng, et al., 2023; May et al., 2023; McDonald et al., 2021, 2022). Based on a preponderance of evidence, worldwide guidelines support 150 min of moderate intensity exercise spread over three to four times per week to obtain the benefits of prenatal exercise (McDonald et al., 2016; Takami et al., 2018). Furthermore, exercise dose at this level or higher appears safe and could in fact benefit offspring. Studies in women of healthy weight, as well as women with overweight or obesity, have shown no adverse changes in birthweight in more frequent (five times per week) exercisers (Davenport, Ruchat, et al., 2019; Duncombe et al., 2006). Additional observational evidence suggests that intensity of prenatal exercise up to 85% of maximum HR also does not harm the fetus (Bonnin et al., 1997; Clapp, 1989; Wolfe et al., 1989); furthermore, vigorous exercise during pregnancy has been shown to decrease the risk of prematurity (Beetham et al., 2019). Studies combining metrics of exercise frequency, duration, and intensity confirm there is no increased risk for adverse birth outcomes in women exercising at or above the recommended volume (MET·min/week) (Davenport, Ruchat, et al., 2019; Duncombe et al., 2006; Lokey et al., 1991; Takami et al., 2018). As for the specific type of prenatal exercise, both aerobic and resistance/muscular strength exercise have been shown as safe to the fetus (Fernández-Buhigas et al., 2023; Hall & Kaufmann, 1987; *Journal of Science and Medicine in Sport*, 2002). Furthermore, concurrent resistance/strength and aerobic exercise is safe and is associated with benefits for perinatal outcomes (Perales et al., 2016). Reports show lower risk of preterm deliveries, abnormal birth weight (Silva-Jose, Sánchez-Polán, Barakat, Díaz-Blanco, Mottola, et al., 2022b), gestational weight gain, gestational diabetes mellitus (GDM) (Silva-Jose, Sánchez-Polán, Barakat, Díaz-Blanco, Carrero Martínez, et al., 2022a; Uria-Minguito et al., 2022), and hypertension (Gascoigne et al., 2023; Juhl et al., 2008).

While large systematic reviews have elucidated some of the expected effects from manipulating the amount, dose, or intensity of exercise during pregnancy (Davenport et al., 2018; Davenport, Kathol, et al., 2019; Davenport, Ruchat, et al., 2019), large-scale randomized controlled trials are lacking. Further investigation is needed to elucidate the influence of prenatal exercise dose in five metrics of exercise training, "FITT-V": frequency (number of sessions), intensity (metabolic equivalents, "METs"), time (duration of sessions), type (exercise mode), volume (exercise MET·min) on birth outcomes. The purpose of this study is to examine the effects of FITT-V on birth outcomes and placental size in a cohort of offspring born to women prescribed supervised exercise. Along the continuum of exercise volumes achieved during pregnancy, we hypothesized that prenatal exercise frequency, intensity, time, type, and volume (FITT-V) would predict birth and placental outcomes, such as birthweight, ponderal index, hospital stay, and placental efficiency.

2 | METHODS

2.1 | Study participants

The current report is a post hoc secondary analysis of data from three prospective, randomized control trials (RCT) investigating the influence of different exercise types throughout pregnancy on fetal and infant outcomes. All protocols were approved by the East Carolina University Institutional Review Board. Women enrolled in each study met the following criteria: clearance from an obstetric provider to participate in exercise; between 18 and 40 years old; pre-pregnancy body mass index (BMI; kg·m^{-2}) between 18.5 and 39.9 kg·m^{-2}; singleton pregnancy; ≤16 weeks gestation; no current alcohol, tobacco, or medication use. Criteria for exclusion included smoking, pre-existing conditions (i.e., diabetes mellitus, hypertension, cardiovascular disease, and comorbidities, systemic lupus erythematosus), and/or medications known to affect fetal growth and well-being. The study population included women from diverse backgrounds, that is, Black or Indigenous People of Color (BIPOC), and participant recruitment was conducted equally to represent different backgrounds and equity.

2.2 | Ethics statement

These studies used data from birth records collected from participants enrolled in an initial pilot RCT study, a second RCT (ClinicalTrials.gov Identifier: NCT03517293), or a third RCT (ClinicalTrials.gov Identifier: NCT03838146). Approval for these studies were obtained from the East Carolina University Institutional Review Board. Written informed consent was obtained from each participant upon enrollment. All experimental procedures were conducted at East Carolina University.

