

Physical Activity Volumes during Pregnancy: A Systematic Review and Meta-Analysis of Observational Studies Assessing the Association with Infant's Birth Weight

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Abstract

Objective This study aims to examine the association between different maternal physical activity exposures during pregnancy and infant's birth weight, body composition, and risk of inadequate weight.

Methods Two reviewers (M.B. and J.L.G.) identified observational studies reporting total or leisure time activity during pregnancy and birth weight outcomes. Pooled analyses were performed to summarize the risk associated with high or moderate volumes of physical activity on birth weight.

Results A total of 54 studies among 4,080 reported the association between physical activity and birth weight (37 studies) or risks of small or large birth weight. The association between physical activity and birth weight was evaluated by physical activity levels (low, moderate, or high). Despite heterogeneity, pooled results (23 studies) suggested that moderate levels of activity are associated with an increased birth weight (mean difference: 61.5 g, 95% confidence interval [CI]: 16.6, 106.5, 15 studies), while high levels were associated with lower birth weight (mean difference: –69.9 g, 95% CI: –114.8, –25.0, 15 studies). Data were insufficient to provide robust estimates for other outcomes.

Conclusions The results of observational studies suggest an inverted u-shaped association between physical activity and birth weight, despite methodological variability. These results could help refining physical activity guidelines for pregnancy and provide guidance for future research.

Keywords

- ▶ birth weight
- ▶ body composition
- ▶ physical activity
- ▶ pregnancy
- ▶ systematic review

As a marker of fetal growth, birth weight, and potentially neonatal body composition, is associated with health markers in later life such as body composition,¹ strength, and cardiorespiratory fitness.^{2–4} Birth weight extremes are also associated with adverse health outcomes, including obesity, cardiovascular diseases, and metabolic dysfunction.^{5–8} Accordingly, these

outcomes are largely studied, although their determinants remain partly understood.

Leisure time physical activity is associated with the course of a healthy pregnancy, as it can increase cardiorespiratory fitness,⁹ decrease gestational weight gain,¹⁰ and may lower the risk of preeclampsia,¹¹ cesarean section,¹² and gestational

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diabetes.^{13,14} Recently, meta-analyses of randomized controlled trials (RCTs) have been published regarding the effect of maternal physical activity interventions on infant's birth weight, suggesting a modest yet significant decrease in birth weight with physical activity interventions.^{15,16}

The important heterogeneity in physical activity interventions during pregnancy and adherence issues might nevertheless preclude a complete portrait of the impact of physical activity on markers of fetal growth, as this impact is likely to depend on the type, volume, and intensity of physical activity, as well as the conditioning level of the mother and timing during pregnancy.^{11,17–20} For instance, RCTs are usually initiated during the second trimester of pregnancy, making it difficult to assess the impact of exercise in early pregnancy.

Also, interventions are limited to moderate intensity physical activity, as it is the intensity recommended by numerous pregnancy guidelines.^{21,22} However, documenting the effects of vigorous intensity activities is crucial to ensure the safety of pregnant women who engage in such activities. In that regard, summarizing data from observational studies could greatly help understanding the effect of this somewhat prevalent behavior. Although previous meta-analyses of RCTs provided important evidence regarding the effect of maternal physical activity on birth weight, data from these studies are insufficient to determine whether these effects are specific to a particular volume, intensity, and timing of physical activity during pregnancy, and whether they rely on a dose–response relationship or if a threshold must be reached to achieve an effect.

Given the large number of observational studies and their potential to complement our understanding of the association between maternal physical activity and fetal growth, we performed a systematic review and when possible a meta-analysis of observational studies with the aim of characterizing the association between different maternal physical activity exposures (volume, intensity, timing during pregnancy, and measurement method) and infant birth weight, body composition, and risk of inappropriate birth weight for gestational age.

Methods

Sources

The protocol was published online on the international prospective register of systematic reviews Web site (CRD42013004968). The search for citations in English or French was performed in PubMed, EMBASE, and Web of Science, considering all articles published from 1946, 1947, and 1956 depending on the database, until June 2013. A second search considering articles published between June 2013 and March 2015 was subsequently performed. Search in PubMed included the following MeSH and/or text terms for physical activity: “exercise,” “exertion,” “pliability,” “physical fitness,” “physical education and training,” “exercising,” “physical condition,” “stamina,” “sports,” and “muscle strengthening exercises.” For weight outcomes, the following MeSH or/and text terms were used: “pregnancy,” “pregnancy complications,” “pregnancy outcome,” “birth weight,” “low

birth weight,” “high birth weight,” “small for gestational age,” “large for gestational age,” “pregnancy,” “pregnanc*,” “pregnant*,” “pregnancy complication*,” “pregnancy outcome,” “birth weight,” “low birth weight,” “high birth weight,” “small for gestational age,” and “large for gestational age.” Terms were combined using the Boolean operator “OR” within each category, and “AND” when combining between exposure and outcome. A similar approach was used with other databases.

Study Selection

Studies were excluded if they were conference abstracts, reviews, case reports, unpublished articles, or intervention trials. Reviews were manually searched for citations not detected by the electronic search. Citations were combined and duplicates excluded. As prespecified in the protocol, studies were considered only if they measured leisure time or total physical activity. Two reviewers (M. B., J. L. G.) independently screened titles for potential relevance. Titles obviously not related to the topic of interest were excluded. Potentially relevant abstracts were screened using a standardized criterion (i.e., human studies, reference to pregnancy or birth weight or physical activity). Abstracts considered by both reviewers as not relevant were excluded, and full articles were retrieved. Any disagreement was solved by discussion and consensus between the two reviewers (M. B., J. L. G.) and a third author (I. M.) if needed. All included articles were independently reviewed for data extraction on a form, especially conceived before extraction, as follows: study year and country, population, design, the number of exposed/unexposed or cases/controls, definitions, and methods for exposure assessment, including type, frequency, intensity, and timing of physical activity, definitions, and methods for outcome assessment, effect estimates or continuous data, and adjustment variables. Studies were classified based on the design and by the outcome. Study quality was assessed using the Newcastle–Ottawa quality assessment scale.²³

Outcomes

The outcomes of interest were the neonate's birth weight in grams, low and high birth weight (LBW, HBW), defined as a birth weight below 2,500 g and above 4,000 g, respectively, small and large for gestational age (SGA, LGA) if birth weight for gestational age was below the 10th and above the 90th percentile, respectively, and body composition, defined as fat percentage, fat mass or lean mass in grams.

Exposure

Maternal physical activity was defined as either leisure time physical activity or total physical activity performed during pregnancy and not related to an intervention. Leisure time activity (including sports, exercise, and recreational activities) was chosen as it is the focus of physical activity recommendations. However, since leisure time activity only accounts for around 10% of pregnant women's energy expenditure,^{24,25} total activity (including all domains, e.g., work-related activity) was also considered. To be as inclusive as possible, it was determined that physical activity could be defined according to volume (product of frequency, intensity,

and duration), frequency, intensity, and/or duration alone. With the increasing popularity of objective measurement devices (e.g., accelerometers), we also wanted to verify whether studies using such technology, or other objective methods to measure physical activity, would provide more consistent results compared with the overall evaluation of all eligible studies.

To investigate whether the association between physical activity and birth weight outcomes differed by physical activity levels, study groups (when available) were classified as “high level,” “moderate level,” or “low level/sedentary.” A study group was classified as “high level” if the authors stated that this group performed vigorous intensity activity, if the group performed a high volume of activity, defined as at least three sessions per week of at least 30 minutes (which is similar to the recommendations of vigorous activity for the general population)²⁶ and ideally with a specification of intensity, or if the group was the one with the highest energy expenditure, duration, or intensity of physical activity in studies with more than two groups, allowing the comparison of groups with the largest difference in physical activity levels. Therefore, in this review, “level” refers to physical activity categorization regardless of whether a study defines physical activity by volume, frequency, intensity, or duration. Study groups not meeting the criteria of “high level” of activity or classified as “moderately active” by the authors were included in our “moderate level” comparison. In both the cases, moderate- and high-level groups were compared with the group having the lowest activity level in the study.

Data Analysis

Due to an important heterogeneity in the way studies defined, measured and quantified physical activity, studies were exclusively pooled to answer our main question regarding how physical activity volume and/or intensity could modulate infant’s birth weight, based on a cautious classification of studies (as described above). To account for variability across studies and to derive conservative assessments of the uncertainty in the estimates, a Der Simonian and Laird random effects model was used.²⁷ Data were pooled using the weighted unstandardized mean difference in effect size across studies. Heterogeneity was assessed with the I^2 statistic,²⁸ with high heterogeneity defined as $I^2 \geq 75\%$.²⁸ The results were considered significant if $p < 0.05$.

Results

Characteristics of the Studies

Among the 4,080 identified citations, 54 studies met the inclusion criteria (► Fig. 1). There were 50 cohort studies and 4 case-control studies.^{29–32} Overall, the studies were of moderate (28 studies, 51.9%)^{29,31–57} or good (21 studies, 38.9%)^{30,58–77} methodological quality, while 5 studies (9.2%) were classified as of poor methodological quality.^{78–82} Most studies were conducted in a community setting (59.3%) and included low-risk, predominantly Caucasian women. Characteristics of the studies are summarized in ►Table 1,

while detailed descriptions of exposures and outcomes of individual studies can be found in ►Table 2.

