

Leisure-Time Physical Activity in Pregnancy and Maternal-Child Health: A Systematic Review and Meta-Analysis of Randomized Controlled Trials and Cohort Studies

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Abstract

Background Evidence suggests that leisure-time physical activity (LTPA) during pregnancy is associated with a reduced risk of preeclampsia, gestational diabetes mellitus (GDM), and preterm birth. However, these results are inconsistent when comparing cohort studies and randomized controlled trials (RCTs).

Objective The purpose of our study was to compare the associations between LTPA in pregnancy and maternal (GDM, preeclampsia, and weight gain during pregnancy) and child health outcomes (preterm birth, birthweight, and fetal growth) between RCTs and cohort studies.

Methods We performed a systematic search in PubMed, Web of Science, and EBSCO up to 31 August 2015. Inclusion criteria for experimental studies required randomized trials with a control group and exposure to a physical activity structured program. The inclusion criteria for cohort studies required information on LTPA during pregnancy as an exposure and at least one maternal–child health outcome. We assessed the methodological quality of all studies and performed a meta-analysis to produce summary estimates of the effects using random models.

Results We included 30 RCTs and 51 cohort studies. The meta-analysis of RCTs indicated that participation in LTPA was associated with lower weight gain during

pregnancy, lower likelihood of GDM, and lower likelihood of delivering a large-for-gestational-age infant. Cohort studies indicated that participation in LTPA was associated with lower weight gain during pregnancy, lower likelihood of GDM, and lower risk of preterm delivery.

Conclusions Our findings support the promotion of LTPA in pregnancy as a strategy to improve maternal and child health.

Key Points

The aim of this systematic review and meta-analysis was to compare the associations between leisure-time physical activity (LTPA) in pregnancy on maternal and child health outcomes between randomized controlled trials and cohort studies.

Our analysis revealed that women who were active during pregnancy were less likely to have excessive weight gain, to have gestational diabetes mellitus, and to deliver a preterm infant or a baby large for gestational age.

The findings presented in our study provide additional evidence of the positive effects of LTPA during pregnancy and support the promotion of LTPA in pregnancy as a strategy to improve maternal and child health.

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1 Introduction

Pregnancy is a period characterized by intense physical changes, in which morphological adaptations occur to create an ideal environment for the development of the

fetus; such rapid changes produce short- and long-term impacts on health [1]. In addition, the gestational period is an opportunity to promote positive health behaviors, considering that women are concerned with the child's well-being. In this context, the health effects of physical activity during pregnancy have been extensively investigated in the literature. The current evidence suggests potential benefits of leisure-time physical activity (LTPA) during pregnancy on maternal and child health [2–5].

Studies have reported that physical activity performed during pregnancy is related to a lower incidence of gestational diabetes mellitus (GDM) [3], preeclampsia [6], and excessive weight gain [2]. In addition, a decreased incidence of preterm birth [7] and obesity in adult life have been linked to maternal physical activity in pregnancy [8]. The prevention of these complications during pregnancy becomes necessary as the development of diabetes and gestational hypertensive disorders, as well as fetal growth restriction and premature birth, are associated with increased risk of cardiovascular disease and mortality in adulthood [9].

Despite substantial advances in the scientific knowledge and evolution of the guidelines to promote physical activity in pregnancy [10], most pregnant women do not reach the current recommendations of at least 150 min of moderate-intensity aerobic exercise per week and continue to be inactive before and after pregnancy [11, 12]. Furthermore, physical activity levels tend to decline during pregnancy [13, 14]. Previous studies from different countries have shown low levels of physical activity during pregnancy, especially in the third trimester [13–16]. Data from Norway showed that the proportion of women who performed regular exercise before pregnancy was 46.4 %, with sharp declines to 28 and 20 % at the 17th and 30th weeks of gestation, respectively [15]. Other studies conducted in the USA [17] and Denmark [16] showed a similar reduction in physical activity with advancing pregnancy, while one study in South Brazil showed that only 4 % of mothers were active in leisure time during the entire pregnancy [13].

Recent systematic reviews have summarized the associations of physical activity during pregnancy with specific maternal and child health outcomes [3–6]. Some reviews focused on experimental studies only [2, 4, 18], whereas others evaluated observational studies [3, 6, 7]. A series of methodological differences mean observational and experimental designs can lead to different findings. For example, whereas the results of previous meta-analyses of cohort studies showed positive associations between LTPA and maternal–child health [3, 6], most RCTs reported no associations [18–20]. An exploration of the different findings of cohort and experimental studies is a key literature gap.

The aim of our systematic review was to compare the associations between LTPA in pregnancy and three

maternal (GDM, preeclampsia, and weight gain during pregnancy) and three child (preterm birth, birthweight, and fetal growth) health outcomes between randomized controlled trials (RCTs) and cohort studies.

2 Methods

This systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [21] and the Cochrane Handbook for Systematic Reviews of Interventions [22].

2.1 Search Strategy

We searched PubMed, Web of Science, and EBSCO up to 31 August 2015 for eligible studies. The following search terms were used in all databases: (physical activity OR exercise OR sports OR motor activity OR leisure time physical activity OR recreational activities OR fitness OR walking) AND (pregnancy OR pregnant woman OR gestation). The terms were entered individually and combined on the advanced search field on each database. We searched the reference lists of included studies and selected reviews for further analysis. In addition, we conducted searches in the Clinical Trials and Cochrane Database Controlled Trials websites. Only publications in English, Spanish, and Portuguese were included. The screening process was carried out independently by two researchers, and disagreements were solved by consensus. If disagreement persisted, a third reviewer resolved the disagreement.

2.2 Inclusion and Exclusion Criteria

The inclusion criteria for experimental studies were (1) RCT; (2) the intervention had to include at least one physical activity component in a structured program; (3) the study had to include a control group; and (4) outcomes had to be presented separately for the intervention and the control groups. Intervention studies were excluded from this review if the sample comprised only women with comorbidities, such as diabetes, preeclampsia, or obesity.

The inclusion criteria for cohort studies were (1) for studies using self-reported physical activity as the exposure variable, only information on LTPA was extracted; (2) studies using accelerometry as the exposure variable; (3) only physical activity during pregnancy was considered (studies evaluating exclusively physical activity before pregnancy were excluded); and (4) the study had to include one of the following three maternal (GDM, preeclampsia, gestational weight gain) or child (birth weight, preterm birth, fetal growth) health outcomes. Cohort studies were

excluded if the sample was selected among a specific group of women with a high risk of developing a given outcome.

2.3 Definitions of Outcomes

Excessive gestational weight gain (EWG) was defined in accordance with the recommendations from the US Institute of Medicine (IOM), which establishes proper weight gain parameters according to categories of body mass index [23]. GDM is a specific disorder of pregnancy, defined as “any degree of glucose intolerance with onset or first recognition during pregnancy” [24]. Preeclampsia is also a specific disorder of pregnancy characterized by hypertension (blood pressure $\geq 140/90$ mmHg) and the presence of protein in the urine from the 20th week of pregnancy in previously normotensive women [25]. Low birth weight was defined as birth weight < 2500 g in term babies [26]. Preterm birth was defined as births occurring before the 37th week of gestation [27]. Fetal growth was divided into two separate outcome variables: [24] large for gestational age (LGA) was defined as a fetus or infant larger or more developed than expected for the baby’s sex and gestational age [28]; small for gestational age (SGA) was defined as a fetus or infant smaller or less developed than expected for the baby’s sex and gestational age [28].

2.4 Data Extraction

Data from selected studies were screened by two reviewers separately. From experimental studies, we extracted the characteristics of the study (author, year, country), participants (number in each group, total number), intervention (type, duration, frequency, and intensity of physical activity intervention), and findings. From cohort studies, we extracted characteristics of the study (author, year, country); cohort characteristics (gestational period, number of participants, measurement methods of physical activity), and findings.

2.5 Quality Assessment

We used the Jadad Scale [29] to evaluate the quality of experimental studies. The scale comprised three main topics: randomization, blinding, and dropouts. Points were also given for appropriate use and description of the randomization and blinding method. Because double blinding was not possible for exercise interventions, the final score ranged from 0 (worst) to 4 (best) points. For the quality assessment of cohort studies, we used the Newcastle–Ottawa Scale [30], comprising eight items on sampling methods, comparability, and outcome accuracy. Two researchers conducted the evaluation process independently. The proportion of disagreement was $< 10\%$, and the two reviewers agreed by consensus in these instances.

2.6 Statistical Analysis

Statistical analyses were conducted using Stata version 13.0. We performed a meta-analysis to assess a summary estimate of the effects in each article by calculating a random model. I^2 was used to test heterogeneity. Usually I^2 values of < 25 , 25 – 50 , and $> 50\%$ are considered to represent small, medium, and large levels of inconsistency. For binary outcomes, we calculated the odds ratios (OR) and 95 % confidence intervals (CIs) for the categorical outcomes of GDM, preeclampsia, and fetal growth (SGA vs. others, and LGA vs. others).

For studies using continuous outcomes, such as gestational weight gain (kg), birth weight (g), and gestational age (weeks), we calculated mean differences (MDs) and difference in standard error (DSE). In cohort studies, gestational weight gain and preterm births (< 37 weeks) were calculated as binary outcomes. For the cohort studies in which birth weight was the outcome variable, we calculated regression coefficients (β) and 95 % CIs.

We used a random-effects meta-analysis to pool the estimates, which takes into account between-study heterogeneity, since the study design and exposure, definition of physical activity, and intensity were not uniform across cohort studies. We chose the DerSimonian and Laird method for estimating random effects to distribute weights evenly, since this method evaluates the contribution of studies with small sample size as well as heterogeneity between studies [22].

To allow for comparability of exposure across cohort studies, we analyzed the OR for the highest physical activity category versus the lowest (reference) category. All analyses were conducted separately for experimental and cohort studies.