2.3 | Pre-intervention exercise testing and randomization

Following study enrollment, participants completed a submaximal exercise treadmill test to determine individual aerobic capacity, fitness level, and calculate specific target HR (THR) ranges for moderate-intensity exercise training. Peak oxygen consumption (VO_2 peak), as a measure of cardiorespiratory fitness, was estimated using the modified Balke protocol previously validated for pregnant women (Mottola, 2008). After completing this test, participants were randomized via computerized sequencing (GraphPad software) to aerobic, resistance (defined as muscular strength exercise), combination (aerobic and resistance), or a stretching/breathing control group for the first and third RCT; for the second RCT, participants were randomized to either aerobic or a stretching/breathing control group.

2.4 | Exercise intervention

All participants were supervised by trained exercise instructors in the university facilities and followed a standard protocol (Jevtovic, Lopez, et al., 2023; Jevtovic, Zheng, et al., 2023). The exercise intervention lasted ∼24 weeks total, as all sessions started before 16 weeks gestation and were performed three times per week until delivery at ∼40 weeks gestation (Birsner & Gyamfi-Bannerman, 2020). All sessions began with a 5-min warm-up, 50 min of assigned randomized group activity, and ended with a 5-min cool-down. Women were supervised and THR corresponding to moderate intensity (40%–59% VO_2 peak, and 12–15 rated perceived exertion) was the goal throughout the exercise session regardless of training mode. Target HR zones validated for pregnant women were utilized (Mottola, 2008).

The aerobic exercise group completed training on treadmills, ellipticals, recumbent bicycles, rowing, and/or stair-stepping equipment. The resistance exercise group completed sessions of two to three sets of 15 repetitions of each of 10–12 exercises at ∼60% of 1 repetition maximum (1-RM), which was determined as previously reported (Moyer et al., 2016). RE was performed in a circuit with minimal rest (∼5 s) using seated machines (Cybex) (leg extension, leg curl, shoulder press, chest press, triceps extension, latissimus dorsi pull down), dumbbells (biceps curls, lateral shoulder raises, front shoulder raises), resistance bands, dumbbells, exercise balls, benches, and/or mats. The combination exercise group performed the aerobic protocol for 25 min and a resistance protocol exercises for 25 min for a total of 50 min three times per week. Resistance exercises were performed at 15 repetitions (same exercises and equipment as RE group), while the aerobic exercises were performed on the same equipment as the AE group. Light intensity stretching and breathing exercises were performed by an attention control (CON) group. To monitor intensity during each session, the Borg rating of perceived exertion (RPE 6–20) scale was used with target heart rate monitoring (Polar FS2C). Supervised exercise and stretching/breathing (control) sessions took place at one of two university-affiliated gyms.

2.5 | Prenatal exercise FITT-V

Exercising women were scheduled for exercise three times per week, for 50 min per session, at 3–6 METs. To control for the effect of interindividual differences in gestational length, for example, premature, or late delivery, on total exercise volume throughout pregnancy, exercise FITT-V was analyzed between 16 and 36 weeks of gestation for all participants. Percent adherence to weekly volume and duration of exercise were calculated from data entered for each exercise session into a REDCap study database (Harris et al., 2009). Frequency, intensity, time, and volume of exercise were calculated for all exercisers and analyzed both as pooled and type-specific exercise FITT-V.

Frequency was expressed as the average number of exercise sessions per week (weekly frequency), as well as the total number of exercise sessions across the pregnancy (total frequency) between 16 and 36 weeks. Intensity (METs) was determined using intensity measured from each exercise session, as well as the published compendium of physical activities (Ainsworth et al., 2011), then averaged from all exercise sessions. Time was determined by averaging exercise duration, in minutes, from each week. Lastly, prenatal exercise volume (MET·min) was calculated by (1) multiplying METs by weekly duration for volume in MET·min/week (weekly volume), and (2) multiplying the weekly MET·min by the total number of weeks of prenatal exercise for total MET·min (total volume).