Physical activity was mainly assessed with questionnaires (including interviews and diaries), but only 10 studies used a questionnaire specifically validated for pregnancy.^{31,32,43,44,59,63,67,72,75,76} Leisure time activity was more often reported than total physical activity. Only eight studies included objective physical activity measures (heart rate monitoring,^{36,37,48} use of pedometers,⁴⁶ or accelerometers^{41,45,48,73,77}). Vigorous activity was reported in eight studies,^{33,36,37,40,53,57,67,71} with the most common definition as follows: exercise at or above 50% of maximal capacity.^{33,36,37,57}

A total of 15 studies (27.8%) reported physical activity as a summary measure for the entire pregnancy.^{32,34–37,42,47,49,54,56,57,60,68,78,81} Numerous studies reported results for more than one trimester, but only eight studies (14.8%) assessed physical activity in each trimester of pregnancy.^{30,50,51,58,59,61,64,75} Physical activity was treated as a categorical variable in most studies. However, the number of physical activity groups varied, as well as the criteria used to define these groups. Indeed, some studies compared active women to a group of women not doing any leisure time activity, while other studies used a “low activity” comparison group or created groups of various physical activity levels (using the median, tertiles, quartiles, etc.).

Most studies extracted birth weight outcomes from medical charts. Body composition was derived from the skinfold measure in one study,³⁶ whereas it was evaluated by air-displacement plethysmography in another one.⁷⁵ Most studies defined birth weight outcomes as prespecified in the protocol, with a few exceptions using close definitions.^{38,49,51,53,55,61,65,72,73,79,81}

A total of 34 studies adjusted for confounding variables, mainly maternal weight or body mass index, gestational weight gain, smoking, age, parity, education, gestational age at delivery, and infant sex. However, the choice of confounders varied substantially between studies.

Association between Maternal Physical Activity and Birth Weight

Global Results of the Association between Maternal Physical Activity and Birth Weight

A total of 37 studies (68.5% of all 54 studies) reported the association between physical activity (total and/or leisure time physical activity) and birth weight. Among these studies, 25 (67.6%) did not observe a statistically significant difference in birth weight within various physical activity levels, or vice versa. Conversely, 8 of the 37 studies (21.6%) found a significant decrease in birth weight with increasing maternal activity,^{33,36,48,57,62,67,68,75} while physical activity was associated with an increased birth weight in the last 4 studies (10.8%).^{38,44,64,79} A total of 21 studies adjusted for confounders, with similar results; 14 (66.7%) did not find a significant association between maternal physical activity and birth weight, while 5 (23.8%) found a significant decrease,^{33,62,67,68,75} and 2

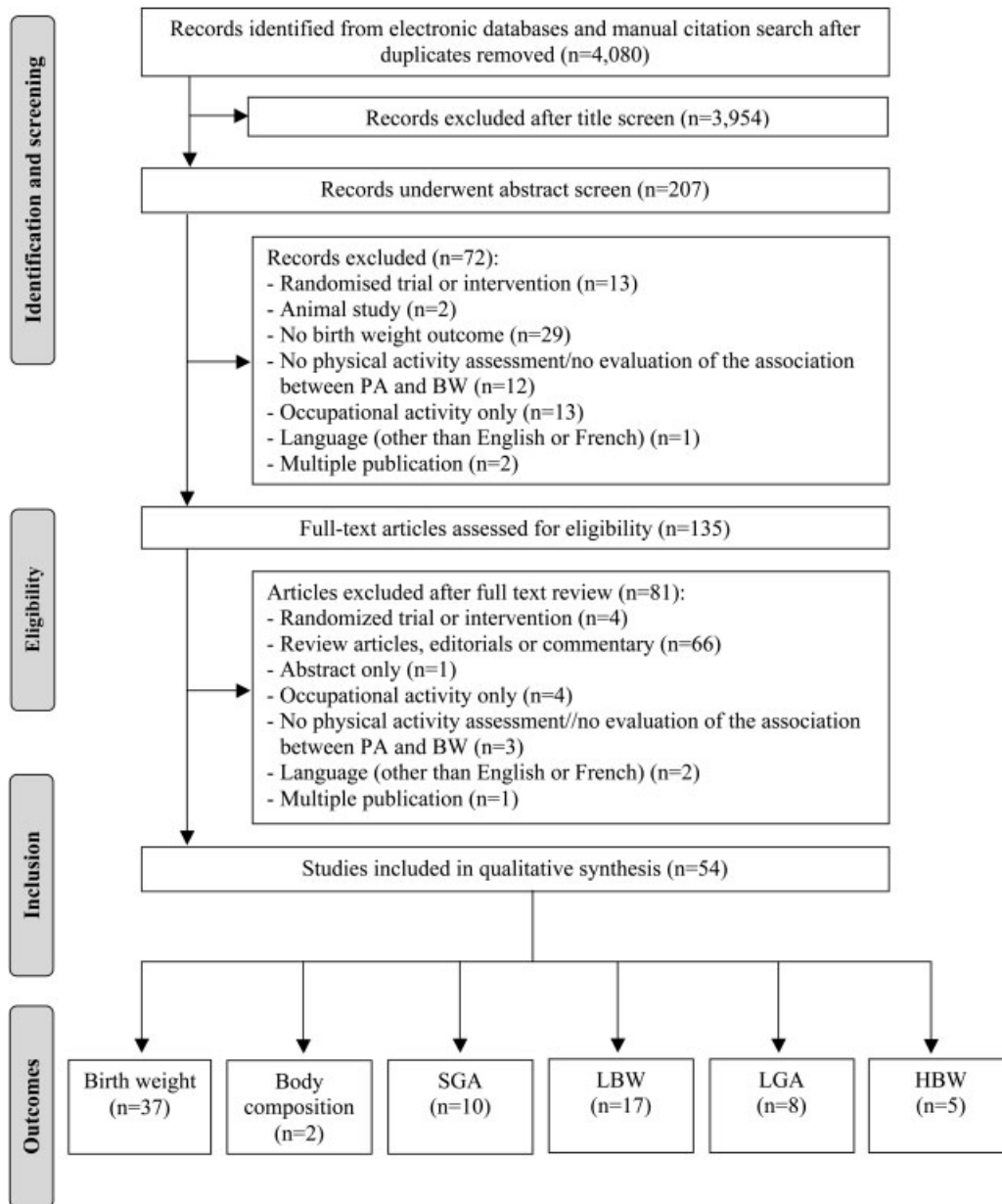


Fig. 1 Flowchart of reviewed citations. HBW, high birth weight; LBW, low birth weight; LGA, large for gestational age; SGA, small for gestational age.

(9.5%) found a significant increase in birth weight with increasing activity.^{44,64}

Among studies that objectively measured physical activity and looked at the association with birth weight, two found a significant decrease in birth weight with increasing activity^{36,48} while the remaining five studies found no significant association birth weight.^{37,41,45,46,73}

Birth Weight Results According to Physical Activity Levels (High or Moderate vs. Low Levels)

Data from 23 studies (62.2% of the 37 studies) could be pooled to evaluate the association between physical activity levels and birth weight. Overall, 17 studies (45.9% of the 37 studies) reported the association between physical activity during pregnancy and birth weight comparing

high levels of physical activity with no activity or low levels (→ **Fig. 2**).^{33,36,37,40,48,50,53,56,57,64–68,71,74,75} Two of them (reporting no significant association between physical activity and birth weight) could not be pooled as they did not report enough quantitative data.^{40,53} From the remaining 15 studies, most (13) reported leisure time physical activity and 9 presented adjusted estimates.^{50,64–68,71,74,75} Despite the significant heterogeneity, individual results and pooled estimates of these studies suggested a decrease in birth weight with high levels of physical activity during pregnancy, compared with low levels. Considering only studies evaluating leisure time physical activity did not change these results (mean difference: -56.1 g, 95% confidence interval [CI]: -100.5 , -11.8 , $n = 13$ studies).

Table 1 Studies' characteristics

Characteristics	n (%)
Study design	
Cohort	50 (92.6)
Case-control	4 (7.4)
Year of publication	
Since 2010 (past 5 y)	21 (38.9)
Origin of the studies	
North America	29 (53.7)
Canada	3 (5.6)
Europe	14 (25.9)
Oceania	4 (7.4)
Asia	4 (7.4)
South America	3 (5.6)
Setting	
Community-based	32 (59.3)
Hospital-based	21 (38.9)
Military-based	1 (1.9)
Sample size	
< 100	12 (22.2)
100–< 1,000	25 (46.3)
1,000–10,000	12 (22.2)
≥ 10,000	5 (9.3)
Ethnicity	
Caucasians or mixed ethnicities	47 (87.0)
Other ^a	7 (13.0)
Physical activity exposure	
Leisure time physical activity	41 (75.9)
Total activity	19 (35.2)
Physical activity assessment^b	
Self-report	49 (90.7)
Objective measure	8 (14.8)
Time covered by physical activity assessment	
Whole pregnancy	15 (27.8)
First trimester	10 (18.5)
Second trimester	20 (37.0)
Third trimester	23 (42.6)
Each trimester separately	8 (14.8)
Variable/unspecified	3 (5.6)
Birth weight outcomes	
Birth weight	37 (68.5)
Body composition	2 (3.7)
SGA/LBW	27 (50.0)
LGA/HBW	13 (24.1)
Outcome provenance	
Medical charts or measured by study team	39 (72.2)
Maternal recall	6 (11.1)
Unspecified	9 (16.7)

Abbreviations: HBW, high birth weight; LBW, low birth weight; LGA, large for gestational age; SGA, small for gestational age.

^aTwo studies conducted in African Americans, two in Asians, two in West Asians, and one in Hispanic women.

^bThree studies used both objective and subjective methods.

Similarly, looking at the difference in infant's birth weight from the 17 studies^{34,37–40,45,50,53,55,57,65–67,71,73,79,80} comparing moderate levels of physical activity with low or no activity during pregnancy suggested that moderate levels increased birth weight (–Fig. 3). Considering only studies assessing leisure time physical activity, reported in 12 of the 15 pooled studies (2 studies reporting nonsignificant results could not be combined due to insufficient quantitative data),^{40,53} did not change these findings (mean difference: 74.2 g, 95% CI: 24.9, 123.5, $n = 12$ studies).