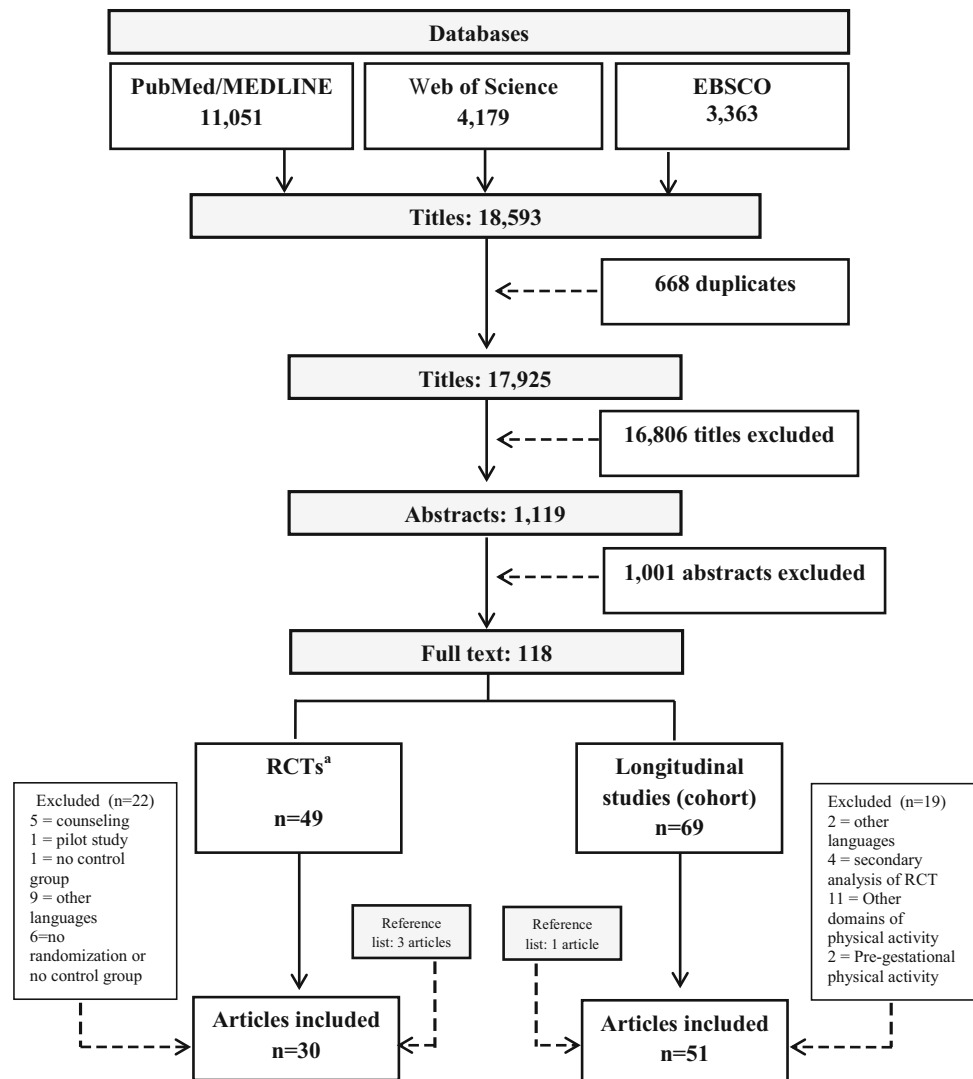
3 Results

The search strategy resulted in 17,925 titles to be examined, of which 1119 were selected for abstract review. After reading the abstracts, we excluded 1001 articles, and therefore read 118 full texts. After we applied the inclusion and exclusion criteria, our review included 30 randomized trials and 51 cohort studies (Fig. 1).

3.1 Randomized Controlled Trials

Table 1 presents the characteristics of the 30 RCTs included in our review. The countries with more studies were Spain ($n = 10$), Brazil ($n = 4$), Norway ($n = 4$), and the USA ($n = 3$). A large variability was found in the number of participants for each intervention, ranging from nine to 481 individuals in the intervention group and six to 481 in the control group. Only the study by de Oliveria Melo [31] included three groups, as described in Table 1. All

Fig. 1 Flowchart reporting the items for systematic reviews of the studies included.
a Randomized controlled trial



interventions comprised a structured exercise program. Most included moderate-intensity physical activities three times per week. The duration of sessions varied between 20 and 70 min. Exercise strategies varied widely, although the majority included aerobic exercises and muscle resistance or strength training. In terms of methodological quality according to the Jadad scale [29], the mean score was 2.7 points, ranging from 1 (worst) to 4 (best) points.

In most included studies, the dropout rate was low (<15 %) [1, 8, 32–42], four studies had a dropout rate between 15 and 20 % [31, 43–45], eight studies between 20 and 25 % [46–53], and five studies had a dropout rate >25 % [54–58]. The main reasons for dropouts in the intervention group were discontinued intervention [1, 34, 38, 40, 46–48, 55–57], risk of premature birth [42, 50, 51], pregnancy-induced hypertension [35, 39], logistical difficulties [54], and lack of flexibility in test scheduling [53]. Regarding compliance with the LTPA intervention protocol, nine studies reported a high rate

(>90 %) [32, 36, 39–41, 43, 44, 48, 49], eight had a rate between 80 and 90 % [8, 34, 35, 44, 46, 47, 50, 51], and six studies had compliance <80 % [1, 33, 38, 42, 54, 58]. In six other studies, the adherence rate could not be identified [37, 52, 53, 55–57]. The main reasons to quit the LTPA programs were unwillingness to do the exercise [41], personal reasons [8, 43–45], transport issues and logistical difficulties [54]. The main barrier reported by women in these studies was related to the difficulties the women had in regularly attending the scheduled programs sessions. Lack of blinding was a methodological flaw recognized in most interventions; however, it is difficult to overcome this problem in physical activity programs for pregnant women.

3.2 Cohort Studies

Table 2 displays the characteristics of the cohort studies included. Most studies came from the USA ($n = 24$), followed by Denmark ($n = 6$), Norway ($n = 5$), and Brazil

Table 1 Characteristics of randomized controlled trials included in the systematic review and meta-analysis ($n = 30$)

| Author, year, country | Subjects (n) | | Intervention description | Gestational period (weeks) | Frequency (times/week) | Duration (min) | Intensity | Main outcomes | Jadad score |
|---|------------------|-----|--|---------------------------------|------------------------|--|----------------------|---------------------|-------------|
| | IG | CG | | | | | | | |
| Cordero et al., 2015, Spain [46] | 101 | 156 | Low impact aerobic exercises, muscle resistance, aquatic exercises, pelvic floor muscle training | 10–14 to end of third trimester | 3 | 50–60 | Moderate | GDM, GWG, BW, GA | 2 |
| Petrov-Fieril et al., 2015, Sweden [47] | 38 | 34 | Muscle resistance, pelvic floor muscle training, advice for extra exercise (walking, cycling, aquatic exercises) | 14–25 | 2 | 60 | Moderate to vigorous | BW | 3 |
| Barakat et al., 2014, Spain [34] | 138 | 152 | Muscle resistance, aerobic dance, lumbar and pelvic floor muscle training | 8–10 to 38–39 | 3 | 55–60 | Moderate | GA, GDM, GWG, BW | 3 |
| Barakat et al., 2014, Spain [48] | 107 | 93 | Muscle resistance, aerobic exercises, stretching, pelvic floor muscle training | 9–13 to 39–40 | 3 | 55–60 | Light to moderate | GDM, GWG, BW, GA | 3 |
| Murtezani et al., 2014, Kosovo [35] | 30 | 33 | Aerobic exercises, strength conditioning | Second trimester to delivery | 3 | 40–45 | Moderate | BW, GA | 3 |
| Salvesen et al., 2014, Norway ^a [33] | 427 | 426 | Aerobic exercises, muscle resistance, pelvic floor muscle training, stretching, encouragement for extra exercises (aerobic, balance, and strength) | 20–36 | 1 | 60–70 | Not reported | BW | 4 |
| Barakat et al., 2013, Spain [43] | 210 | 218 | Aerobic exercises, muscle strength and flexibility | 10–12 to 38–39 | 3 | 50–55 | Moderate | GDM, GWG, BW, GA | 3 |
| Ruiz et al., 2013, Spain [36] | 481 | 481 | Aerobic exercises, muscle resistance and stretching | 9 to 38–39 | 3 | 50–55 | Light to moderate | GDM, GWG, BW, GA | 3 |
| Tomic et al., 2013, Croatia [8] | 166 | 168 | Aerobic exercises, stretching | 6–8 to delivery | 3 | 50 | Light to moderate | FG, PE, GDM, BW, GA | 3 |
| Barakat et al., 2012, Spain [44] | 40 | 43 | Aerobic land activities and aquatic exercises | 6–9 to 38–39 | 3 | 35–45 | Light to moderate | GDM, GWG, BW, GA | 3 |
| De Oliveira Melo et al., 2012, Brazil [31] | A: 54; B: 60 | 57 | Walking, stretching | A: 13–38; B: 20–38 | 3 | 15 (increasing according to physical capacity) | Moderate | FG, PE, GA, BW | 3 |
| Price et al., 2012, USA [54] | 31 | 31 | Walking, cycling, and weight training | 12–14 to 36–delivery | 4 | 45–60 | Moderate | GDM, GWG, BW, FG | 3 |
| Rodriguez et al., 2012, Spain [55] | 25 | 30 | Land and water aerobic exercises, muscle resistance, stretching | 6–10 to 38–39 | 3 | 50 | Moderate | GDM, GWG, BW, GA | 2 |
| Stafne et al., 2012, Norway [42] | 375 | 327 | Aerobic exercise, strength training, balance exercises, advice for home-based activities | 20–36 | 1 | 60 | Not reported | PE, GDM, BW, GA | 3 |
| Barakat et al., 2011, Spain [45] | 34 | 33 | Muscular resistance, aerobic dance, pelvic floor muscle training | 6–9 to 38–39 | 3 | 35–45 | Light | GWG, BW, GA | 3 |
| Haakstad and Bo, 2011, Norway [50] | 52 | 53 | Aerobic dance, strength training, advice to extra activities | 12–24 to 36–38 | 2 | 60 | Moderate | GWG | 4 |

Table 1 continued

| Author, year, country | Subjects (n) | | Intervention description | Gestational period (weeks) | Frequency (times/week) | Duration (min) | Intensity | Main outcomes | Jadad score |
|---|--------------|-----|--|----------------------------|------------------------|----------------|-------------------|-----------------|-------------|
| | IG | CG | | | | | | | |
| Haakstad and Bo, 2011, Norway [51] | 52 | 53 | Aerobic dance, strength training, advice to extra activities | 12–24 to 36–38 | 2 | 60 | Moderate | BW, GA | 4 |
| Hopkins et al., 2011, New Zealand ^b [38] | 47 | 37 | Stationary cycling | 20–36 | 5 | 40 | Moderate | GWG, BW, GA | 3 |
| Ramírez-Vélez et al., 2011, Colombia [52] | 26 | 24 | Aerobic exercises, stretching | 16–20 to 32–36 | 3 | 45 | Moderate | GWG, GA | 3 |
| Hopkins et al., 2010 New Zealand [1] | 47 | 37 | Stationary cycling | 20–36 | 5 | 40 | Moderate | GWG, BW, GA, FG | 2 |
| Cavalcante et al., 2009, Brazil ^c [56] | 33 | 37 | Aquatic aerobic exercises | 16–20 to delivery | 3 | 50 | Moderate | GWG, BW, GA, FG | 3 |
| Barakat et al., 2009, Spain ^d [39] | 72 | 70 | Muscular strength and resistance training | 12–13 to 38–39 | 3 | 35–40 | Light to moderate | GA, GWG, BW | 3 |
| Baciuk et al., 2008 Brazil [57] | 34 | 33 | Aquatic aerobic exercises | 18–20 to delivery | 3 | 50 | Moderate | GA, BW | 2 |
| Barakat et al., 2008, Spain [40] | 72 | 70 | Muscular strength and resistance training | 12–13 to 38–39 | 3 | 35–40 | Light to moderate | GA | 3 |
| Sedaghati et al., 2007, Iran [41] | 40 | 50 | Cycling | Second to third trimester | 3 | 45 | Moderate | GWG | 1 |
| Garshabi et al., 2005, Iran [49] | 107 | 105 | Aerobic exercises, resistance training | 17–22 to 29–39 | 3 | 60 | Light to moderate | GWG, BW | 2 |
| Prevedel et al., 2003, Brazil [58] | 22 | 19 | Aquatic resistance training, stretching, respiratory exercises | 16–20 to 36–40 | 3 | 60 | Moderate | GWG, BW, GA, FG | 1 |
| Marquez-Sterling et al., 2000, USA [53] | 9 | 6 | Stationary aerobic cycling, walking and rowing | Not reported | 3 | 60 | Moderate | GWG, BW | 2 |
| Clapp et al., 2000, USA [32] | 22 | 24 | Stationary walking, step aerobics, stair stepper | Not reported | 3–5 | 20 | Moderate | GWG, BW, GA | 2 |
| Kihlstrand et al., 1999, Sweden [37] | 121 | 119 | Water gymnastics | 15–18 to delivery | 1 | 60 | Not reported | GWG, BW, GA | 2 |