2.6 | Birth and placental outcomes

All birth and placental outcomes were collected by trained medical staff to standard operating procedure at one hospital. At birth, delivery type (spontaneous vaginal delivery, C-section), neonate sex, gestational age, neonatal measures (heart rate; chest, head, and abdominal circumferences; birth weight, length, ponderal index (PI)) were measured by standard procedures of the labor and delivery nurses blinded to randomized group allocation and entered into the electronic health record. Within each neonate sex, *z*-scores for all morphometric measures (circumferences, weight, length, PI) were calculated as: $(X - \text{mean})/\text{standard deviation}$. Women with pregnancy complications reported in the health record (gestational diabetes mellitus, gestational hypertension, preterm birth) were excluded from analysis. Head circumference:abdominal circumference (HC:AC) and weight-to-length ratios were calculated. Apgar scores were measured at 1 and 5 min after birth by a labor and delivery nurse along with the presence of seven reflexes (sucking, Moro, hand grasp, feet grasp, traction, Babinski, and stepping). At birth, the placenta was collected by the study team, blinded by group, and manual measurement of diameter (cm), thickness (cm), volume (cm^3), weight (g), and density (g/cm^3) were obtained. Two measures of placental efficiency by volume and by weight were calculated by dividing birth weight by either (1) placental volume or (2) placental weight, respectively.

2.7 | Maternal covariates

Maternal age, gravida, parity, pre-pregnancy weight and height, as well as race, and ethnicity were collected from pre-screening eligibility questionnaires. Pre-pregnancy BMI (healthy BMI 18.0–24.99; overweight 24.5–29.99, obese ≥30) was calculated using height (m), measured by stadiometer, and weight (kg) collected from the pre-screening eligibility questionnaire. Maternal pre-pregnancy BMI was calculated via the following established equation: $[\text{weight (kg)}]/[\text{height (m)}]^2$. Race and ethnicity were used to dichotomize participants into BIPOC or not. Maternal VO_2 peak was also considered a covariate.

2.8 | Statistical analysis

To obtain statistical power of 80% with significance $\alpha = 0.05$, analysis justified a sample size of 29 total participants to detect a moderate two-tailed Pearson product–moment coefficient of 0.50 (Miot, 2018). Analyses by exercise group was performed on all four groups (AE, RE, AERE, CON); however, the effect of exercise metrics, FITT-V, throughout pregnancy was analyzed on exercise participants only, excluding controls. Furthermore, exercise frequency, intensity, time and volume were compared across the 4 groups using one-way ANOVA. Stratified analyses were performed for exercise type. Pearson product–moment correlations were performed between each exercise FITT-V metric and each birth and placental outcome. In order to minimize the risk of too readily rejecting the null hypothesis, adjustments were not made for multiple comparisons (Rothman, 1990). Stepwise regressions were conducted to determine significant associated variables with birth and placental outcomes, controlling for covariates. One-way ANOVA was performed for investigations of randomized exercise group effect, with Tukey post-hoc test applied to significant group effects. Correlations and ANOVAs were performed using SPSS software (version 28.0.1.1, SPSS Inc. IBM Corp., Chicago, IL), while regressions were completed with JMP Pro 17 (SAS, Cary, NC).

3 | RESULTS

Birth outcomes were obtained for 358 women who enrolled in one of the studies. Across all births, 88 (25%) were Cesarean section, while 270 were spontaneous vaginal delivery. As this investigation focused on healthy pregnancies, participants with adverse pregnancy outcomes were excluded from analysis (gestational diabetes mellitus (GDM)—19; GDM and pre-term—2; pre-term—25, pre-term and hypertensive disorder of pregnancy (HDP)—1; HDP only—13). The final study sample included 298 healthy neonates, with 140 females and 158 males. In addition to 83 control participants, 215 intervention participants (AE: 91, RE: 59, AERE: 65) had complete exercise FITT-V metrics and were included in final analysis (Table 1).

Women on average were 30.3 years of age, BMI of 27.0 $kg \cdot m^{-2}$, with VO_2 peak of 21.65 $mL \cdot kg^{-1} \cdot min^{-1}$, on their second pregnancy. The population was diverse, with 25% of participants identified as BIPOC, 37% with overweightness, and 28% with obesity. Women participated in exercise for an average of 17 weeks during pregnancy (range 3–20 weeks). In the current study assessing from 16 to 36 weeks for standardization, exercise volume ranged between 100 and 850 MET·min/week, spread over 10–76 total sessions, and resulting in 1000–20,000 total MET·min through pregnancy.