Birth Weight Results According to Leisure Time or Total Physical Activity

A total of 25 studies (67.6% of the 37 studies) investigated the association between leisure time physical activity and birth weight. Five found a significant decrease in birth weight with increasing activity,^{33,36,57,62,67} 3 found a significant increase in birth weight with increasing activity^{38,64,79} while the remaining 17 found no association.^{34,37,39,43,50,53,54,56,59,65,66,71,74,78,80–82} Total physical activity was evaluated in 13 studies (35.1%), with 3 studies finding a significant decreased birth weight with increasing activity,^{48,68,75} 1 study observing the contrary⁴⁴ and the other 9 studies finding no significant association.^{40,41,45,46,52,55,68,72,73}

Birth Weight Results According to Physical Activity Timing during Pregnancy

The majority of studies evaluating first trimester physical activity did not observe any significant association with birth weight,^{50,55,59,64,75} while one found a decreased birth weight within women doing a leisure time activity.⁶⁷ Similar results were observed for the second trimester; most studies found no significant association with birth weight.^{41,50,52,59,65,71,74,75} Two studies observed a decreased birth weight with increasing leisure time activity^{33,62} while two others found the opposite with either total⁴⁴ or leisure time activity.⁶⁴ Again, for the third trimester, most studies did not observe an association between maternal activity and birth weight.^{41,45,50,52,59,64,65,80,82} Two studies found a decreased birth weight with increasing total⁷⁵ or leisure time activity⁶² and one found an increased birth weight in neonates of exercising mothers.³⁸

Association between Maternal Physical Activity and Newborn's Body Composition

Several studies reported more than one birth weight outcome, but only two did report on the association between maternal physical activity and infant's body composition.^{36,75} Clapp and Capeless³⁶ compared a group of recreational athletes pursuing a heavy exercise regimen throughout pregnancy to a group of matched active women not involved in high-intensity training. Skinfold thickness, fat mass, and body fat percentage of the newborns were all significantly reduced in the heavy exercise group as compared with the comparison group, with a difference in fat mass of 220 g between groups. Similarly, Harrod et al⁷⁵ observed a significant decrease in neonatal fat mass with increased total physical activity during

Table 2 Description and results of the 54 included studies, by outcome

Study, y, country, and design	Sample size	PA assessment			Objective	Total PA	LTPA	Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	LTPA						
Studies assessing birth weight										
Bell et al 1995, ³³ Australia cohort	99	×	-	-	-	×	Sessions of vigorous exercise/wk at 25 wks	BW (crude vs. 0 session): 3 times/wk: 318 g (95% CI: 72, 564) 5-7 times/wk: -633 g (95% CI: -988, -278)	Infant sex, prepregnancy weight, GWG	
Both et al 2010, ⁵⁹ United Kingdom cohort	8,879	×	-	-	-	×	LTPA categories: Never, less than 1 h/wk, 2-6 h/wk, and ≥ 7 h/wk	LTPA not associated with BW (no estimate given)	Infant sex, marital status, education, prepregnancy BMI, smoking, drug and alcohol use, economic status, and more	
Botkin and Driscoll 1991, ³⁴ U.S. cohort ^a	44	×	-	-	-	×	≥ 3 sessions of ≥ 20 min/wk and for ≥ 20 wks of the pregnancy (yes/no)	BW: Exercise: 3,663.8 ± 318.4 g No exercise: 3,523.3 ± 351.0 g, <i>p</i> = ns	None	
Clapp and Dickstein 1984, ⁵⁷ U.S. cohort	228	×	-	-	-	×	Sedentary (group 1) vs. exercise before pregnancy but stopped < 28th wk (group 2) vs. maintained exercise (group 3)	BW: Group 1: 3,518 ± 43 g (SEM) Group 2: 3,577 ± 92 g Group 3 (n = 29): 3,009 ± 100 g Group 3 vs. 1 or 2: <i>p</i> < 0.01	None	
Clapp and Capeless 1990, ³⁶ U.S. cohort	132	-	×	-	-	×	≥ 3 sessions/wk of ≥ 30 min prepregnancy and continuation during pregnancy at ≥ 50% of preconception level vs. no high-intensity exercise regimen during pregnancy	BW: Exercise: 3,381 ± 322 g No exercise: 3,691 ± 348 g, <i>p</i> = 0.01	None, but exercise and control groups were matched for general health, fitness, education, income, age, parity, dietary intake, smoking, and more	
Dale et al 1982, ⁷⁸ U.S. cohort ^{ab}	44	×	-	-	-	×	Running during pregnancy (yes/no)	BW: Runners: • Retrospective sample: 7.5 lb • Prospective sample: 7.45 lb Controls (prospective): 7.60 lb	None	
Downs and Hausenblas 2007, ⁷⁹ U.S. cohort	59	×	-	-	-	×	MVPA ≥ 20 min, 3-5 times/wk (yes/no)	BW: Exercise: 126.75 ± 3.23 oz No exercise: 111.78 ± 7.12 oz	None	
Duncombe et al 2006, ³⁷ Australia cohort	148	×	×	-	-	×	Frequency of sustained exercise	BW: No exercise: 3,482.6 ± 538.2 g	None	

(Continued)

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Fleten et al 2010, ⁶² Norway cohort	43,705	×	-	-	×	Sum of frequencies per month of all exercise activities	<p>1-2 times/wk: 3,548.6 ± 558.0 g 3-4 times/wk: 3,528.2 ± 395.6 g ≥5 times/wk: 3,324.0 ± 526.1 g p for linear trend = 0.49</p> <p>BW: Overall: -2.1 g per unit increase in exercise, p < 0.03 Exercise before wk 17: -0.72 g, 95% CI: -1.33, -0.10 Exercise between wks 17-30: -1.40 g, 95% CI: -2.01, -0.78</p>	Maternal height, age, parity, cohabitant status, education, smoking, PA pre-pregnancy
Harrod et al 2014, ⁷⁵ U.S. cohort	826	×	-	×	×	Total energy expenditure in quartiles, or meeting or not guidelines (for sports/exercise; not significant for any outcome in any TM)	<p>BW: Early pregnancy: 1st quartile: 3,172.8 ± 37.0 g (SEM) 2nd quartile: 3,208.3 ± 35.9 g 3rd quartile: 3,175.6 ± 35.7 g 4th quartile: 3,220.4 ± 40.0 g p for trend = 0.49 Midpregnancy: 1st quartile: 3,212.7 ± 38.7 g 2nd quartile: 3,200.6 ± 39.5 g 3rd quartile: 3,206.3 ± 38.1 g 4th quartile: 3,178.4 ± 44.7 g p for trend = 0.58 Late pregnancy: 1st quartile: 3,239.9 ± 36.3 g 2nd quartile: 3,173.0 ± 36.1 g 3rd quartile: 3,212.4 ± 34.6 g 4th quartile: 3,142.9 ± 38.6 g p for trend = 0.10</p>	GA, infant sex, gravidity, maternal age, ethnicity, education, income, pre-pregnancy BMI, smoking
Hatch et al 1993, ⁶⁴ U.S. cohort	462	×	-	-	×	No exercise, low-moderate exercise (≤1,000 kcal/wk in LTPA), high-exercise volume (>1,000 kcal/wk; conditioned vs. unconditioned)	<p>BW (vs. no exercise): 1st TM: Low-moderate: β = 60 g (95% CI: -30, 151) High unconditioned: β = 94 g (95% CI: -79, 267) High conditioned: β = 28 g (95% CI: -111, 168) 2nd TM: Low-moderate: β = 97 g (95% CI: 10, 184)</p>	GA, prepregnancy weight, GWG, parity, nausea, income, history of LBW, smoking

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Hegaard et al 2010, ⁶⁵ Denmark cohort	4,558	×	-	-	×	Level of LTPA (light, moderate-heavy vs. sedentary) or hours of sports/wk	High unconditioned: $\beta = -104$ g (95% CI: -277, 69) High conditioned: $\beta = 144$ g (95% CI: -11, 298) 3rd TM: Low-moderate: $\beta = 86$ g (95% CI: -1, 174) High unconditioned: $\beta = 26$ g (95% CI: -158, 212) High conditioned: $\beta = 117$ g (95% CI: -69, 304) Exercise throughout pregnancy: Low-moderate: $\beta = 124$ g (95% CI: -6, 255) High: $\beta = 276$ g (95% CI: 54, 497)	Prepregnancy BMI, GA, education, parity, smoking
Horns et al 1996, ⁸⁰ U.S. cohort	101	×	-	-	×	Exercise ≥ 3 times/wk for ≥ 15 min (yes/no)	BW: Active: $3,496 \pm 486$ g Sedentary: $3,467 \pm 434$ g, $p = ns$	None
Koushkie Jahromi et al 2011, ³⁸ Iran cohort	132	×	-	-	×	Exercise ≥ 2 times/wk for ≥ 30 min (yes/no)	BW: Exercise: 3.23 ± 0.40 kg No exercise: 2.91 ± 0.36 kg, $p = 0.021$	None
Jarrett and Spellacy 1983, ⁸¹ U.S. cohort ^a	67	×	-	-	×	Running distance (in miles)	BW: Correlation with distance: $r = 0.089, p = ns$	None

(Continued)