BW birthweight, CG control group, FG fetal growth, GA gestational age, GDM gestational diabetes mellitus, GWG gestational weight gain, IG intervention group, min minutes, PE preeclampsia

^a Data also published in Stafne et al. [42]

^b Data also published in Hopkins et al. [1]

^c Data also published in Baciuk et al. [57]

^d Data also published in Barakat et al. [40]

Table 2 Characteristics of cohort studies included in the systematic review and meta-analysis ($n = 51$)

| Author, year, country | Sample size | Gestational period | PA definition | PA instrument | Reference group | Adjustment for confounders | Outcomes | Newcastle-Ottawa score |
|---|-------------|--------------------|--------------------------------------|-----------------------------|-----------------------|---|-----------------------|------------------------|
| McCullough et al., 2015, USA [86] | 1281 | Early, mid, late | Quartiles | Questionnaire | 1st quartile | Maternal race, PTB | BW | 7 |
| Chasan-Taber et al., 2014, USA [87] | 1240 | Early | Tertiles | Questionnaire | 1st tertile | Age, BMI, parity | PE | 6 |
| Chasan-Taber et al., 2014, USA [64] | 1276 | Early, mid, late | LTPA (none/high) | Questionnaire | None | Age, BMI, parity, early pregnancy smoking | GWG | 6 |
| Currie et al., 2014, Canada [88] | 1749 | Total | Tertiles | Questionnaire | 1st tertile | Age, PP-BMI, education, parity, GDM history, GA | GWG, GDM, PE, GA, GDM | 7 |
| Harrod et al., 2014, USA [74] | 826 | Early, mid, late | Met American College Guidelines LTPA | Questionnaire | No LTPA | Age, GA, offspring sex, gravidity, age, race, education, household income, PP-BMI, prenatal smoking, energy expenditure | BW, FG | 8 |
| Morkrid et al., 2014, Norway [61] | 759 | Total | Continuous | Questionnaire/accelerometer | 1 SD | GA, age, parity, PP-BMI, PP-PA | GDM | 9 |
| Morgan et al., 2014, UK [60] | 270 | Not reported | PA daily counts (low/high) | Accelerometer | Low PA | Age, parity, smoking, alcohol consumption, maternal education, SES | BW, GA, FG | 7 |
| Portela et al., 2014, Brazil [89] | 56 | Not reported | Active/inactive (IPAQ) | Questionnaire | Inactive | No adjustment | GWG, GA, FG | 4 |
| Restall et al., 2014, NZ, Australia, Ireland [90] | 1950 | Mid | Change of PA during pregnancy | Questionnaire | Unchanged | Age, BMI, smoking, mother BW, immigrant in past 5 years, h of sleep, seafood intake, fertility treatment, limiting behavior score | GWG | 7 |
| Schlaff et al., 2014, USA [63] | 135 | Mid | LTPA (active/not active) | Questionnaire | Not active | Age, race, education, marital status, income, childbirth outcome | GWG | 6 |
| Sealy-Jefferson et al., 2014, USA [91] | 832 | Early and mid | Any LTPA | Interview | No LTPA | Drug use, smoking, locus of control, family resource scale | GA | 6 |
| Tinloy et al., 2014, USA [92] | 2370 | Total | LTPA (min/week) | Questionnaire | <60 min/week | Age, race, marital status, education, poverty status, PP weight category, GWG, PP-DM or hypertension | GWG, GA | 6 |
| Kraschewski et al., 2013, USA [93] | 2767 | Late | Minutes/week PA (<60/60–149) | Questionnaire | Lowest (<60 min/week) | Age, race, education, poverty status, marital status, GA, smoking daily during pregnancy | GWG | 6 |
| Owe et al., 2012, Norway [72] | 61,098 | Early and mid | Exercise (times/week) | Questionnaire | No PA | Age, PP-BMI, education, smoking, parity, working hours, spontaneous abortions, bleedings, assisted reproduction, high BP | GA | 7 |
| Mudd et al., 2012, USA [94] | 596 | Total | LTPA (meeting ≥ 150 min/week) | Questionnaire | Inactive | PP-BMI, maternal height, GWG, parity, smoking, Medicaid enrolment, relationship status, age at delivery, education, occupational, race, diagnoses of GDM/PE/gestational HTN | BW, FG | 7 |

Table 2 continued

| Author, year, country | Sample size | Gestational period | PA definition | PA instrument | Reference group | Adjustment for confounders | Outcomes | Newcastle-Ottawa score |
|---------------------------------------|-------------|----------------------------------|---|---------------|-----------------|--|-------------|------------------------|
| Jukic et al., 2012, USA [95] | 1552 | Early | Recreational activity | Questionnaire | No exercise | Age, height, race, education, income, marital status, alcohol use, BMI, smoking, illicit drug use, infant sex, history of miscarriage, history of PTB, parity, vaginal bleeding, nausea/vomiting, DM | BW, GA | 7 |
| Jiang et al., 2012, China [65] | 862 | First trimester | Step counts (<5000/ ≥10,000 daily steps) | Pedometer | Sedentary | Age, education, job type, family income, PP-BMI, GA, newborn's sex, passive tobacco exposure, daily food energy intake | GWG | 8 |
| Doustan et al., 2012, Iran [96] | 671 | Early, mid, late | PA (continuous) | Questionnaire | Continuous | No adjustment | BW | 5 |
| Gollenberg et al., 2011, USA [75] | 1040 | Early, mid | Tertiles | Questionnaire | 1st tertile | Age, PP-BMI, parity, maternal education, smoking | FG | 8 |
| Fortner et al., 2011, USA [97] | 1043 | Early | METS/day (total PA and domains) | Questionnaire | 1st quartile | Age, parity, BMI, education, income | PE | 7 |
| Fleten et al., 2010, Norway [71] | 43,705 | Early, late | LTPA (continuous) | Questionnaire | Continuous | Exercise during the 3 months before pregnancy and in other trimesters during pregnancy, age, parity, cohabitant status, education, smoking, PP exercise, BMI, height. Interactions between BMI and exercise, smoking and exercise, smoking and BMI | BW | 6 |
| Melzer et al., 2010, Sweden [59] | 44 | Late | Moderate PA (≥30 min/day) | Accelerometer | Inactive | No adjustment | GWG, BW | 6 |
| Vollebregt et al., 2010, Holland [67] | 3679 | Early | LTPA (min/week) | Questionnaire | No LTPA | Age, ethnicity, education and marriage/cohabitation, PE, LTPA, BMI | GA, PE | 7 |
| Juhl et al., 2010, Denmark [98] | 74,486 | Early, mid, throughout pregnancy | Min/week swimming or bicycling | Questionnaire | No exercise | Maternal age, parity, occupational status, smoking during pregnancy, gravidity, previous spontaneous abortions, illnesses overall, abdominal diseases, subfecundity, bleeding Early in pregnancy, coffee and alcohol consumption, PP-BMI, working h, working position, physically strenuous work, psycho-social job strain, gestational age, sex of the offspring | PTB, FG, BW | 8 |
| Juhl et al., 2010, Denmark [99] | 79,692 | Early, mid | LTPA (h/week) | Questionnaire | 0 h exercise | Adjusted for gestational age, offspring sex, maternal age, PP-BMI, socio-occupational status, parity, smoking | FG, BW | 8 |
| Hegaard et al., 2010, Denmark [16] | 4458 | Mid, late | LTPA (h/week) | Questionnaire | Sedentary | PP-BMI, parity, smoking, education, GA | BW | 7 |

Table 2 continued

| Author, year, country | Sample size | Gestational period | PA definition | PA instrument | Reference group | Adjustment for confounders | Outcomes | Newcastle-Ottawa score |
|--------------------------------------|-------------|--------------------|---------------------------------|---------------|-----------------|--|----------|------------------------|
| Stuebe et al., 2009, USA [100] | 1388 | Mid | Total PA (h/week) | Questionnaire | <2.5 h/week | PP-BMI, age race, smoking status, GA at delivery, nausea in the 1st trimester | GWG | 6 |
| Tavares et al., 2009, Brazil [101] | 118 | Early, mid, late | PA (METs) | Questionnaire | Continuous | Income, initial nutritional status | GWG, BW | 6 |
| Owe et al., 2009, Norway [15] | 36,869 | Mid, late | Exercise frequency | Questionnaire | No PA | Age, maternal education, parity, HTN, GDM, weight gain, PP-BMI, PE, smoking habits, maternal height | BW, GA | 6 |
| Chasan-Taber et al., 2008, USA [66] | 1006 | Early, mid | Quartiles | Questionnaire | 1st quartile | Age, BMI | GDM | 7 |
| Osterdal et al., 2008, Denmark [102] | 85,139 | Total | LTPA (min/week) | Questionnaire | No LTPA | Age, PP-BMI, smoking, height, parity, SES, ownership of residence, cohabitant status | PE | 7 |
| Rudra et al., 2008, USA [103] | 2241 | Early | Recreational PA (h/week) | Questionnaire | No PA | Age, race, parity, education, employment, PP-HTN, PP-BMI | PE | 8 |
| Magnus et al., 2008, Norway [104] | 59,573 | Total | Recreational PA frequency/month | Questionnaire | No PA | Smoking, parity, PP-BMI, educational attainment, age at delivery, year of childbirth, height, physically demanding job | PE | 8 |
| Hegaard et al., 2008, Denmark [70] | 5749 | Early, mid | MVPA | Questionnaire | Sedentary | Age, education, PP-BMI, maternal smoking during pregnancy | GA, PTB | 6 |
| Domingues et al., 2008, Brazil [84] | 4147 | Total | LTPA | Interview | No LTPA | Family income, ethnicity, education, age, birth interval, onset of prenatal care, morbidities | GA, PTB | 6 |
| Juhl et al., 2008, Denmark [105] | 87,232 | Early, late | LTPA | Questionnaire | Sedentary | Age, gravidity, parity, previous spontaneous abortions, uterine fibroids/malformations/cone biopsy, subfecundity, coffee consumption, alcohol consumption, smoking, BMI, job status, working h, working position, job strain | GA, PTB | 8 |
| Dwarkanath et al., 2007, India [106] | 546 | Early, mid, late | Tertiles | Questionnaire | 1st tertile | Weight, energy intake, education | BW | 6 |
| Downs et al., 2007, USA [107] | 62 | Late | Exercise (days/week) | Questionnaire | No exercise | No adjustment | BW, GA | 4 |
| Perkins et al., 2007, USA [62] | 51 | Mid, late | Aerobic PA | Accelerometer | Continuous | No adjustment | BW, FG | 5 |
| Watson and McDonald, 2007, NZ [108] | 197 | Mid, late | PA (METs) | Questionnaire | Inactive | SES, age, smoking, parity, morning sickness, energy intake, height, BMI | BW, FG | 4 |
| Oken et al., 2006, USA [109] | 1581 | Early, mid | Total PA (h/week) | Questionnaire | <2 h/week | Age, race, PP-BMI, history of GDM, history of DM | GDM | 8 |