There were no significant differences for exercise FIT-V between exercise types (Table 2), except for a significantly higher weekly duration of exercise in combination compared to aerobic ($p < .05$). Among exercise types, attendance to sessions averaged 80%. Participant compliance to weekly volume (MET·min/week) averaged 92% for AE and AERE groups, and 100% for RE; exercise compliance to weekly duration (min) was 82% (AE), 78% (AERE), or 86% (RE). No differences between exercise types were seen for any of the birth outcomes measured (Table 3).

However, prenatal exercise in general led to a clinically significant 11%–17% reduction in the occurrence of cesarean section (Table 3), though this finding was not statistically significant. Weekly and total volume of exercise was positively associated with gestational age at birth (Table S1). Greater exercise weekly volume, weekly

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TABLE 1 Maternal characteristics across exercise type.

Maternal characteristic	Control	AE	RE	AERE	*p* value
Age (years)	29.6 ± 4.4	29.8 ± 4.4	30.1 ± 4.1	31.2 ± 4.0	.14
Pre-pregnancy BMI ($kg{\cdot}m^{-2}$)	28.0 ± 6.0	25.0 ± 5.2*	25.0 ± 3.9*	26.0 ± 5.0	.002
VO_2 peak ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	20.3 ± 5.3	23.0 ± 4.7*	23.4 ± 6.2*	23.7 ± 5.7*	.002
% BIPOC	37%	24%	10%*	17%	.009
Gravida	2 (1,6)	2 (1,4)	2 (1,5)	2 (1,4)	.11
Parity	1 (0,4)	1 (0,2)*	1 (0,3)	1 (0,2)*	.03
Pregnancy Complications (%)	15 (21%)	13 (15%)	11 (20%)	8 (13%)	.81

Note: Data reported as mean ± SD. Maternal characteristics measured before commencement of exercise (12–16 weeks of gestation) or documented at birth (pregnancy complications).
Abbreviations: AE, aerobic exercise; AERE, combination exercise; BIPOC, Black or Indigenous People of Color; RE, resistance exercise.
*Tukey post-hoc results: $p < .05$ versus control.

TABLE 2 Prenatal exercise FITT-V across exercise type.

Exercise metrics	Control	AE	RE	AERE	*p* value
Weekly frequency (sessions/week)	-	2.46 ± 0.55	2.48 ± 0.37	2.63 ± 0.40	.20
Total frequency (total # sessions)	-	49.9 ± 15.3	52.2 ± 13.9	55.1 ± 13.4	.25
Intensity (METs)	-	3.94 ± 0.46	3.92 ± 0.17	3.99 ± 0.62	.58
Time (min/week)	-	123.2 ± 29.8	128.8 ± 23.5	136.6 ± 25.6*	.05
Weekly volume (MET·min/week)	-	483.3 ± 132.0	506.7 ± 102.2	537.1 ± 150.5	.12
Total volume (total MET·min)	-	9739 ± 3579	10,467 ± 3753	11,469 ± 3977	.26

Note: Data reported as mean ± SD. Exercise FITT-V calculated within each group between 16 and 36 weeks of gestation.
Abbreviations: AE, aerobic exercise; AERE, combination exercise; METs, metabolic equivalent; RE, resistance exercise.
*Tukey post-hoc results: $p < .05$ combination versus aerobic.

frequency, intensity, and time were significantly associated with improved birth measures (e.g., head, and abdominal circumferences, BMI, birthweight) (Table S1). Although placental measures did not vary between prenatal exercise type (Table 4), multiple positive associations were seen between prenatal RE FITT-V and measures of placental weight, diameter, density, and efficiency by volume (Table 5). Further, exercise FITT-V metrics were associated with improved measures of gestational age, hospital stay, morphometrics, and reflexes at birth (Table 6), after controlling for maternal covariates such as BMI, age, race, and gravida/parity. Maternal race and BMI were found to be significant covariates (Table 7).