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Johnson et al 1994, ³⁹ U.S. cohort	234	×	-	-	×	Exercise (yes/no, not defined)	BW (crude): Exercise: 3,296.0 ± 39.5 g (SEM) No exercise: 3,186.8 ± 51.6 g, p < 0.05 Adjusted results not significant (no estimate given)	Maternal anthropometry, smoking, drug use, infant sex
Juhl et al 2010, ⁶⁶ Denmark cohort	79,692	×	-	-	×	Hours of exercise/wk	BW (adjusted for GA only, vs. 0): > 0 ≤ 1h: 1 g (95% CI: -8, 10) > 1 ≤ 2 h: 5 g (95% CI: -6, 15) > 2 ≤ 3 h vs. 0: 0 g (95% CI: -14, 13) > 3 ≤ 4 h vs. 0: -8 g (95% CI: -26, 9) > 4 ≤ 5 h vs. 0: -6 g (95% CI: -27, 16) > 5 h vs. 0: -11 g (95% CI: -30, 7) p for trend = 0.1276	GA, infant sex, maternal age, parity, prepregnancy BMI, smoking, socio-occupational status
Jukic et al 2012, ⁶⁷ U.S. cohort	1,118	×	-	×	×	Recreational activity (none, nonvigorous, vigorous) or frequency of vigorous activity sessions/wk	BW (vs. no activity): Nonvigorous: -62 g (95% CI: -118, -5) ≥ 1 min/wk Vigorous: -57 g (95% CI: -124, 9) Frequency (vs. ≤ 1 time/wk) 2-3 times/wk: 82 g (95% CI: -104, 269) ≥ 4 times/wk: 40 g (95% CI: -154, 234)	Maternal age, height, BMI, ethnicity, education, drug/alcohol use, income, smoking, infant sex, parity, and more
Klebanoff et al 1990, ⁴⁰ U.S. cohort	7,100	×	-	×	×	h/d of light or heavy work/exercise	BW: Heavy work/exercise (h/d): 0 h: 3,210 g 1-3 h: 3,187 g ≥ 4 h: 3,261 g, p for trend = 0.289 Light work/exercise (h/d) 0 h: 3,182 g 1-3 h: 3,250 g 4-7 h: 3,217 g ≥ 8 h: 3,226 g, p for trend = 0.247	Ethnicity, age, education, parity, marital status, income, smoking, alcohol use, GA, employment, and more
Langhoff-Roos et al 1987, ⁴¹ Sweden cohort	56	-	×	×	-	Time spent doing physical activity	BW: At 17 wks: regression coefficient:	Maternal lean body mass and energy intake

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups			Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA					
Lobel et al 2008, ⁴³ U.S. cohort	279	×	-	-	×				1.27 ± 7.68 g (SEM) per PA unit; p = 0.87 At 33 wks: regression coefficient: 1.22 ± 6.53 g, p = 0.85 BW: Correlation with exercise: r = 0.03	None
Magann et al 1996, ⁴⁴ Australia cohort	750	×	-	×	-				BW (vs. group 3): Group 1 = - 73 g (p = 0.011) Group 2 = - 60 g (p = 0.017) Group 4 = - 23 g (p = 0.33) Group 5 = - 22 g (p = 0.515)	GA, infant sex, parity, GWG, ethnicity, prepregnancy weight, height, smoking, DM
Magann et al 2001, ⁶⁸ U.S. cohort	2,743	×	-	×	×				BW: Group 4 vs. 1: -86.5 ± 43.7 g (SEM), p = 0.048 Group 2 vs. 1: p = 0.068 (no estimate reported)	GA, smoking, infant sex, prepregnancy weight, height, parity
Mäkelä et al 2013, ⁵⁴ Finland cohort	163	×	-	-	×				BW: Quantitative results of regression analysis not given for PA (p = ns)	Maternal diet, prepregnancy BMI, GWG, glucose/insulin metabolism
Melzer et al 2010, ⁴⁵ Switzerland cohort	71	-	×	×	-				BW: Active: 3,448 ± 310 g Inactive: 3,518 ± 418 g p = 0.53	None
Montpetit et al 2012, ⁴⁶ Canada cohort	81	×	×	×	-				BW: Multiple regression estimate per 1,000 steps/d: 10.2 g, p = 0.733	Prepregnancy BMI, GWG, energy intake
Morgan et al 2014, ⁷³ United Kingdom cohort	240	-	×	×	-				BW (crude): Low activity: 3.4 ± 0.5 kg High activity: 3.5 ± 0.4 kg	Maternal age, parity, alcohol use, smoking, education, socioeconomic status
Mparmpakas et al 2013, ⁸² Greece cohort	113	×	-	-	×				BW: Physical activity did not predict birth weight (no estimate given)	None
Nieuwenhuijsen et al 2002, ⁷⁴ United Kingdom cohort	11,462	×	-	-	×				BW: ≤1 h vs. 0: 7.84 g (95% CI: -10.36, 26.05)	GA, parity, smoking, age, ethnicity, education, housing tenure, drugs/alcohol use

(Continued)

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Perkins et al 2007, ⁴⁸ U.S. cohort	51	×	×	×	-	Average metabolic equivalent unit value in quartiles Quartile 1: 4,007 ± 488 g Quartile 2: 3,757 ± 625 g Quartile 3: 3,595 ± 377 g Quartile 4: 3,399 ± 381 g A one-quartile change associated with average 203 g change in BW	None	
Portela et al 2014, ⁵⁵ Brazil cohort	56	×	-	×	-	Active or sedentary, based on total activity scoring	GA	
Rice and Fort 1991, ⁵⁶ U.S. cohort	23	×	-	-	×	Active (≥3 times/wk for ≥30 min) vs. sedentary	None	
Rose et al 1991, ⁷¹ U.S. cohort	21,342	×	-	-	×	Ratings of usual activity (light, moderate, vigorous)	Prepregnancy weight, height, age, infant sex, gravidity, and more	
Sternfeld et al 1995, ⁵⁰ U.S. cohort	388	×	-	-	×	Heavy exercise (aerobic exercise ≥3 times/wk for ≥60 min), low-moderate exercise (aerobic exercise ≥1 time/wk for <60 min), or no exercise	Infant sex, GA, parity, prepregnancy BMI	
Watson and McDonald 2007, ⁵² New Zealand cohort	195	×	-	×	-	Daily activity in METs	Maternal age, parity, height, smoking, BMI, energy intake, socioeconomic status, and more	

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups			Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA					
Wojtyla et al 2012, ⁷² Poland cohort ^a	2,588	×	-	×	-	Total activity in METs-h/wk	change results (no estimates given)	Activity levels in BW categories (in METs-h/wk): <2 kg: 211.38 ± 118.81 2-2.5 kg: 214.66 ± 160.44 2.5-3.5 kg: 209.48 ± 120.09 3.5-4 kg: 212.10 ± 118.45 >4 kg: 216.52 ± 125.07 p for ANOVA rank test = 0.798	None	
Zeanah and Schlosser 1993, ⁵³ U.S. cohort ^a	173	×	-	-	×	Exercise groups (high, moderate, and low intensity, or long, moderate, and short duration)	None	By intensity: High: 129.0 oz Moderate: 121.0 oz Low: 120.0 oz, p = 0.1421 By duration: Long: 124.1 oz Moderate: 120.6 oz Short: 123.5 oz, p = 0.5645	None	
Studies assessing LBW										
Bell et al 1995, ³³ Australia cohort	99	×	-	-	×	Sessions of vigorous exercise/wk at 25 wks	LBW: 0 session: n = 1 (2%) 3 sessions/wk: n = 0 5-7 sessions/wk: n = 5 (22%)	None	None	
Campbell and Mottola 2001, ²⁹ Canada case-control ^a	529	×	-	-	×	Frequency of structured (to improve fitness) or leisure (socially oriented) exercise	LBW (<15th percentile): Structured (vs. 3-4 times/wk) ≥5 times/wk: OR: 4.61 (95% CI: 1.73, 12.32) <3 times/wk: OR: 2.64 (95% CI: 1.40, 3.94) Leisure (vs. 3-4 times/wk): ≥5 times/wk: OR: 1.19 (95% CI: 0.71, 2.00) <3 times/wk: OR: 1.99 (95% CI: 0.95, 4.18)	None	None	
Cavalli and Tanaka 2000, ³⁵ Japan cohort ^a	1,704	×	-	-	×	LTPA and/or sports activities (yes/no)	LBW: OR: 1.05, 95% CI: 0.64, 1.73	Infant sex, GA, maternal age, height, smoking, prepregnancy weight, alcohol use, past PA, and more		

(Continued)

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment					Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA				
Currie et al 2014, ⁷⁶ Canada cohort	1,719	×	-	×	-	Physical activity scores in tertiles	LBW (vs tertile 1): Tertile 2: OR: 1.20 (95% CI: 0.51, 2.79) Tertile 3: OR: 0.88 (95% CI: 0.36, 2.18) p for trend = 0.76	Maternal age, education, prepregnancy BMI, parity, GA, and GWG	
Dumith et al 2012, ⁶⁰ Brazil cohort ^a	2,557	×	-	-	×	Physical exercises during pregnancy (yes/no)	LBW: OR: 0.84 (95% CI: 0.64, 1.09)	Maternal age, education, marital status, income, parity, and more	
Duncombe et al 2006, ³⁷ Australia cohort	148	×	×	-	×	Frequency of sustained exercise	LBW: No exercise: n = 1 (6%) 1-2 times/wk: n = 1 (2%) 3-4 times/wk: n = 0 ≥5 times/wk: n = 2 (7%)	None	
Dwarkanath et al 2007, ⁶¹ India cohort	546	×	-	×	-	Composite measure of daily physical activity in tertiles	LBW (lowest BW tertile): 1st TM (vs. tertile 1): Tertile 2: OR: 1.27 (95% CI: 0.81, 1.99) Tertile 3: OR: 1 (95% CI: 1.00, 2.44) 2nd TM: Tertile 2: OR: 1.66 (95% CI: 0.99, 2.80) Tertile 3: OR: 1.65 (95% CI: 0.96, 2.81) 3rd TM: Tertile 2: OR: 0.68 (95% CI: 0.39, 1.18) Tertile 3: OR: 1.29 (95% CI: 0.77, 2.18)	Maternal weight, energy intake, education	
Fleten et al 2010, ⁶² Norway cohort	43,705	×	-	-	×	Sum of frequencies per mo of all exercise activities	LBW: <1 time/wk: n = 109 (1%) 1-2 times/wk: n = 84 (1%) ≥3 times/wk: n = 99 (1%)	None for this outcome	
Hegaard et al 2010, ⁶⁵ Denmark cohort	4,558	×	-	-	×	Level of LTPA (light, moderate-heavy vs. sedentary) or h of sports/wk	LBW: 2nd TM Light: OR: 1.2 (95% CI: 0.7, 2.1) Moderate-heavy: OR: 1.7 (95% CI: 0.6, 4.7) 1-2 h/wk: OR: 0.7 (95% CI: 0.3, 1.5)	Prepregnancy BMI, GA, education, parity, smoking	