Table 2 continued

| Author, year, country | Sample size | Gestational period | PA definition | PA instrument | Reference group | Adjustment for confounders | Outcomes | Newcastle-Ottawa score |
|--|-------------|--------------------|---------------------------------|---------------------|------------------|--|----------------------|------------------------|
| Duncombe et al., 2006, Australia [110] | 148 | Early, mid, late | Exercise (intensity, frequency) | Questionnaire | - | No adjustment | BW, GA | 4 |
| Takito et al., 2005, Brazil [111] | 152 | Early, mid, late | PA (min/week) | Questionnaire | No PA | Smoking status, education, cohabitant with spouse, initial nutritional status | GDM | 7 |
| Dempsey et al., 2004, USA [112] | 909 | Early | Recreational PA (h/week) | Questionnaire | No PA | Age, race, parity, PP-BMI | GDM | 7 |
| Magann et al., 2002, USA [113] | 750 | Total | Aerobic exercise (intensity) | Questionnaire | No exercise | Age, race, gravidity, parity, maternal illness, education, income after taxes, marital status, height, PP weight, GWG, prior preterm delivery, smoking, social support, and stress | GWG, GDM, PE, BW, GA | 6 |
| Evenson et al., 2002, USA [73] | 2359 | Early, mid | Vigorous leisure activity | Telephone interview | No vigorous LTPA | Smoking, age, BMI, marital status, education, race, parity, energy intake, bed rest | GA | 7 |
| Nieuwenhuijsen et al., 2002, UK [114] | 11,462 | Early, mid | Swimming (h/week) | Questionnaire | No exercise | Parity, smoking, education, housing tenure, age, cannabis, hard drugs, alcohol consumption, GA, ethnicity | BW | 6 |
| Hatch and Levin, 1998, USA [115] | 717 | Early, mid, late | Exercise (kcal/week) | Questionnaire | No exercise | Smoking, previous miscarriage, PTD, dating by ultrasound | GA | 6 |
| Misra et al., 1998, USA [82] | 719 | Early, mid | Leisure time exercise (days) | Interview | <60 days | Race, age, use of illicit drugs, prenatal care, height, smoking, insurance, prior fetal losses, prior LBW delivery, bleeding, HTN, antepartum hospitalization, febrile/antibiotic administration | GA | 9 |
| Sternfeld et al., 1995, USA [68] | 388 | Early, mid, late | LTPA (frequency/week) | Questionnaire | No exercise | GA, parity, PP-BMI, newborn's sex | BW, GA | 6 |
| Hatch et al., 1993, USA [69] | 462 | Early, mid, late | LTPA (kcal/week) | Questionnaire | No exercise | GA, parity, log of PP weight, GWG, smoking, nausea, per capita income | BW, FG | 6 |

BMI body mass index, *BW* birthweight, *DM* diabetes mellitus, *FG* fetal growth, *GA* gestational age, *GDM* gestational diabetes mellitus, *GWG* gestational weight gain, *HTN* hypertension, *IPAQ* International physical activity questionnaire, *LBW* low birthweight, *LTPA* leisure time physical activity, *METs* metabolic equivalents, *MVPA* moderate vigorous physical activity, *NZ* New Zealand, *PA* physical activity, *PE* preeclampsia, *PP* pre-pregnancy, *PTB* preterm birth, *PTD* preterm delivery, *SD* standard deviation, *SES* socioeconomic status

($n = 4$). Sample sizes ranged from 44 to 87,232 participants. We observed a clear heterogeneity of physical activity definitions, including continuous scores in metabolic equivalents (METs) multiplied by time, counts from accelerometry, and duration. Most instruments used to assess physical activity were self-reported questionnaires; four studies included accelerometry [59–62]. The quality assessment resulted in a mean of 6.6 points in the Newcastle–Ottawa Scale, ranging from 4 (worst) to 9 (best) points. The main methodological problems detected were the use of self-reported information on physical activity instead of accelerometry and the lack of a detailed characterization of non-respondents.

3.3 Meta-Analysis: Weight Gain During Pregnancy

Figures 2, 3, 4, 5, 6, 7 and 8 display the meta-analysis graphs comparing experimental and cohort studies. For gestational weight gain (GWG), the meta-analysis of the RCTs included 1605 women in the control groups and 1598 in the exercise groups. The meta-analysis resulted in a mean difference in GWG of -1.11 kg (DSE -1.53 ; -0.69). Women exposed to exercise interventions gained less weight during pregnancy than those not taking part in an exercise intervention. There was no heterogeneity across the trials ($I^2 = 0\%$; $p = 0.868$; Fig. 2a).

For cohort studies (Fig. 2b), most studies dichotomized the outcome as exceeding or not exceeding the GWG guidelines from the IOM [19]. Active women during pregnancy had an 18 % lower risk of GWG that exceeded the IOM recommendations as compared with inactive women (OR 0.82; 95 % CI 0.68–0.99). The sample of cohort studies included 9795 women, and the studies exhibited moderate heterogeneity ($I^2 = 60.2\%$; $p = 0.005$). The article by Schlaff et al. [63] included separate findings for moderate- and vigorous-intensity physical activity, and both were included in the meta-analysis. The papers by Chasan-Taber et al. [64] and by Jiang et al. [65] included measures of early, mid, and late pregnancy, and all results were included in the meta-analysis.

3.4 Meta-Analysis: Gestational Diabetes

In terms of GDM, ten trials were included, with 1907 women in the control groups and 1883 in the exercise groups. Barakat et al. [43] included analysis with two criteria for GDM diagnostics: World Health Organization criteria and the International Association for Diabetes in Pregnancy Study Group criteria; both findings were included in the meta-analysis. The meta-analysis suggested

a protective role of exercise interventions on the development of GDM (relative risk [RR] 0.67; 95 % CI 0.49–0.92). The studies showed low heterogeneity ($I^2 = 33\%$; $p = 0.135$).

When taking cohort studies into account, the total sample size was 6754. The summary OR for GDM comparing high/moderate and low/no LTPA was 0.75 (95 % CI 0.55–1.01), with no evidence of heterogeneity across studies ($I^2 = 0\%$; $p = 0.615$). The paper by Chasan-Taber et al. [66] included measures of early- and mid-pregnancy physical activity; both findings were included in the meta-analysis (Fig. 3).