4 | DISCUSSION

The current study aimed to determine if there is an association between exercise FITT-V and birth and placental outcomes. We hypothesized that prenatal exercise FITT-V would, in general, improve outcomes at birth, such as birthweight, PI, hospital stay, and placental efficiency. We found a plethora of significant associations between exercise FITT-V and gestational age, resting heart rate at birth, body circumferences and morphometrics, and reflexes at birth. Relationships were found for many specific FITT-V metrics. In brief, exercise weekly frequency was associated with PI and total number of reflexes present at birth, while exercise intensity correlated with gestational age and birth length; weekly exercise volume was related to hospital stay, with trends influencing placenta weight. These effects were specific to exercise type, with RE generally showing more associations than AE, especially in placenta weight and diameter and PI. Pre-pregnancy BMI and VO_2 peak were found to be significantly different between exercise and control groups, VO_2 peak was within acceptable range for this population, and average BMI across all groups was classified as overweight (25.0–29.9 $kg{\cdot}m^{-2}$). Maternal race had a significant effect on birth outcomes such as duration of hospital stay and weight:length ratio. Specifically, women identifying as BIPOC saw longer neonatal hospital stays than White. In addition, higher weight and lower length in BIPOC offspring increased weight: length ratio. However, in agreement with previous findings, exercise

TABLE 3 Birth outcomes across exercise type.

Birth outcome	Control	AE	RE	AERE	*p* value
% female	46%	40%	44%	60%	.67
GA at birth (weeks)	39.2 ± 1.5	39.6 ± 1.1	39.5 ± 0.9	39.3 ± 1.2	.24
Hospital stay (days)	1.9 ± 0.8	2.1 ± 1.0	1.8 ± 0.6	2.1 ± 0.9	.31
% C-section	36%	20%	19%	25%	.30
Resting HR (beats/min)	126 ± 16	123 ± 14	125 ± 14	126 ± 14	.36
Circumferences (*z*-scores)					
Chest	.73	.82	.79	.85	.38
Abdominal	.82	.91	.88	.95	.12
Head	.89	.94	.95	.97	.36
HC:AC	.82	.92	.88	.92	.20
Weight (*z*-score)	.97	.99	.97	1.0	.37
Length (*z*-score)	.92	.97	.96	1.0	.10
Weight:length (*z*-score)	.89	.98	.97	1.0*	.01
Ponderal index	27.7 ± 4.4	28.9 ± 4.3	28.9 ± 4.7	28.7 ± 3.0	.26
Ponderal index (*z*-score)	.88	.99*	.98	1.0*	.01
1-min Apgar	8 ± 1	8 ± 1	8 ± 1	8 ± 1	.69
5-min Apgar	9 ± 1	9 ± 0	9 ± 1	9 ± 0	.74
# reflexes present at birth	6 ± 1	6 ± 1	6 ± 2	6 ± 2	.93

Note: Data reported as mean ± SD. Birth outcomes collected at delivery or documented upon hospital discharge (duration of hospital stay). No significant differences observed between groups for exercise type.
Abbreviations: AE, aerobic exercise; AERE, combination exercise; GA, gestational age; HC:AC, head circumference:abdominal circumference ratio; HR, heart rate; RE, resistance exercise.
*Tukey post-hoc results: $p < .05$ versus control.

TABLE 4 Placenta measures across exercise type.

Placenta measure	Control	AE	RE	AERE	*p* value
Diameter (cm)	18.7 ± 1.0	17.4 ± 1.6	18.5 ± 0.6	17.2 ± 2.8	.26
Thickness (cm)	5.4 ± 0.9	4.5 ± 1.4	5.1 ± 1.2	4.6 ± 1.7	.76
Volume (cm^3)	1806 ± 392	1113 ± 504	1365 ± 334	1113 ± 459	.50
Weight (g)	492 ± 13	453 ± 109	438 ± 23	430 ± 149	.67
Density (g·cm^{-3})	0.28 ± 0.10	0.50 ± 0.22	0.34 ± 0.08	0.44 ± 0.20	.44
Efficiency by volume (BW/Pvol)	2.3 ± 0.9	4.3 ± 1.5	2.8 ± 0.4	3.8 ± 1.6	.86
Efficiency by wt (BW/PW)	7.7 ± 0.5	8.4 ± 1.4	8.6 ± 1.2	8.1 ± 2.0	.84

Note: Data reported as mean ± SD. Placenta collected at delivery and immediately stored at 4°C. Processed and measured at 25°C. Diameter calculated as average of placental width and length. Efficiency by volume (BW/Pvol) calculated as dividing birth weight by placental volume. Efficiency by wt. (BW/PW) calculated as dividing birth weight by placental weight. No significant differences observed.
Abbreviations: AE, aerobic exercise; AERE, combination exercise; RE, resistance exercise.

during appears to mitigate interracial disparities in birth outcomes (Raper et al., 2021).