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups		Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA				
Leiferman et al 2003, ⁴² U.S. cohort ^a	9,089	×	-	-	×	Exercise ≥3 times/wk during pregnancy (exercise vs. no exercise) and before pregnancy (conditioned vs. unconditioned)	<p>≥3 h/wk: OR: 1.1 (95% CI: 0.4, 2.7) 3rd TM Light: OR: 1.2 (95% CI: 0.7, 2.0) Moderate-heavy: OR: 0.6 (95% CI: 0.1, 4.3) 1-2 h/wk: OR: 1.1 (95% CI: 0.5, 2.5) ≥3 h/wk: OR: 0.8 (95% CI: 0.3, 2.8)</p> <p>LBW (vs. conditioned exercise): Conditioned no exercise: OR: 1.28 (95% CI: 1.05, 1.56) Unconditioned exercise: OR: 0.85 (95% CI: 0.62, 1.17) Unconditioned no exercise: OR: 1.15 (95% CI: 0.99, 1.34) VLBW (vs. conditioned exercise): Conditioned no exercise: OR: 2.05 (95% CI: 1.69, 2.48) Unconditioned exercise: OR: 1.13 (95% CI: 0.85, 1.49) Unconditioned no exercise: OR: 1.75 (95% CI: 1.50, 2.04)</p>	Ethnicity, maternal age, marital status, education, income, smoking, BMI	
Lobel et al 2008, ⁴³ U.S. cohort	279	×	-	-	×	Exercise score on a 5-point scale (0 = never to 4 = very often)	<p>LBW: Correlation with exercise: $r = 0.1$ $p = ns$</p>	None	
Mahmoodi et al 2013, ³² Iran case-control ^a	750	×	-	×	×	Ratio of energy expenditure of physical activity and resting energy expenditure for various durations of activity or duration	<p>Exercise energy expenditure between cases (LBW, i.e., BW <2,500 g) and controls (BW ≥2,500 g): Cases: 3.30 ± 3.25 METs Controls: 2.90 ± 3.76 METs, $p = 0.79$ LBW: OR/1 h increase in exercise: 2.20 (95% CI: 1.28, 3.80)</p>	None	
Orr et al 2006, ⁶⁹ U.S. cohort	922	×	-	-	×	Exercise (yes/no)	<p>LBW (crude): Exercise: 12.7% No exercise: 11.2% OR: 1.15 (95% CI: 0.76, 1.76) Exercise not associated with risk</p>	Alcohol/drug use, bleeding, disease, previous poor pregnancy outcomes, smoking	

(Continued)

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Schramm et al 1996, ³⁰ U.S. case-control ^a	2,378	×	-	-	×	Exercise ≥3 times/wk (yes/no)	of LBW in adjusted models (no estimate given) OR of exercising ≥3 times/wk: VLBW mothers (vs. normal BW) 1st TM: OR: 0.70 (95% CI: 0.53, 0.92) 2nd TM: OR: 0.54 (95% CI: 0.40, 0.74) 3rd TM: OR: 0.33 (95% CI: 0.20, 0.53) LBW mothers (vs. normal BW) 1st TM: OR: 1.16 (95% CI: 0.91, 1.48) 2nd TM: OR: 1.07 (95% CI: 0.83, 1.39) 3rd TM: OR: 1.00 (95% CI: 0.76, 1.32)	Age, education, prepregnancy weight, smoking, ethnicity, and more
Takito et al 2010, ³¹ Brazil case-control ^a	819	×	-	-	×	Time per d in various activities	LBW: Light activities (vs. <210 min) 210–420 min/d: OR: 0.71 (95% CI: 0.47, 1.08) ≥420 min/d: OR: 0.61 (95% CI: 0.39, 0.94), p for trend = 0.026 Leisure walking (vs. none) <20 min/d: OR: 0.76 (95% CI: 0.50, 1.15) ≥20 min/d: OR: 0.7 (95% CI: 0.46, 1.08) p for trend = 0.072	Education, age, ethnicity, smoking, and more
Studies assessing SGA								
Alderman et al 1998, ⁵⁸ U.S. cohort ^a	291	×	-	×	-	Any MVPA for ≥ 2 h/wk in any mo during 2nd or 3rd TM (also assessed in 1st TM)	SGA: OR: 0.8 (95% CI: 0.3, 2.3)	Smoking, alcohol use
Clapp and Dickstein 1984, ⁵⁷ U.S. cohort	228	×	-	-	×	Sedentary (group 1) vs. exercise before pregnancy but stopped <28th wk (group 2) vs. maintained exercise (group 3)	SGA: Group 1: n = 5 (3%) Group 2: n = 5 (11%) Group 3: n = 11 (38%) Group 3 vs. 1 or 2: p < 0.0001	None
Gollenberg et al 2011, ⁶³ U.S. cohort	1,040	×	-	×	×	Domain-specific activity indices in quartiles	SGA (vs. 1st quartile): Sports/exercise, early pregnancy: 2nd quartile: RR: 1.02 (95% CI:	Maternal age, parity, prepregnancy BMI, smoking, education

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups (sports/exercise and total activity)	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Harrod et al 2014, ⁷⁵ U.S. cohort	826	×	-	×	×	<p>0.61, 1.73) 3rd quartile: RR: 0.86 (95% CI: 0.48, 1.54) 4th quartile: RR: 0.84 (95% CI: 0.49, 1.44) p for trend = 0.41</p> <p>Midpregnancy: 2nd quartile: RR: 2.88 (95% CI: 1.41, 5.90) 3rd quartile: RR: 1.53 (95% CI: 0.73, 3.20) 4th quartile: RR: 2.14 (95% CI: 1.04, 4.39) p for trend = 0.33</p> <p>Total activity, early pregnancy: 2nd quartile: RR: 1.16 (95% CI: 0.69, 1.95) 3rd quartile: RR: 0.63 (95% CI: 0.63, 1.15) 4th quartile: RR: 1.02 (95% CI: 0.58, 1.79) p for trend = 0.88</p> <p>Midpregnancy: 2nd quartile: RR: 0.94 (95% CI: 0.54, 1.63) 3rd quartile: RR: 0.48 (95% CI: 0.26, 0.88) 4th quartile: RR: 0.42 (95% CI: 0.21, 0.82) p for trend = 0.003</p>	GA, infant sex, gravidity, maternal age, ethnicity, education, income, pre-pregnancy BMI, smoking	
Juhl et al 2010, ⁶⁶ Denmark cohort	79,692	×	-	-	×	<p>Total energy expenditure in quartiles, or meeting or not guidelines (for sports/exercise; not significant for any outcome in any TM)</p> <p>Hours of exercise/wk</p>	<p>SCA (vs. 1st quartile): Not significant in early and mid-pregnancy Late pregnancy 2nd quartile: OR: 2.2 (95% CI: 1.1, 4.3) 3rd quartile: OR: 1.8 (95% CI: 0.9, 3.5) 4th quartile: OR: 3.0 (95% CI: 1.4, 6.7) p for trend = 0.07</p> <p>SCA: Exercise vs. no exercise: HR: 0.88</p>	GA, infant sex, maternal age, parity.

(Continued)

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Magann et al 1996, ⁴⁴ Australia cohort	750	×	-	×	-	Group 1: ≤2,300 kcal/d; group 2: 2,301–2,500 kcal/d; group 3: 2,501–2,700 kcal/d; group 4: 2,701–2,900 kcal/d; group 5: >2,900 kcal/d	(95% CI: 0.83, 0.93) h/wk (vs. 0): ≤1 h: HR: 0.87 (95% CI: 0.81, 0.93) 1–2 h: HR: 0.83 (95% CI: 0.76, 0.91) 2–3 h: HR: 1.00 (95% CI: 0.89, 1.14) 3–5 h: HR: 0.83 (95% CI: 0.72, 0.95) >5 h: HR: 1.04 (95% CI: 0.87, 1.23) p for trend = 0.1168	prepregnancy BMI, smoking, socio-occupational status
Magann et al 2001, ⁶⁸ U.S. cohort	2,743	×	-	×	×	Exercise groups (1 = no exercise, 2 = light exercise, 3 = moderate exercise, and 4 = heavy exercise)	SGA: G1: n = 23 (11%) G2: n = 26 (12%) G3: n = 13 (18%) G4: n = 37 (16%)	None
Morgan et al 2014, ⁷³ United Kingdom cohort	240	-	×	×	-	Low vs. high-activity (cutoff at the 50th of total accelerometry counts)	SGA (crude): Low activity: n = 2 (1%) High activity: n = 0 No adjusted estimates (p = ns)	Maternal age, parity, alcohol use, smoking, education, socioeconomic status
Mudd et al 2012, ⁴⁷ U.S. cohort ^a	1,014	×	-	-	×	Inactive (0 min/wk), insufficiently active or active (≥150 min/wk of MVPA)	SGA (vs. inactive): Nonsubcohort: Active: OR: 0.20 (95% CI: 0.04, 1.08) Insufficiently active: OR: 1.80 (95% CI: 0.61, 5.31) Subcohort: Active: OR: 1.10 (95% CI: 0.59, 2.06) Insufficiently active: OR: 0.84 (95% CI: 0.38, 1.83)	Prepregnancy BMI, height, parity, recall length, GWG, smoking, education, ethnicity, age