3.5 Meta-Analysis: Preeclampsia

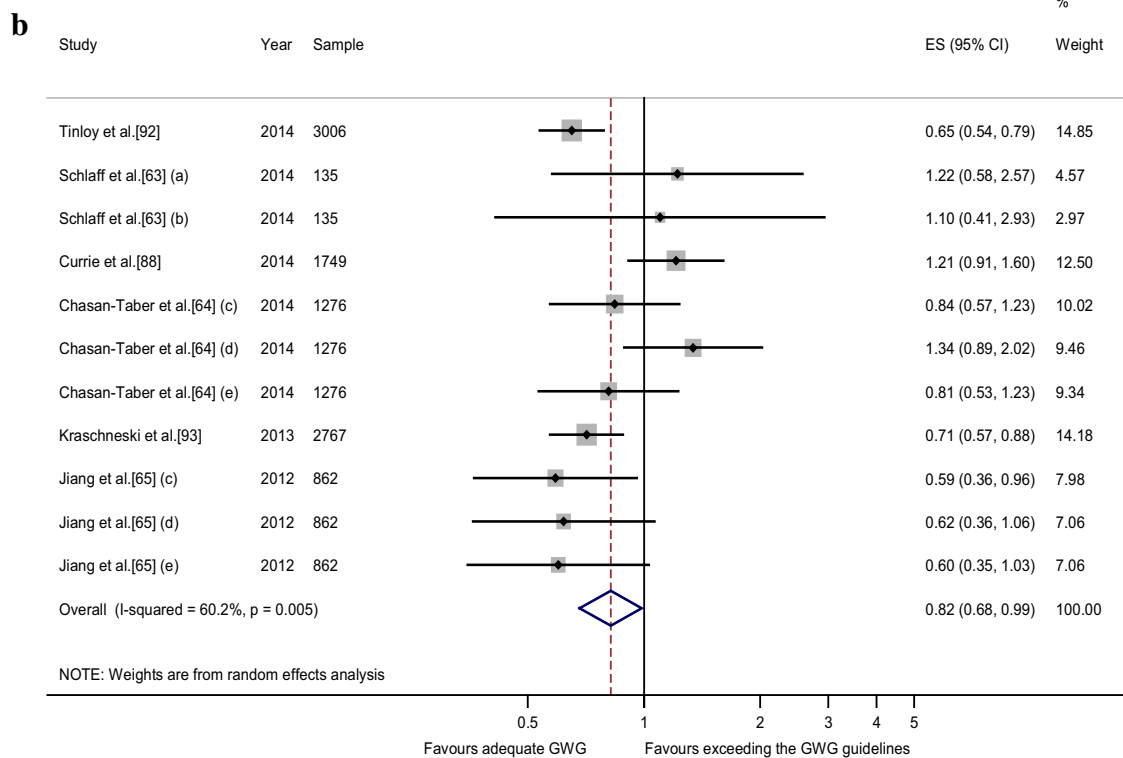
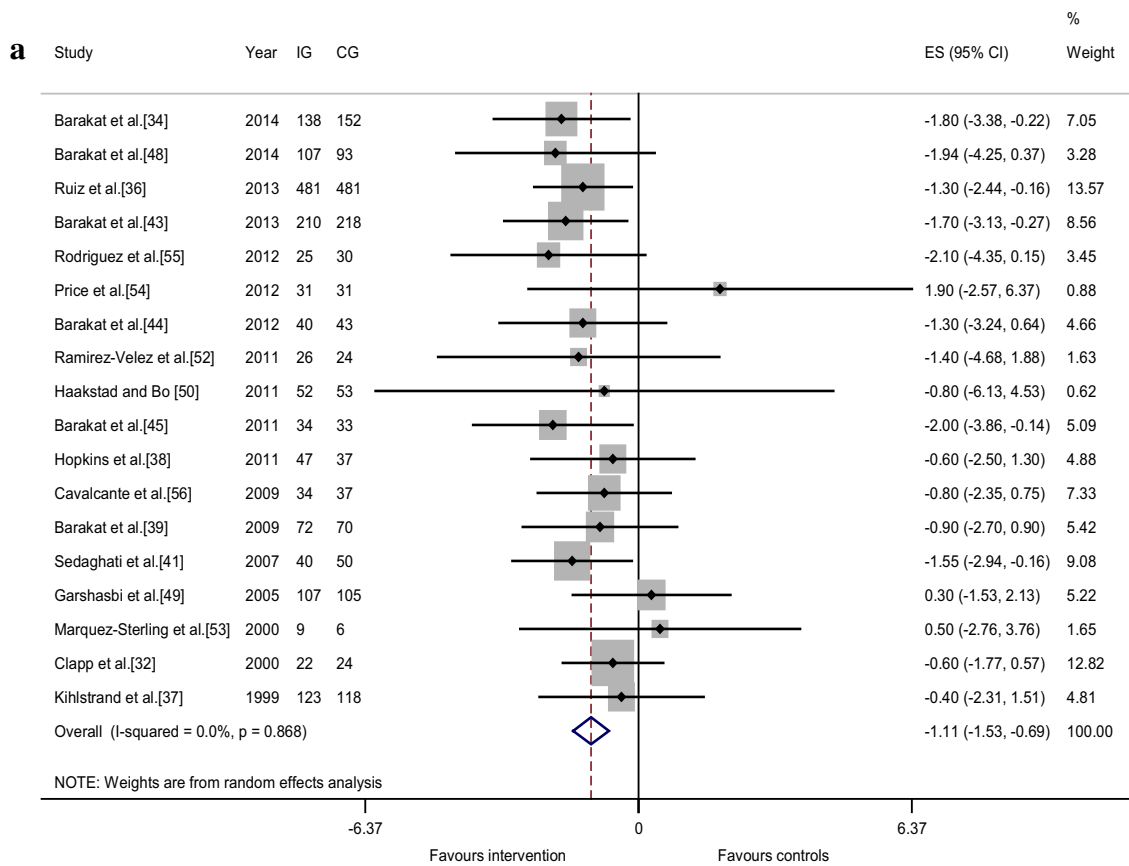
Data from three trials were included in the meta-analysis of preeclampsia, with 708 women in the control groups and 709 in the exercise groups. No evidence of an association between exercise interventions in pregnancy and risk of preeclampsia was observed (RR 0.93; 95 % CI 0.55–1.57). There was no evidence of heterogeneity across the trials ($I^2 = 0\%$; $p = 0.872$).

In the cohort analysis, eight studies were included, with a sample size of 155,414 women. Similar to the findings of the randomized trials, there was no evidence of an association between LTPA in pregnancy and preeclampsia. There was low heterogeneity across cohort studies ($I^2 = 19.4\%$; $p = 0.270$). The paper by Vollebregt et al. [67] included effect measures for moderate-intensity and vigorous-intensity physical activity, and both were included in the meta-analysis (Fig. 4).

3.6 Meta-Analysis: Birthweight

A total of 22 randomized trials (2431 women in exercise groups and 2478 in control groups) evaluated the effect of exercise interventions on birthweight. There was no evidence of an effect of LTPA on average birthweight (MD -31.09 g; DSE -69.91 ; 7.73). However, high heterogeneity was detected across randomized trials ($I^2 = 98.8\%$; $p < 0.001$).

The analysis of the six cohort studies ($n = 62,127$ women) showed a small effect of LTPA on mean birthweight ($\beta -1.05$ g; 95 % CI -1.49 ; -0.62) and no heterogeneity ($I^2 = 0\%$; $p = 0.445$). Sternfeld et al. [68] and Hatch et al. [69] included measures of early, mid, and late pregnancy physical activity; again, all estimates were included in the meta-analysis. Hegaard et al. [70] and Fleten et al. [71] included measures of early and mid/late pregnancy physical activity; both were included in the meta-analysis (Fig. 5).



◀ **Fig. 2** Meta-analysis of the effect of physical activity on gestational weight gain in randomized controlled trials and cohort studies: **a** mean difference and difference in standard error between intervention group and control group (continuous analysis); **b** odds ratio \pm 95 % confidence interval for exceeding the gestational weight gain guidelines from the US Institute of Medicine [23] (binary analysis). Schlaff et al. [63] (**a**) = effect measure for moderate physical activity; Schlaff et al. [63] (**b**) = effect measure for vigorous physical activity; Chasan-Taber et al. [64] (**c**) and Jiang et al. [65] (**c**) = effect measure for physical activity during early pregnancy; Chasan-Taber et al. [64] (**d**) and Jiang et al. [65] (**d**) = effect measure for physical activity during mid pregnancy; Chasan-Taber et al. [64] (**e**) and Jiang et al. [65] (**e**) = effect measure for physical activity during late pregnancy. The point estimate drawn represents graphically the weight of the study in the random-effects analysis. *CG* control group, *CI* confidence interval, *ES* effect size, *GWG* gestational weight gain, *IG* intervention group

3.7 Meta-Analysis: Gestational Age

Data from 17 trials were included in the meta-analysis of gestational age, comprising 2169 women in the control groups and 2109 in the exercise groups. The meta-analysis showed no difference between the groups in gestational age at delivery (MD -0.07 weeks, DSE $-0.29; 0.16$). There was no heterogeneity across the trials ($I^2 = 0\%$; $p < 0.001$).

The 11 cohort studies ($n = 81,595$) showed an inverse association between LTPA and the risk of preterm birth (OR 0.80; 95 % CI 0.70–0.91). A low heterogeneity across studies was found ($I^2 = 13.4\%$; $p = 0.310$). Owe et al. [72] and Evenson et al. [73] included more than one measure of LTPA in pregnancy, and all findings were included in the meta-analysis (Fig. 6).

3.8 Meta-Analysis: Fetal Growth

Four trials (754 women in exercise groups and 745 in control groups) evaluated the effect of exercise interventions on the risk of being born SGA, and three trials (302 women in exercise groups and 301 in control groups) evaluated the effect of exercise interventions on the risk of being born LGA. No association was observed between exercise and SGA (Fig. 7), but women undergoing exercise interventions during pregnancy had a lower risk of having an LGA baby (RR 0.51; 95 % CI 0.30–0.87) (Fig. 8). There was no heterogeneity across the trials ($I^2 = 0\%$; $p < 0.001$) in both analyses, LGA and SGA.

In cohort studies, it was only possible to analyze the outcome ‘SGA’ given the low number of studies including the outcome ‘LGA’. Data from three studies were included in the meta-analysis for SGA. There was no association between LTPA and SGA (OR 1.03; 95 % CI 0.81–1.30), and low heterogeneity across studies ($I^2 = 25.2\%$; $p = 0.245$). Harrod et al. [74] and Gollenberg et al. [75]

included more than one measure of physical activity during pregnancy; all estimates were included in the meta-analysis (Fig. 7).

4 Discussion

To the best of our knowledge, this is the first meta-analysis comparing associations between LTPA during pregnancy and maternal and child health between experimental and cohort studies. Previous reviews on the associations of LTPA on maternal–child outcomes were limited to specific groups of women of specific study designs [76, 77].

Consistent associations for LTPA in pregnancy were observed for weight gain (active women gained less weight during pregnancy), GDM (active women were less likely to develop GDM), preterm birth (active women were less likely to deliver a preterm infant), and fetal growth (active women were less likely to deliver an LGA baby). In methodological terms, the comparisons presented here are particularly relevant because of the different features of experimental and cohort studies.

The first difference between these two study designs relates to the nature of the exposure variable (i.e., physical activity). Cohort studies relied on self-reported LTPA and moderate–vigorous physical activity from accelerometry, whereas most experimental studies delivered structured exercise interventions to pregnant women. Observational studies therefore face higher variability in physical activity levels, whereas randomized trials are more prone to homogeneous physical activity levels in the intervention groups.

Another issue is the possibility of confounding in cohort studies, which is not the case for RCTs of sufficient sample size. For example, high socioeconomic status women are more active in leisure time [13] and have better maternal and child health indicators. In unadjusted analysis, it is therefore likely that active women will present better health indicators than inactive women, at least partly because they are from high socioeconomic groups. Adjusting for socioeconomic status could theoretically remove this artefact, but residual confounding is always a possibility.

Sample sizes also varied considerably between cohort and experimental studies. Most trials had fewer than 100 participants per group, whereas most cohort studies had sample sizes of more than 1000 women. Therefore, differences of the same magnitude could have been captured as significant in cohort studies, and not in experimental studies. Furthermore, another important issue when comparing RCTs and cohort studies is the selection of exposure to physical activity during pregnancy. While some cohort studies considered physical activity before pregnancy to be a confounding variable in the analysis, most did not specify