4.1 | Prenatal exercise volume

Similar to a previous systematic review in 2018 (Davenport et al., 2018) and a longitudinal study in 2022 (Beetham et al., 2022), we found that neither weekly nor total exercise volume were associated with birthweight within a healthy population of women and neonates. These findings differ from a Chinese cohort, which found self-report volume during pregnancy was associated with greater birthweight (Li et al., 2023); however, the Chinese cohort included preterm and small-for-gestational age births. Chasan-Taber et al. (2007) noted that while the

TABLE 5 Associations between prenatal exercise FITT-V and placental measures.

Outcome	Weekly frequency (sessions/week)			Total frequency (total # sessions)			Intensity (METs)			Time (min/week)			Weekly volume (MET·min/week)			Total volume (total MET·min)		
	AE	RE	AERE	AE	RE	AERE	AE	RE	AERE	AE	RE	AERE	AE	RE	AERE	AE	RE	AERE
Diameter (cm)	**.821****	**.898***	**.653***	**.678***	.654	**.774****	**.844****	**.995****	**.670****	**.643***	**.901***	**.589***	**.785****	**.895***	.469	**.678***	.596	**.620***
Thickness (cm)	.544	.552	.045	.324	.233	.303	.497	**.843***	.461	.329	.554	−.032	.557	.556	.051	.259	.144	.112
Volume (cm^3)	.320	.521	−.053	.084	.155	.314	.359	**.825***	.508	.017	.522	−.037	.351	.522	.088	.108	.072	.454
Weight (g)	**.648***	**.923****	.259	.369	.724	.393	.396	**.995****	**.630***	.500	**.930****	.396	.286	**.930****	.478	.303	.668	.411
Density ($g \cdot cm^{-3}$)	.273	**.971****	.451	.334	**.949***	.284	.396	**.832***	.187	.362	**.981****	.423	.204	**.981****	.334	.301	**.936***	.123
Efficiency by volume (BW/Pvol)	.268	**.965****	.538	.601	.874	.327	.519	**.934****	.224	.383	**.976****	.517	.410	**.980****	.433	.583	.836	.087
Efficiency by wt (BW/PW)	**.678***	.733	**.681***	**.901****	.445	**.747***	**.810****	**.949****	.409	**.707***	.742	.470	**.866****	.744	.270	**.882****	.368	.527

Note: Pearson's *r* correlation coefficient reported. Placental measures performed at 25°C. Min minutes, Efficiency by volume (BW/Pvol) calculated as dividing birth weight by placental volume. Efficiency by wt. (BW/PW) calculated as dividing birth weight by placental weight.

Abbreviations: AE, aerobic exercise; AERE, combination exercise; RE, resistance exercise.

*$p < .05$. **$p < .01$.

TABLE 6 Associations of prenatal exercise with birth outcomes.

Birth outcomes	Estimate	Std. error	Lower 95%	Upper 95%	*p* value
Gestational age (1) (p value = .028,* adjusted $R^2 = 0.08$, $F = 3.14$)					
Intensity (METs)	0.718	0.356	0.013	1.423	.046
Gravida	−0.293	0.159	−0.607	0.021	.067
Duration of hospital stay (2) (p value = .0001,* adjusted $R^2 = 0.24$, $F = 4.73$)					
Pre-pregnancy BMI	1.196	0.679	−0.149	2.542	.081
Race	1.315	0.438	0.446	2.184	.003
Weekly volume (MET·min/week)	−1.899	0.724	−3.335	−0.465	.010
Length (z score) (3) (p value = .006,* adjusted $R^2 = 0.12$, $F = 3.86$)					
Race	−0.010	0.003	−0.017	−0.004	.001
Intensity (METs)	0.016	0.008	0.001	0.032	.040
Ponderal index (z score) (4) (p value = .016, adjusted $R^2 = 0.15$, $F = 2.76$)					
Weekly frequency (sessions/week)	0.608	0.310	−0.008	1.224	.053
Placenta weight (5) (p value = .019, adjusted $R^2 = 0.58$, $F = 4.93$)					
Age	106.53	29.54	39.71	173.4	.006
Race	−123.50	31.27	−194.2	−52.76	.003
Exercise type (AE)	101.79	31.66	30.17	173.4	.011
Exercise type (AERE)	−70.609	23.78	−124.4	−16.82	.016
Weekly volume (MET·min/week)	85.103	42.16	−10.27	180.5	.074
Placenta diameter (6) (p value = .049,* adjusted $R^2 = 0.47$, $F = 3.51$)					
Gravida	1.717	0.864	−0.237	3.672	.078
Exercise type (AERE)	−2.401	0.929	−4.503	−0.299	.030
Exercise type (RE)	2.538	0.751	0.838	4.237	.008
Reflexes present at birth (7) (p value < .0001,* adjusted $R^2 = 0.24$, $F = 7.89$)					
Total frequency (total # exercise sessions)	1.736	0.329	1.084	2.387	<.001