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Portela et al 2014, ⁵⁵ Brazil cohort	56	×	-	×	-	Active or sedentary, based on total activity scoring	SCA (crude): Active women: 13.5% Sedentary women: 0%	None
Studies assessing HBW								
Currie et al 2014, ⁷⁶ Canada cohort	1,719	×	-	×	-	Physical activity scores in tertiles	HBW (vs. tertile 1): Tertile 2: OR: 0.74 (95% CI: 0.54, 1.02) Tertile 3: OR: 0.61 (95% CI: 0.43, 0.85) p for trend = 0.005	Maternal age, education, prepregnancy BMI, parity, GA, and GWC
Fleten et al 2010, ⁶² Norway cohort	43,705	×	-	-	×	Sum of frequencies per mo of all exercise activities	HBW: <1 time/wk: n = 3,983 (26%) 1-2 times/wk: n = 3,911 (25%) ≥3 times/wk: n = 2,922 (22%)	None for this outcome
Hegaard et al 2010, ⁶⁵ Denmark cohort	4,558	×	-	-	×	Level of LTPA (light, moderate-heavy vs. sedentary) or h of sports/wk	HBW: 2nd TM: Light: OR: 1.0 (95% CI: 0.7, 1.4) Moderate-heavy: OR: 0.7 (95% CI: 0.3, 1.5) 1-2 h/wk: OR: 0.73 (95% CI: 0.46, 1.22) ≥3 h/wk: OR: 0.85 (95% CI: 0.4, 1.6) 3rd TM: Light: OR: 1.1 (95% CI: 0.8, 1.6) Moderate-heavy: OR: 1.1 (95% CI: 0.4, 2.8) 1-2 h/wk: OR: 0.7 (95% CI: 0.4, 1.3) ≥3 h/wk: OR: 1.5 (95% CI: 0.8, 2.9)	Prepregnancy BMI, GA, education, parity, smoking
Reid et al 2014, ⁷⁷ Ireland cohort	100	-	×	×	-	Energy expenditure	Intensity of free living PA: If predicted to deliver macroscopic infant: 1.2 ± 0.2 METs If predicted to deliver normal weight infant: 1.3 ± 0.2 METs Difference = 0.1 METs (95% CI: 0.19, 0.01) Exploratory analyses (according to actual birth weight): Average METs and time spent at	GA, parity, maternal age, education, smoking, infant sex

(Continued)

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Voldner et al 2008, ⁵¹ Norway cohort	533	×	-	-	×	h of physical activity per wk	MVPA differed significantly between women who delivered macrosomic infants and women who delivered appropriate for GA infants ($p = 0.027$ and 0.034) HBW ($\geq 4,200$ g): < 1 h/wk vs. ≥ 1 h/wk 1st TM: OR: 1.6 (95% CI: 0.9, 3.0) 2nd TM: OR: 1.3 (95% CI: 0.7, 2.4) 3rd TM: OR: 1.2 (95% CI: 0.6, 2.3)	None
Studies assessing LGA								
Alderman et al 1998, ⁵⁸ U.S. cohort ^a	291	×	-	×	-	Any MVPA for ≥ 2 h/wk in any mo during 2nd or 3rd TM (also assessed in 1st TM)	LGA: OR: 0.3 (95% CI: 0.2, 0.7)	Smoking, alcohol use
Clapp and Dickstein 1984, ⁵⁷ U.S. cohort	228	×	-	-	×	Sedentary (group 1) vs. exercise before pregnancy but stopped < 28 th wk (group 2) vs. maintained exercise (group 3)	LGA: Group 1: $n = 17$ (11%) Group 2: $n = 8$ (17%) Group 3: $n = 0$	None
Juhl et al 2010, ⁶⁶ Denmark cohort	79,692	×	-	-	×	h of exercise/wk	LGA: Exercise vs. no exercise: HR: 0.93 (95% CI: 0.88, 0.98) ≤ 1 h: HR 0.98 (95% CI: 0.92, 1.05) 1-2 h: HR 0.90 (95% CI: 0.82, 0.98) 2-3 h: HR 0.85 (95% CI: 0.74, 0.98) 3-5 h: HR 0.89 (95% CI: 0.77, 1.04) > 5 h: HR 0.72 (95% CI: 0.57, 0.91) p for trend = 0.0037	GA, infant sex, maternal age, parity, prepregnancy BMI, smoking, socio-occupational status
Morgan et al 2014, ⁷³ United kingdom cohort	240	-	×	×	-	Low vs. high activity (cutoff at the 50th of total accelerometry counts)	LGA (crude): Low activity: $n = 19$ (13%) High activity: $n = 20$ (16%) OR (high vs. low activity): 1.24 (95% CI: 0.63, 2.44) No adjusted estimates ($p = ns$)	Maternal age, parity, alcohol use, smoking, education, socioeconomic status

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Mudd et al 2012, ⁴⁷ U.S. cohort ^a	1,014	×	-	-	×	Inactive (0 min/wk), insufficiently active or active (≥ 150 minute/wk of MVPA)	LGA (vs. inactive): Nonsubcohort: Active: OR: 0.30 (95% CI: 0.14, 0.64) Insufficiently active: OR: 1.03 (95% CI: 0.59, 1.90) Subcohort (women at risk of preterm birth): Active: OR: 0.68 (95% CI: 0.34, 1.34) Insufficiently active: OR: 1.08 (95% CI: 0.57, 2.04)	Prepregnancy BMI, height, parity, recall length, GWG, smoking, education, ethnicity, age
Owe et al 2009, ⁷⁰ Norway cohort	36,869	×	-	-	×	Exercise frequency	LGA (vs. none): At 17 wks, nulliparous: 1-3 times/mo: OR: 0.93 (95% CI: 0.74, 1.18) 1-2 times/wk: OR: 0.91 (95% CI: 0.73, 1.14) ≥ 3 times/wk: OR: 0.72 (95% CI: 0.56, 0.93) <i>p</i> for trend = 0.008 Multiparous: 1-3 times/mo: OR: 1.05 (95% CI: 0.91, 1.22) 1-2 times/wk: OR: 0.95 (95% CI: 0.83, 1.10) ≥ 3 times/wk: OR: 0.90 (95% CI: 0.76, 1.07) At 30 wk, nulliparous: 1-3 times/mo: OR: 1.04 (95% CI: 0.86, 1.27) 1-2 times/wk: OR: 0.90 (95% CI: 0.75, 1.09) ≥ 3 times/wk: OR: 0.77 (95% CI: 0.61, 0.96) Multiparous: 1-3 times/mo: OR: 1.02 (95% CI: 0.90, 1.15) 1-2 times/wk: OR: 1.00 (95% CI: 0.89, 1.13) ≥ 3 times/wk: OR: 0.96 (95% CI: 0.83, 1.12)	Maternal age, education, prepregnancy BMI, smoking, prepregnancy exercise, GWG energy intake, diabetes/GDM, preeclampsia
Portela et al 2014, ⁵⁵ Brazil cohort	56	×	-	×	-	Active or sedentary, based on total activity scoring	LGA (crude): None in both groups	None for this outcome

(Continued)

Table 2 (Continued)

Study, y, country, and design	Sample size	PA assessment				Definition PA groups	Main results	Adjustment variables
		Self-reported	Objective	Total PA	LTPA			
Snapp 2008, ⁴⁹ USA Cohort ^a	75,160	×	-	-	×	Exercise ≥3 times/wk for ≥30 minute, for ≥6 months of pregnancy (yes/no)	LGA: Exercise: 0.73% (95% CI 0.10, 5.18) No exercise: 9.46% (4.41, 19.12) p = 0.0017 RR (no exercise): 12.9 (10.9, 15.2)	None
Studies assessing body composition								
Clapp and Capeless 1990, ³⁶ U.S. cohort	132	-	×	-	×	≥3 sessions/wk of ≥30 min prepregnancy and continuation during pregnancy at ≥50% of preconception level vs. no high-intensity exercise regimen during pregnancy	Calculated body fat: Exercise: 11.2 ± 3.1% No exercise: 16.2 ± 4.9%, p = 0.01 Calculated fat mass: Exercise: 382 ± 136 g No exercise: 603 ± 231 g, p = 0.01	None, but exercise and control groups were matched for general health, fitness, education, income, age, parity, contraceptive use, pre-gravid weight, job type, dietary intake, sleep-activity cycles, smoking, and alcohol intake
Harrod et al 2014, ⁷⁵ U.S. cohort	826	×	-	×	×	Total energy expenditure in quartiles, or meeting or not guidelines (for sports/exercise; not significant for any outcome in any TM)	Fat mass: Not significant in early and mid-pregnancy Late pregnancy: 1st quartile: 290.5 ± 14.2 g 2nd quartile: 277.4 ± 14.2 g 3rd quartile: 277.5 ± 13.5 g 4th quartile: 249.4 ± 15.1 g p for trend = 0.04	GA, infant sex, gravidity, maternal age, ethnicity, education, income, pre-pregnancy BMI, smoking

Abbreviations: ANOVA, analysis of variance; BMI, body mass index; BP, blood pressure; BW, birthweight; CI, confidence interval; DM, diabetes mellitus; GA, gestational age at delivery; GDM, gestational diabetes; GWG, gestational weight gain; HBW, high birth weight; HR, heart rate; LBW, low birth weight; LGA, large for gestational age; LTPA, leisure time physical activity; MVPA, moderate and vigorous physical activity; ns, nonsignificant; OR, odds ratio; PA, physical activity; P-P, postpartum; PTB, preterm birth; RR, relative risk; SGA, small for gestational age; TM, trimester; VLBW, very low birth weight.

^aRetrospective design.
^bA case-control design was also employed in this study.