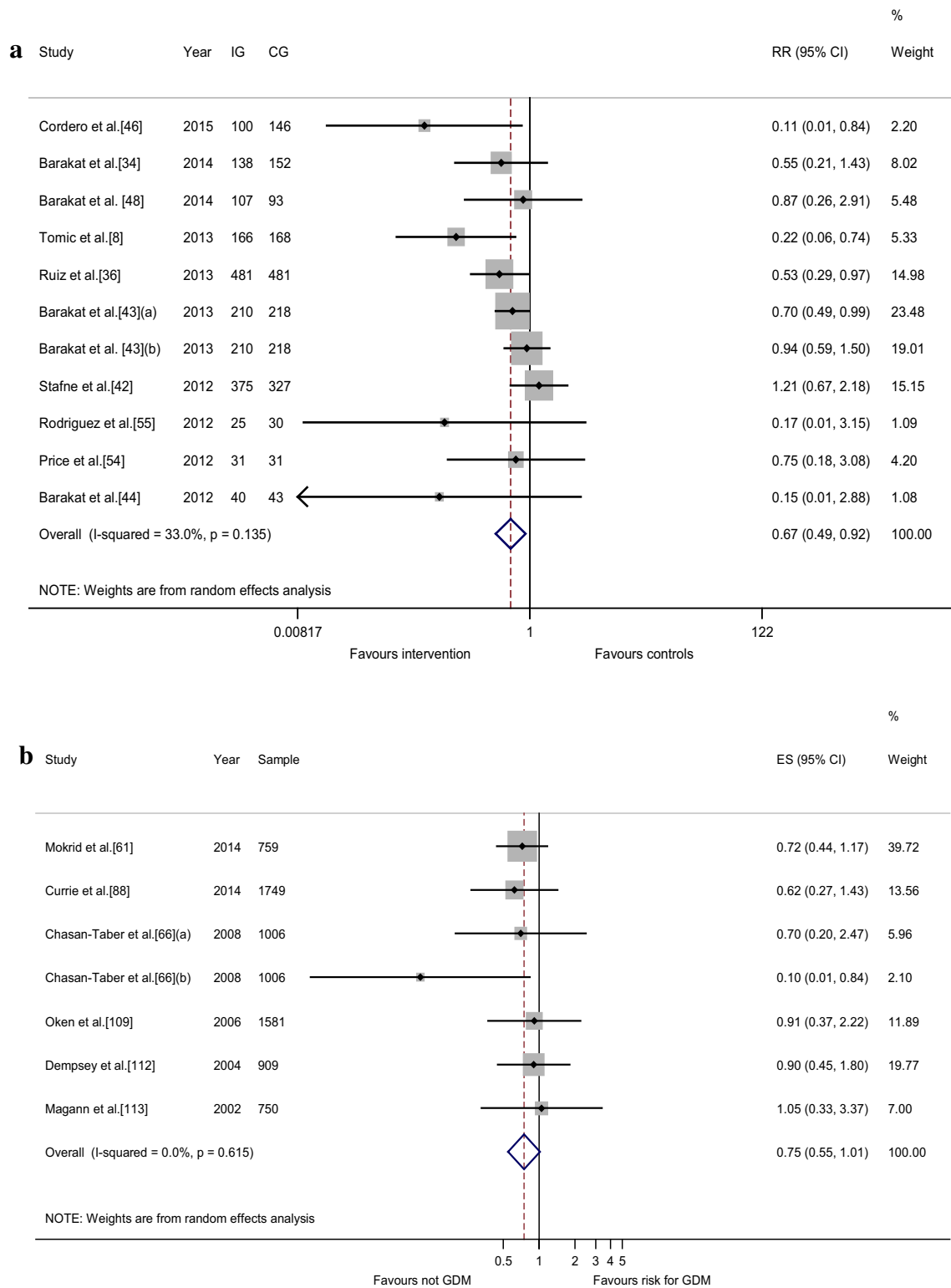


Fig. 3 Meta-analysis of the effect of physical activity on gestational diabetes mellitus: **a** relative risk \pm 95 % confidence interval in randomized controlled trials; **(b)** odds ratio \pm 95 % confidence interval in cohort studies. Barakat et al. [43] **(a)** = analysis with World Health Organization criteria; Barakat et al. [43] **(b)** = analysis with International Association for Diabetes in Pregnancy Study Group criteria. Chasan-Taber et al. [66] **(c)** = effect measure for physical

activity during early pregnancy; Chasan-Taber et al. [66] **(d)** = effect measure for physical activity during mid pregnancy. The point estimate drawn represents graphically the weight of the study in the random-effects analysis. *CG* control group, *CI* confidence interval, *ES* effect size, *GDM* gestational diabetes mellitus, *IG* intervention group, *RR* relative risk

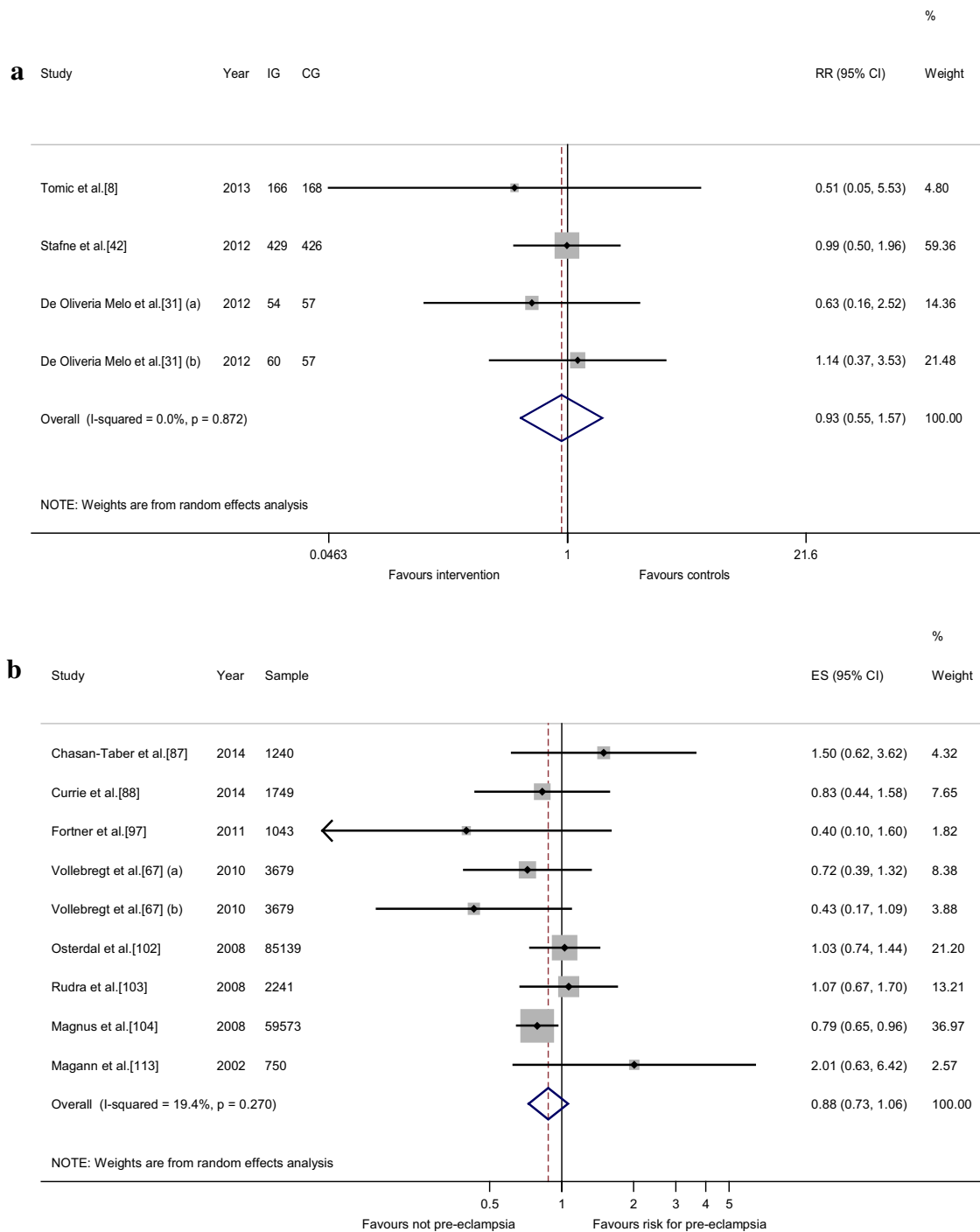


Fig. 4 Meta-analysis of the effect of physical activity on pre-eclampsia: **a** relative risk ± 95 % confidence interval in randomized controlled trials; **b** odds ratio ± 95 % confidence interval in cohort studies. De Oliveria Melo et al. [31] **(a)** = exercise initiated at 13 weeks; De Oliveria Melo et al. [31] **(b)** = exercise initiated at 20 weeks; Vollebregt et al. [67] **(a)** = effect measure for moderate

physical activity; Vollebregt et al. [67] **(b)** = effect measure for vigorous physical activity. The point estimate drawn represents graphically the weight of the study in the random-effects analysis. CG control group, CI confidence interval, ES effect size, IG intervention group, RR relative risk

whether women were active before pregnancy; in most RCTs, being inactive before pregnancy was an inclusion criterion. The positive effects found in cohort studies, but

not in intervention studies could be attributed to long-term physical activity participation and not just to physical activity during pregnancy.

Despite differences between cohort and experimental studies, some of the findings were markedly consistent. In terms of weight gain during pregnancy, findings were similar when comparing cohort ($n = 11$) and experimental ($n = 18$) analyses; regardless of the study design, active women had lower weight gain during pregnancy. These results are consistent with the meta-analysis of 12 studies conducted by Streuling et al. [2], which showed an average weight gain significantly lower in the intervention groups (-0.61 ; 95 % CI -1.17 to 0.06) compared with controls. On the other hand, our findings differ from those of a Cochrane review of four articles on aerobic exercise during pregnancy, in which Kramer and McDonald [78] concluded that exercise showed no significant effect on weight gain during pregnancy.

Regarding GDM, our meta-analysis of 11 experimental studies showed a protective effect in women who engaged in physical activity during pregnancy. The same direction of association was observed in seven cohort analyses, although the difference was borderline in terms of statistical significance. In a previous meta-analysis of five cohort and case-control studies, Tobias et al. [3] showed a protective effect of physical activity on the development of GDM, but the same was not observed in the meta-analysis of five RCTs conducted by Yin et al. [18].

A protective effect of physical activity on the incidence of preeclampsia was not confirmed in our meta-analysis of four experimental and nine cohort studies. Aune et al. [6] conducted a systematic review and meta-analysis of seven cohort and four case-control studies, and found an inverse association between physical activity and preeclampsia. However, this association was not observed in a Cochrane review of three trials conducted by Meher and Duley [19].

There were no differences in mean birthweight of newborns according to maternal LTPA in pregnancy, consistent with two previous meta-analyses [20, 79]. A 2015 meta-analysis of 15 RCTs found that active women delivered lighter babies [4]; however, this study did not include articles published in 2014 and 2015, which were the studies tending to show results in the opposite direction. All weights were similarly distributed, with the exception of the meta-analysis of mean birth weight in cohort studies, where two studies carried almost 100 % of the weighted effect. The observed difference was because Fleten et al. [71] had a sample of 43,705 individuals, whereas other studies had fewer participants. However, we used a model that takes into consideration the size of the sample in the meta-analysis to distribute the weights evenly considering the contribution of studies with small sample size as well as heterogeneity between studies. In addition, we performed an additional analysis to observe a possible change in the effect estimation with the withdrawal of the Fleten et al.