Note: Models also included: (1) gravida, exercise duration; (2) BMI, race, gravida, parity, exercise group; (3) age, gravida, parity, total MET·min; (4) age, gravida, parity, total MET·min, VO_2 peak; (5) MET·min/week; (6) average METs, exercise frequency; (7) race, parity, average METs. No significant influence on birth weight seen in exercise FITT-V.
Abbreviations: AE, aerobic exercise; AERE, combination exercise; RE, resistance exercise.

effect of physical activity on birth outcomes is likely to be modest, effect might not be observed since the majority of previous studies have not consistently assessed type, frequency, intensity, and duration during each trimester of pregnancy.

Importantly, we found greater weekly prenatal exercise volume to decrease the duration of hospital stay of the baby after delivery. This is the first study showing a direct effect of prenatal exercise weekly volume in a diverse population of women on hospital stay after delivery. As prolonged hospital stay is associated with greater cost and risk of complications (Sahiledengle et al., 2020), this finding is clinically relevant. Further, a trend was found for a significant predictive effect of weekly RE volume on placental weight, which confirms previous findings in AE (Clapp, 2003; Clapp et al., 2002). These findings support that exercise, in general, during pregnancy increases the exchange capability of the placenta, thus enhancing nutrients to the fetus. Overall, our findings suggest that 450 MET·min/week prenatal exercise is safe for birth and placental outcomes, while higher prenatal exercise volume has been associated with improved birth outcomes (Claiborne, Jevtovic, & May, 2023; Clapp et al., 2002; Duncombe et al., 2006; Hatch et al., 1998; McDonald et al., 2018, 2022; Takami et al., 2018).

4.2 | Prenatal exercise frequency

PI was 4% higher in exercise-exposed offspring and weekly frequency, ranging from 1 to 4 sessions per week was positively correlated with improved ponderal index and reflexes present at birth. This finding suggests that

TABLE 7 Maternal covariates.

Birth outcomes	Mean square	F	p value
Duration of hospital stay (p value = .02, F = 2.333)			
Race	57.8	6.736	.01
Pre-P BMI	36.6	4.264	.04
Weight z score (p value = .03, F = 2.135)			
Race	0.33	11.39	<.001
Length z score (p value = .12, F = 1.594)			
Race	0.32	8.554	.004
Exercise group × race	0.16	4.732	.004
Weight:length z score (p value = .06, F = 1.883)			
Race	.42	8.987	.003
Exercise group × race	0.19	4.449	.005

Note: All models included: pre-pregnancy BMI, maternal age, race, gravida and parity, pre-pregnancy VO_2 peak, and group. Interaction effect displayed for exercise group × race.
Abbreviation: Pre-P BMI, pre-pregnancy body mass index.

even exercising one time per week could improve PI and reflexes at birth. Weekly frequency predicted PI, such that greater frequency led to greater ponderal index, within normal ranges, a notion suggesting offspring could experience improved health outcomes long-term (Cole et al., 1997; Morris, 1998). Previous work has shown an inverse relationship between exercise frequency and PI (Pastorino et al., 2019), however the investigators found this relationship only in exercise completed late in gestation (≥30 weeks). Our findings suggest in comparison that when frequent exercise is completed through all three trimesters, ponderal index is increased in offspring. It is possible the greater PI reflects the advanced gestational age in high-frequency exercisers; potentially the neonates from exercisers have more muscle mass as well. Total number of exercise training sessions throughout pregnancy predicted critical neonatal reflexes present at birth, which may indicate enhanced neuromotor development in these offspring (Edwards & Al, 2023; Modrell & Tadi, 2023). It has been previously shown that prenatal aerobic exercise enhances neuromotor development at 1-month of age (McMillan et al., 2019), while a similar dose–response in cardiac autonomic responses is also present (May et al., 2010, 2014).