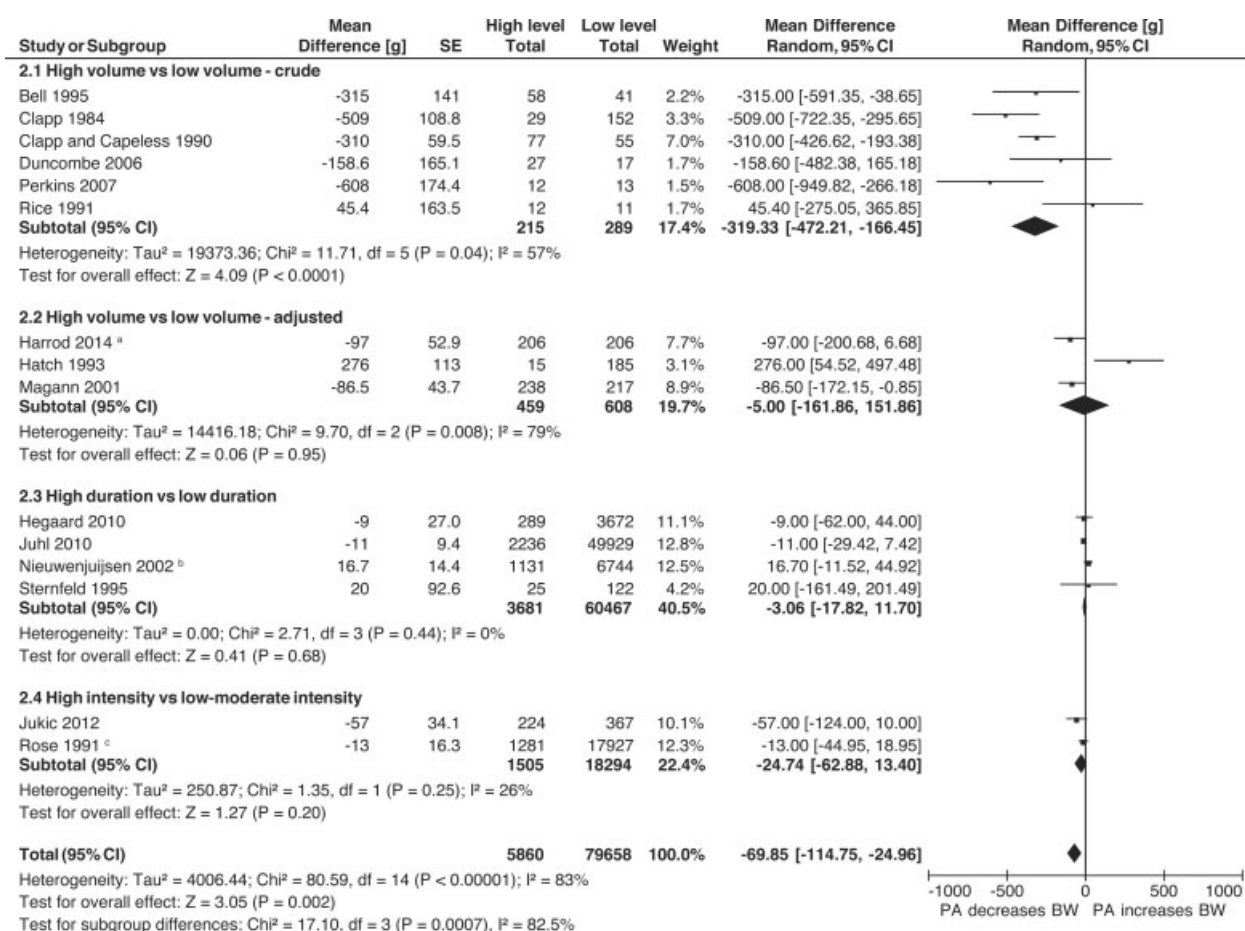


Fig. 2 Association between maternal physical activity during pregnancy and infant's birth weight—high levels of physical activity. (2.1) Results from studies providing crude results only, based on activity volume. (2.2) Results from studies providing adjusted results, based on activity volume. (2.3) Results from studies based on duration. (2.4) Results from studies based on intensity. ^aSignificant difference between groups (nonsignificant here due to estimated equal sample size per quartile). ^bThis study reported only time spent swimming. ^cThis study compared high-intensity exercise with moderate-intensity exercise. BW, birth weight; PA, physical activity.

the third trimester (p for linear trend = 0.04). A significant 41.1 g difference between neonates of women in the highest versus the lowest quartile of total activity was observed after adjustment for various confounders. However, early and midpregnancy physical activity had no significant effect on body composition, nor did meeting exercise recommendations in either trimester.

Association between Maternal Physical Activity and Risk of Low-Birth-Weight and Small for Gestational Age Neonates

The association between physical activity and LBW was explored in 17 (31.5%) of the 54 included studies,^{29–33,35,37,40,42,43,60–62,65,69,71,76} including all 4 case-control studies.^{29–32} Adjusted results were presented in 11 of the studies (64.7%),^{29–32,35,40,42,60,61,65,76} and all but two^{61,76} reported leisure time activity. Eleven of the 13 cohort studies (84.6%) did not find an association between maternal activity and risk of LBW,^{33,35,37,40,43,60,62,65,69,71,76} while 1 found an increased risk of LBW⁶¹ with increasing total activity, and another 1 found a decreased risk of LBW and very LBW⁴² with regular maternal exercise. As for the case-control

studies, two suggested an increased risk of LBW with higher levels of maternal exercise,^{29,32} although one of them also found that low levels of exercise increased the risk of LBW, compared with moderate levels.²⁹ The other case-control studies found a decreased risk of LBW with increasing maternal leisure activity.^{30,31}

The association between maternal activity and SGA risk was reported in 10 studies (18.5% of all studies),^{44,47,55,57,58,63,66,68,73,75} Six of them reported total physical activity^{44,55,58,63,73,75} and six adjusted for potential confounders.^{47,58,63,66,73,75} Overall, most studies (60%) did not find a significant association between maternal activity and SGA risk.^{44,47,55,58,68,73} However, two studies found an increased risk of SGA with the highest level of either total⁷⁵ or exercise activity⁵⁷ compared with the lowest level, and one study found a decreased risk in women doing exercise compared with those not doing so in the second half of pregnancy.⁶⁶ Finally, one study found that a higher level of total activity in midpregnancy was associated with a decreased risk of SGA, while a higher level of sports and exercise during the same period was associated with an increased risk of SGA.⁶³

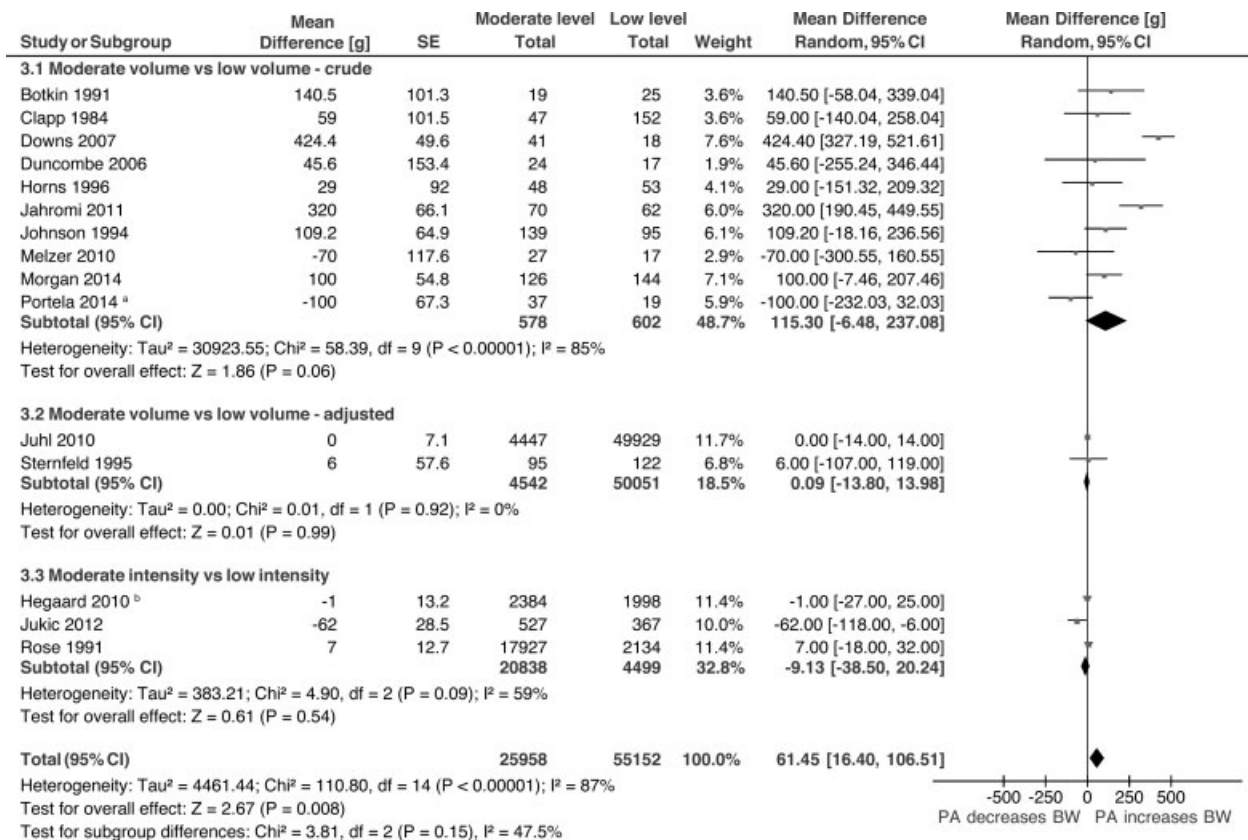


Fig. 3 Association between maternal physical activity during pregnancy and infant's birth weight—moderate levels of physical activity. (3.1) Results from studies providing crude results only, based on activity volume. (3.2) Results from studies providing adjusted results, based on activity volume. (3.3) Results from studies based on intensity. ^aThis study mentioned nonsignificant adjusted results without providing estimates. ^bThis study compared light intensity activity with no activity. BW, birth weight; PA, physical activity.