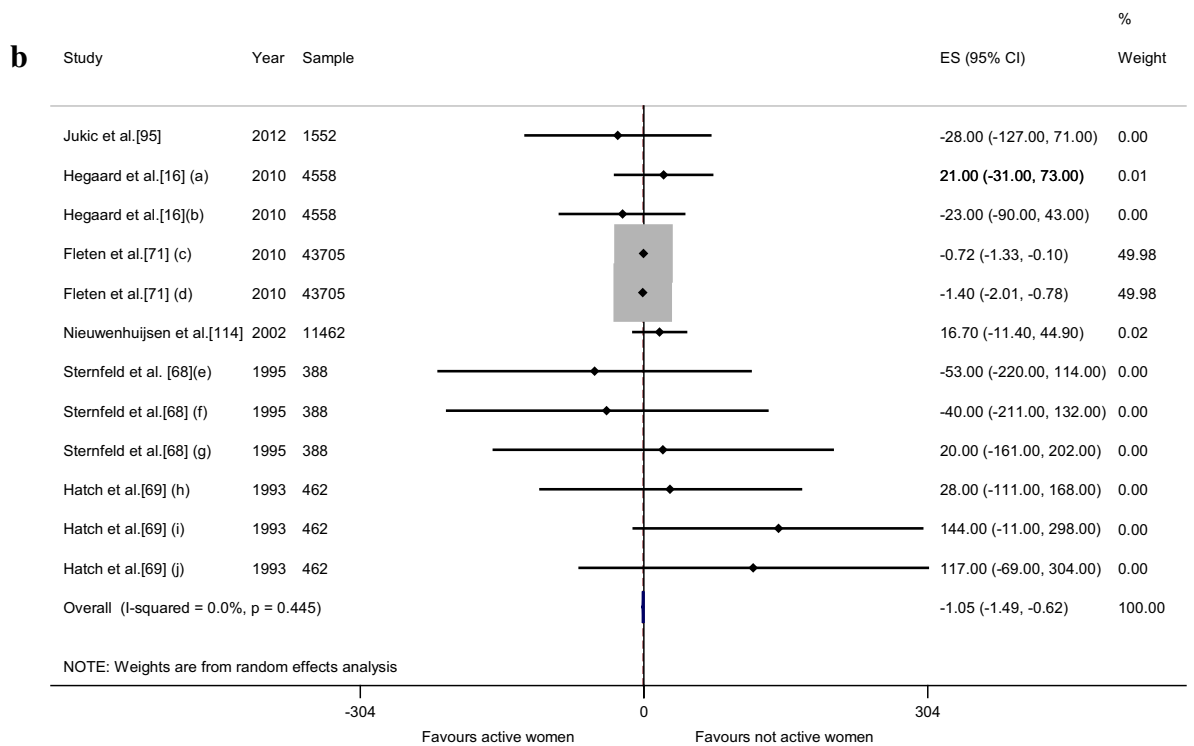
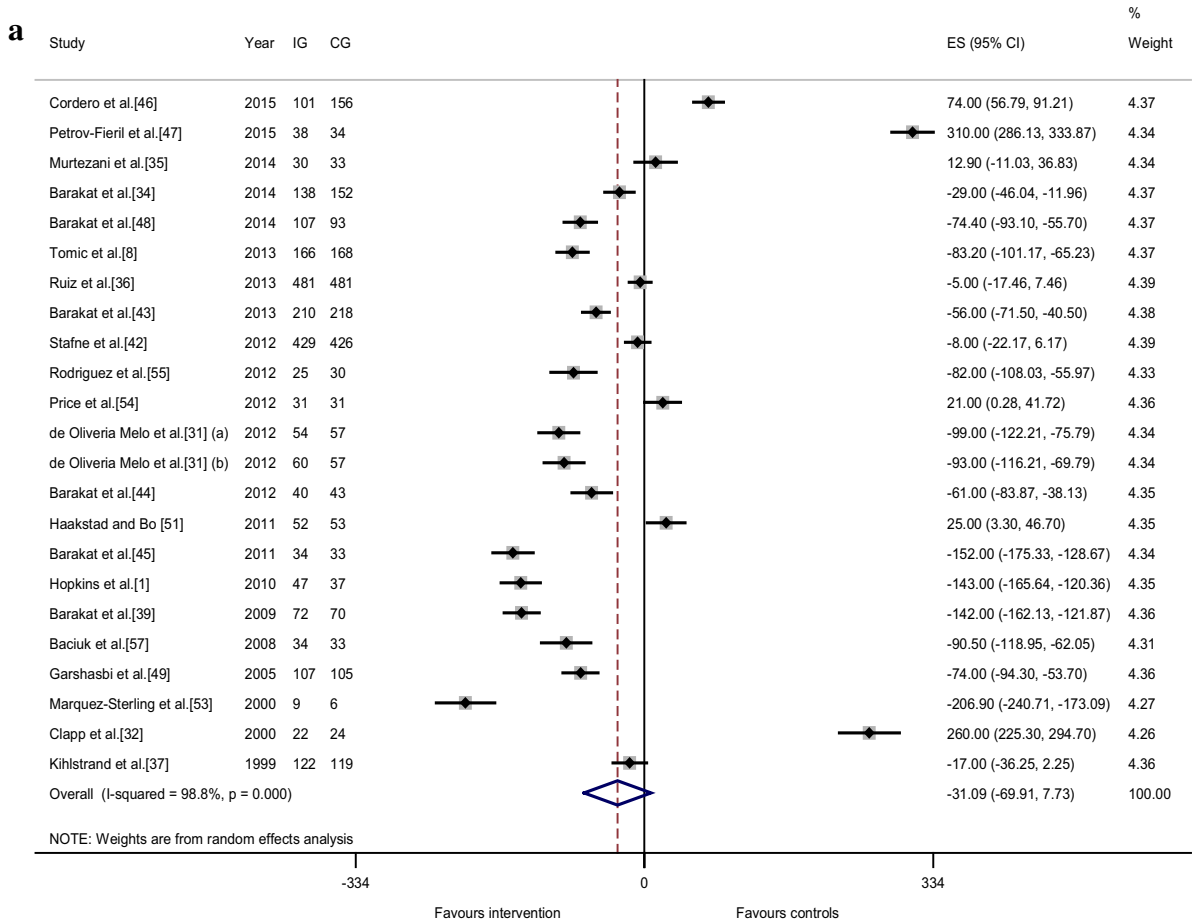
Fig. 5 Meta-analysis of the effect of physical activity on difference in mean birthweight: **a** mean difference and difference in standard error in randomized controlled trials; **b** adjusted regression coefficient ($\beta \pm 95$ % confidence interval in cohort studies. De Oliveria Melo et al. [31] (**a**) = exercise initiated at 13 weeks; De Oliveria Melo et al. [31] (**b**) = exercise initiated at 20 weeks; Hegaard et al. [16] (**a**), Sternfeld et al. [68] (**f**), and Hatch et al. [69] (**i**) = effect measure for physical activity during mid pregnancy; Fleten et al. [71] (**c**), Sternfeld et al. [68] (**e**), and Hatch et al. [69] (**h**) effect measure for physical activity during early pregnancy; Hegaard et al. [16] (**b**), Sternfeld et al. [71] (**g**), Fleten et al. [71] (**d**), and Hatch et al. [69] (**j**) = effect measure for physical activity during late pregnancy. The point estimate drawn represents graphically the weight of the study in the random-effects analysis. *CG* control group, *CI* confidence interval, *ES* effect size, *IG* intervention group

[71] study. No significant changes in the pooled effect were observed.

In terms of preterm births, experimental evidence does not support an association with physical activity in pregnancy, similar to the findings by Sanabria-Martinez et al. [4]. In the past, there was a concern in the literature as to whether exercise during pregnancy could cause adverse effects on maternal and fetal growth and increase the risk of premature births [80]. According to Goldenberg et al. [81] working long hours and undertaking hard physical labor under stressful conditions are probably associated with an increase in preterm birth, especially in relation to occupational physical activity. However, several studies that focused on vigorous sports training several times a week during pregnancy found it was associated with a decreased or unchanged risk of preterm delivery [69, 73, 82]. Observational studies have shown that regular LTPA during pregnancy can even reduce the incidence of preterm births [83, 84], an association that was confirmed in our meta-analysis of 13 cohort studies.

Our meta-analysis of RCTs suggests that exercise during pregnancy leads to decreased odds of delivering an LGA newborn. Similar results were found in the meta-analysis conducted by Wiebe et al. [5]. It is important to highlight that the available literature focusing on fetal growth is still limited compared with other outcomes.

Most physical activity interventions designed to prevent prenatal complications have focused on LTPA of moderate intensity. Less attention has been paid to sedentary behavior or light-intensity activity during pregnancy [85]. Increasing time spent in light-intensity activity could have important health implications during pregnancy by directly reducing time spent in sedentary behavior. Future studies might help address this literature gap. Another important research question is the impact of exercise intensity on maternal and child health outcomes. In our meta-analysis, it was not possible to evaluate the separate effects of moderate- and vigorous-intensity activities due to the small number of studies focusing on vigorous-intensity activities.