4.3 | Prenatal exercise intensity

Average exercise METs were predictive of both gestational age and offspring length at birth. These findings coupled with multiple significant correlations with other markers of morphometrics, as well as placental volume and efficiency confirm that increasing exercise intensity benefits pregnancy and fetal growth (Bø et al., 2016; Siebel et al., 2012; Yu et al., 2022). This information aligns with a systematic review and meta-analysis (Perales et al., 2016; Raper et al., 2021) which showed that vigorous intensity maternal exercise significantly increases gestational length and reduces risk of prematurity (Beetham et al., 2019).

4.4 | Prenatal exercise type

The current study used data from those who participated in aerobic (AE), resistance (RE) and combination exercise (AERE). While many birth outcome variables were not different between exercise groups, ponderal index and weight-to-length ratio were greater for both AE and AERE than controls. Between birth weight and birth length, length tended to be higher in exercise groups, while no differences were observed in birth weight between groups. It is interesting that the correlations seen between exercise FITT-V and birth outcomes were different between exercise types. RE typically resulted in the strongest relationships in placental diameter, and the only positive association seen with placental thickness. This finding further supports that exercise enhances the exchange capacity of the placenta and thus nutrient exchange to the developing fetus. Although we did not analyze changes in early and late pregnancy, we noted the greatest changes with aerobic-only or resistance-only prenatal exercise types. Previous research (Clapp, 2003) notes greater placental size with aerobic exercise as well; this innovative analysis compares aerobic-only, resistance-only, and combination exercise.

4.5 | Strengths and limitations

The current analysis was the first to show a direct effect of prenatal exercise FITT-V on birth and placental outcomes. The study is strengthened by a large sample size of participants from rigorous supervised RCT exercise intervention trials. The measures were done as standard procedure at the local hospital and thus were blinded to group allocation. The variety of outcomes obtained at birth offer a holistic image on the effects of prenatal exercise FITT-V on birth and placental outcomes. However, the study had a few limitations. First, prenatal exercise FITT-V was controlled within a prescribed range, which limits our investigation of high- and low-FITT-V; however, this is a critical step to demonstrating the dose-dependent influence of exercise on beneficial pregnancy and birth outcomes. Second, although some delivery measures were obtained as standard hospital procedures after delivery and may have interindividual differences between nurses, these are standard processes in the hospital setting, thus, most likely have a small margin of error (Bhushan & Paneth, 1991; Doull et al., 1995). Overall, these initial findings support the need for further research in this area and support further work on this topic.

5 | CONCLUSION

These exploratory findings contribute significantly to guiding future prenatal exercise recommendations. Prenatal exercise frequency, intensity, and weekly and total volume are predictive measures of fetal growth and health. Interestingly, our data suggest that prenatal exercise FITT-V influences birth outcomes differentially across prenatal exercise types. Future research should address the potential benefits of a broader range of frequency, intensity, time, and volume in the pregnant population. These promising findings suggest that every minute and every session of exercise during pregnancy is important, as well as intensity, throughout the pregnancy for improved birth and placental outcomes.

AUTHOR CONTRIBUTIONS

Alex Claiborne: visualization, writing—original draft, writing—review and editing, formal analysis, investigation; **Kara Kern**: data curation, software, writing—review and editing; **Filip Jevtovic**: data curation, software, writing—review and editing; **Breanna Wisseman**: data curation, software, writing—review and editing; **Dylan Steen**: data curation, software, writing—review and editing; **Samantha McDonald**: data curation, software, writing—review and editing; **Cody Strom**: data curation, software, writing—review and editing; **Edward Newton**: project administration, writing—review and editing; **Christy Isler**: project administration, writing—review and editing; **James DeVente**: project administration, writing—review and editing; **Steven Mouro**: project administration, writing—review and editing; **David Collier**: project administration, writing—review and editing; **Devon Kuehn**: project administration, writing—review and editing; **George A. Kelley**: project administration, writing—review and editing; **Linda E. May**: conceptualization, data curation, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors report no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Alex Claiborne https://orcid.org/0000-0001-7427-3851
Samantha McDonald https://orcid.org/0000-0002-7191-5086
Linda E. May https://orcid.org/0000-0002-8231-2280

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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