Association between Maternal Physical Activity and Risk of High-Birth-Weight and Large for Gestational Age Neonates

A total of five studies (9.3%) reported on HBW,^{51,62,65,76,77} with three of them reporting leisure time activity.^{51,62,65} Three studies found a decreased risk of HBW with increasing total^{76,77} or leisure activity,⁶² the remainder finding no association.^{51,65} From the eight studies reporting on LGA (14.8%),^{47,49,55,57,58,66,70,73} five reported leisure time physical activity.^{47,49,57,66,70} Four of these studies found a reduced risk of LGA with increasing leisure time activity,^{47,49,66,70} and the fifth one suggested a similar trend (no LGA in the most active group vs. 11 and 17% of LGA in the other groups).⁵⁷ However, two of these studies showed significant results only in a subsample of women (e.g., nulliparous women⁷⁰ or low-risk women⁴⁷). One of the three studies reporting total activity found a decreased risk of LGA with increasing activity,⁵⁸ while the other two found no significant association with risk of LGA.^{55,73}

Discussion

The present systematic review identified 54 observational studies evaluating the association between maternal physical activity during pregnancy and birth weight, the risk of LBW or HBW, risk of SGA or LGA, or body composition. Despite the

substantial heterogeneity, results from these studies suggest that moderate levels of physical activity during pregnancy are associated with an increased birth weight, as compared with lower levels. On the contrary, high levels of physical activity were associated with a decreased birth weight. These associations remained when leisure time physical activity alone was considered. Despite the fact that only a few studies evaluated physical activity using objective methods, results from these studies suggested similar conclusions.

Consistent with the decrease in birth weight observed with high physical activity levels, the two studies evaluating neonatal body composition found that high levels of activity were associated with a decreased infant fat mass. Reduced neonatal fat mass was previously found in an RCT comparing women pursuing either a moderate or high volume exercise regimen from the 8th week to end of pregnancy, compared with women pursuing a low volume exercise regimen.¹⁹ The same authors found no difference in neonatal fat mass or percentage in previously inactive women randomized to either a low volume exercise regimen or no exercise throughout pregnancy,¹⁸ which is also consistent with the findings of the present review. These observations could either imply that the association between maternal activity and birth weight follows an inverted U-shaped curve, or that a certain amount of exercise is needed before birth weight is reduced. Some observational studies are more suggestive of a dose–

response relationship; Harrod et al⁷⁵ showed that the association between total physical activity in late pregnancy and neonatal fat mass followed a linear trend. Another large cohort study ($n = 43,705$) found that each additional monthly exercise session was associated with a significant 2.1 g decrease in infant birth weight.⁶²

Overall, despite substantial heterogeneity between studies, maternal physical activity does not seem to negatively influence the risk of birth weight extremes. Indeed, the present review highlighted that most studies evaluating HBW and LGA risk found a protective effect with increasing maternal activity, which is in line with the decreased neonatal fat mass or body weight observed in numerous studies. The association between maternal activity and risk of LBW and SGA was less clear, although available studies are reassuring. Globally, results from observational studies are confirmed by a recent meta-analysis evaluating the effects of 28 physical activity interventions during pregnancy. This meta-analysis found a significant reduction in birth weight ($n = 5,214$) and a reduction in the risk of delivering a macrosomic infant (19 studies, $n = 3,982$) without an increased risk of LBW/SGA (11 studies, $n = 2,183$), with exercise interventions.¹⁵ However, the impact of exercise dose was not examined in this meta-analysis.

Physical activity is thought to modulate fetal growth through oxygen and nutrient availability and delivery to the fetus.⁸³ Indeed, glucose availability is reduced during exercise due to an increased uptake by active muscles,⁸³ and uteroplacental blood flow also appears to be decreased with exercise.^{84,85} It has been hypothesized that in response to this intermittent reduction in oxygen and nutrient delivery during exercise, which seems modulated by exercise intensity and/or volume,^{84–86} blood flow is then enhanced at rest.⁸³ Consistent with our thorough review, Clapp previously reported the results of a few studies suggesting that a low-to-moderate volume of exercise throughout pregnancy was associated with an increased birth weight while a high-intensity, high-volume exercise regimen throughout pregnancy was associated with a decreased birth weight, with various effects in between.⁸³ Accordingly, it appears that below a certain threshold, the reduced nutrient availability induced by exercise is compensated and results in enhanced fetal growth, while above this threshold nutrient availability cannot be completely compensated, leading to reduced birth weight. Of course, glucose availability and delivery to the fetus is also influenced by other factors, including maternal nutrition, health condition, and fitness,^{83,87} thus it is possible that the effects of exercise on fetal growth are seldom counterbalanced by other maternal behaviors and conditions. Thus, this suggested inverted u-shape relationship between physical activity and birth weight, which can be modulated by factors such as maternal diet, could explain the discrepancy observed in RCTs' results.

Previous meta-analyses of RCTs also showed a small reduction in infant's birth weight with physical activity interventions, but were unable to distinguish the effects of various volumes or intensity of physical activity.^{15,16} Although it was not possible to combine the results in a

quantitative estimate for all outcomes and comparisons, we still attempted to determine the influence of physical activity volume on birth weight. Despite significant statistical heterogeneity, our prudent classification of studies provided new insights on the association between maternal physical activity and birth weight. However, whether our classification was adequate to truly discriminate moderate level from high level of physical activity remains debatable, as we mostly relied on the studies' own classification of physical activity levels. For instance, although some studies stated having evaluated vigorous intensity activity, their definition of vigorous intensity did not necessarily comply with accepted definitions ($\geq 60\%$ aerobic capacity reserve)⁸⁸ or was somewhat imprecise. This implies that the measure of physical activity in these studies likely included both moderate and vigorous intensity activity. Thus, adequately defining intensity will be of prime importance in future studies, to accurately evaluate the impact of various physical activity intensities on pregnancy outcomes.

Limitations

This systematic review included observational studies evaluating the association between maternal physical activity and birth weight outcomes; therefore, the associations observed may not constitute causal relationships. Results must also be interpreted with caution due to the high heterogeneity found between study results, methodology, and quality, which on one hand limited the possibility to pool some studies in the meta-analysis, leading to a potential selection bias, and on the other hand might also have decreased the strength of the associations found in the present review. It should also be acknowledged that study results were included in the analyses, even when adjustment for confounders was lacking. Indeed, more than one-third of the studies included in the present review did not adjust for covariates known or thought to influence physical activity and fetal growth. Finally, publication bias cannot be ruled out, as some studies with null results might not have been published. Although a publication bias would imply that the associations observed in the present review overestimate the real association between maternal physical activity and birth weight, and despite the aforementioned limitations, we believe that it is unlikely that our finding of a different association between maternal physical activity and birth weight depending on physical activity volume would be discredited. Nevertheless, further confirmation of this volume-dependent association is needed.

Recommendations for Future Research

The present review highlighted that observational studies can help us gain a better insight of the mechanisms explaining the association between maternal activity and birth weight outcomes. However, to further clarify the association between maternal physical activity and birth weight, some issues need to be addressed first. For instance, a precise and meticulous measure of maternal physical activity, including all physical activity parameters, will be needed to identify the potential thresholds where physical activity can be expected to

influence birth weight differently. As previously proposed, since physical activity might exert only a modest effect on birth weight outcomes, accurate methods to measure physical activity are needed to avoid missing this effect because of measurement error.⁸⁹ Accordingly, studies using objective measurement methods such as accelerometry, which are thought to provide more precise and accurate estimates of physical activity, free of recall, and self-report bias, are needed as only five studies using accelerometry were available for inclusion in the present review. However, efforts should also be made in harmonizing accelerometry data processing in pregnancy studies to allow a better reliability of physical activity estimates and comparability between studies, since no cut point has been developed specifically for pregnancy and no consensus has been made regarding data processing, leading to great methodological variability regarding accelerometry data in pregnancy studies.^{73,77,90,91}

Also, although the decreased birth weight observed with increasing physical activity in the present review and in previous meta-analyses of RCTs might be beneficial for the child's health, it is possible that this effect could become detrimental above a certain level of physical activity, leading to an increased risk of SGA or other adverse outcomes. Obviously, the identification of this potential threshold will not be possible through RCTs for ethical reasons. The same situation applies regarding the effects of vigorous intensity activity on pregnancy outcomes, or the effects of physical activity in high-risk populations, emphasizing the need for additional high-quality observational studies. Similarly, to improve our understanding of the impact of physical activity performed during the first trimester, which remains limited due to the difficulty in initiating a physical activity intervention before the end of this trimester, observational studies appear as an important alternative, complementing knowledge acquired through RCTs. To further precise the association between physical activity and fetal growth, future research should also focus on outcomes such as neonatal body composition and mechanistic pathways while considering important confounders.

Refining physical activity guidelines for pregnant women to optimize fetal growth will only be possible when the aforementioned issues and others will be adequately answered. In light of available evidence, we believe that this can only be achieved through high-quality observational studies and RCTs.

Conclusion

Based on observational studies, maternal physical activity during pregnancy does not seem to negatively influence birth weight or risk of birth weight extremes in healthy, low-risk pregnant women. The association between maternal physical activity levels and infant's birth weight suggests an inverted U-shaped curve, where moderate levels seem associated with an increased birth weight while high levels of physical activity seem associated with a decreased birth weight. Maternal physical activity also appears to be associated with a reduced neonatal fat mass, but the small number of

studies evaluating neonatal body composition precludes definitive conclusions. Future studies should focus on precisely defining and measuring physical activity in each trimester to determine the volume, type, and intensity of physical activity needed to influence the neonate's body size and composition and to allow better study comparability. Underrepresented groups of pregnant women, such as women with high-risk pregnancy, should also be studied. As the intrauterine environment might have a long term influence on the child's health, it is crucial to evaluate the effects of various levels and patterns of physical activity during pregnancy to identify the optimal physical activity prescription. A careful monitoring of physical activity type, frequency, intensity, and duration in each trimester of pregnancy and of its effects on pregnancy outcomes in various populations will definitely contribute to this important objective.

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Note

Protocol Registration Prospero, available at: <http://www.crd.york.ac.uk/PROSPERO/>, CRD42013004968.

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