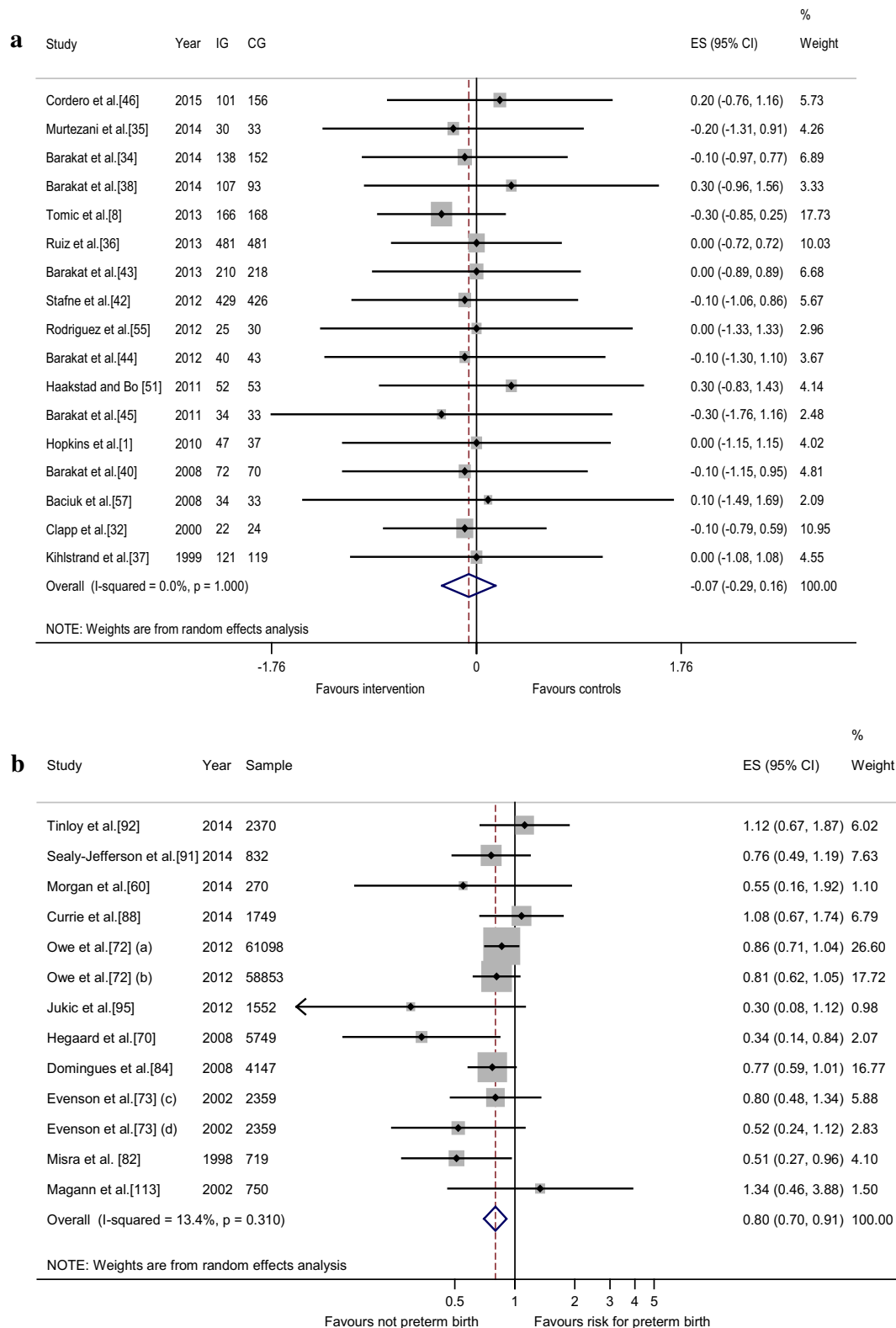


Fig. 6 Meta-analysis of the effect of physical activity on gestational age: **a** mean difference and difference in standard error in randomized controlled trials (continuous analysis); **b** odds ratio \pm 95 % confidence interval in cohort studies (binary analysis). Owe et al. [72] (a), Evenson et al. [73] (d) = effect measure for physical activity during mid pregnancy;

Owe et al. [72] (b) = effect measure for physical activity during late pregnancy; Evenson et al. [73] (c) = effect measure for physical activity during early pregnancy. The point estimate drawn represents graphically the weight of the study in the random-effects analysis. CG control group, CI confidence interval. ES effect size, IG intervention group

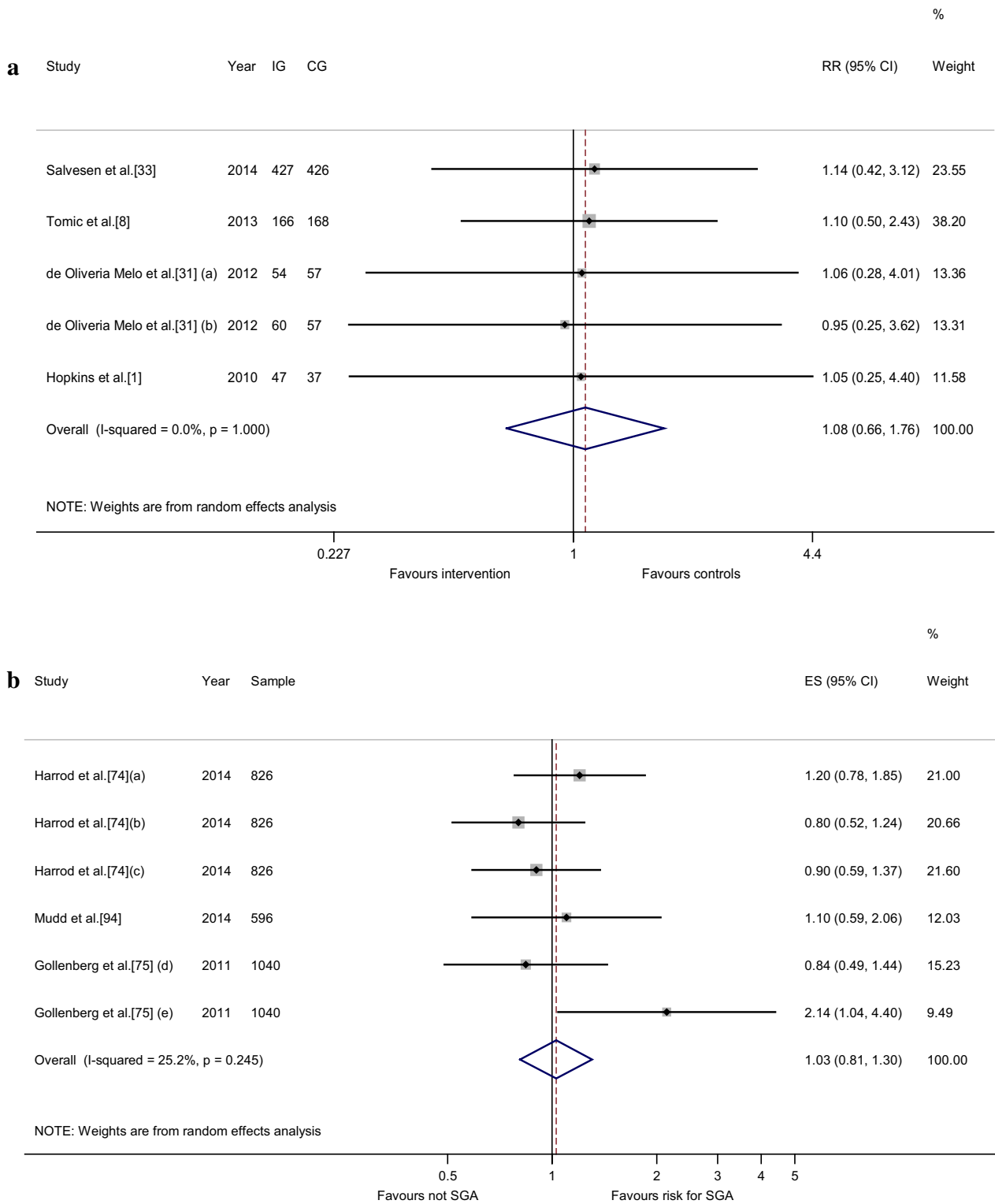


Fig. 7 Meta-analysis of the effect of physical activity on being born small for gestational age (defined as birth weight below the 10th centile or 2500 g): **a** relative risk \pm 95 % confidence interval in randomized controlled trials; **b** odds ratio \pm 95 % confidence interval in cohort studies. De Oliveria Melo et al. [31] (**a**) = exercise initiated at 13 weeks; De Oliveria Melo et al. [31] (**b**) = exercise initiated at 20 weeks; Harrod et al. [74] (**a**), Gollenberg et al. [75] (**d**) = effect

measure for physical activity during early pregnancy; Harrod et al. [74] (**b**), Gollenberg et al. [75] (**e**) = effect measure for physical activity during mid pregnancy; Harrod et al. [74] (**c**) = effect measure for physical activity during late pregnancy. The point estimate drawn represents graphically the weight of the study in the random-effects analysis. *CG* control group, *CI* confidence interval, *ES* effect size, *IG* intervention group, *RR* relative risk, *SGA* small for gestational age

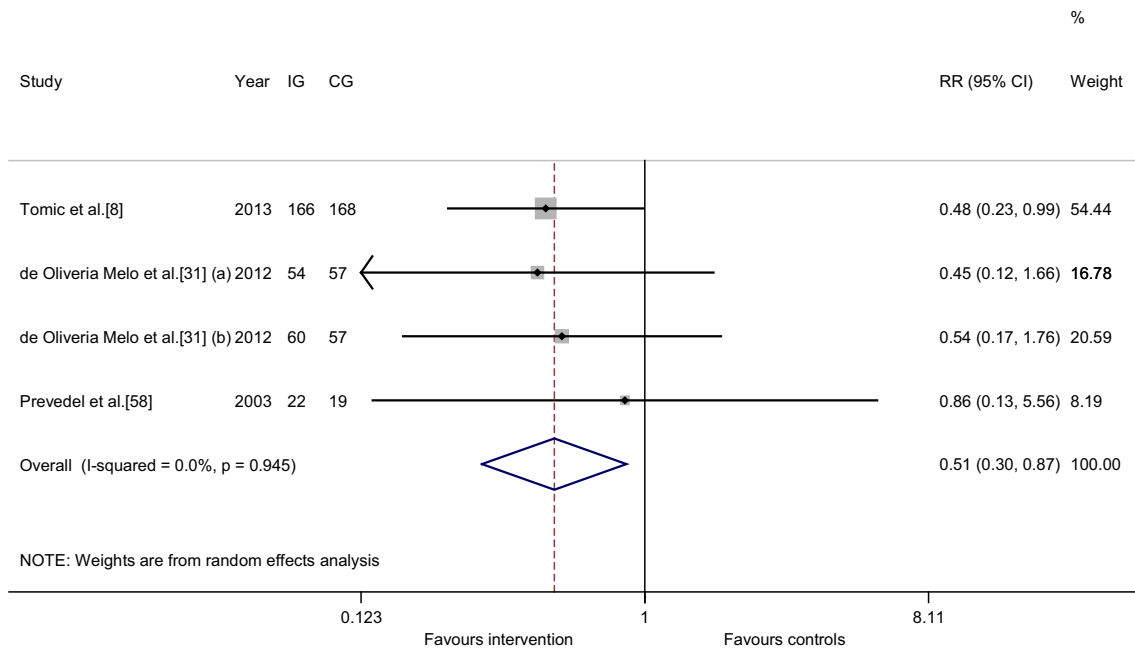


Fig. 8 Meta-analysis of the effect of physical activity on being born large for gestational age (defined as birth weight above the 90th centile or 4000 g): relative risk \pm 95 % confidence interval in randomized controlled trials. De Oliveria Melo et al. [31] (a) = exercise initiated at 13 weeks; De Oliveria Melo et al. [31]

(b) = exercise initiated at 20 weeks. The point estimate drawn represents graphically the weight of the study in the random-effects analysis. CG control group, CI confidence interval, ES effect size, IG intervention group, RR relative risk

Our systematic review and meta-analysis differs from others published in the literature in some respects because we adopted methodological criteria such as the inclusion of studies in three languages (English, Portuguese, and Spanish), allowing a greater number of studies to be included, whereas most previously published reviews included only studies in English. Furthermore, we performed a meta-analysis only with LTPA from observational studies to enable a better comparison with intervention studies, whereas other meta-analyses included all domains of physical activity (occupational, leisure-time, domestic, and active commuting) in the same analysis [6].

5 Conclusion

The available evidence supports associations between LTPA during pregnancy and the following outcomes: weight gain in pregnancy, GDM, preterm births, and LGA. No evidence of an association with preeclampsia was detected, but only three trials have been conducted on this topic so far. Collectively, our findings support the promotion of LTPA in pregnancy as a strategy to improve maternal and child health.

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Compliance with Ethical Standards

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