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Interval training and cardiometabolic health in reproductive-aged females

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Abstract

Physical activity and exercise training are especially important for reproductive-aged females as exercise-induced health benefits can also affect their infants. However, levels of physical inactivity remain high among females in this age group, before, during, and after pregnancy. There is a great need for practical and feasible exercise modes to increase adherence to exercise in this population, and interval training may be a time-efficient training modality. Interval training is a form of exercise involving intermittent bouts of intense effort interspersed with recovery periods of rest or lower-intensity exercise. A substantial amount of research indicates that interval training induces superior cardiometabolic health benefits compared with iso-energetic moderate-intensity continuous exercise. This review provides a comprehensive overview of research on interval training interventions in reproductive-aged females across various life stages, focusing on the cardiometabolic health benefits. We discuss the potential role of interval training in premenopausal females with overweight/obesity, polycystic ovary syndrome, and subfertility, as well as the potential influence of oral contraceptives on cardiometabolic adaptations to interval training. Furthermore, this review also highlights recent findings supporting the beneficial role of high-intensity interval training for cardiometabolic health outcomes during pregnancy. In summary, the existing evidence suggests that interval training can improve several cardiometabolic and reproductive outcomes in females spanning different life stages. However, more research is needed to further strengthen the evidence-base for physical activity recommendations for females in their reproductive years of life.

Keywords: Body composition, aerobic exercise, resistance exercise, exercise intensity, exercise metabolism, insulin resistance, obesity, reproduction, bone health, dyslipidemia

Introduction

Physical activity is established as a critical component of female health during preconception, pregnancy, and postpartum. For reproductive-aged females, the benefits of exercise training may not only affect their own health but also the health of their infants, since obesity and insulin resistance affect egg cell quality and the intrauterine environment (Moholdt and Hawley, 2020). Yet the majority of adolescent girls worldwide are insufficiently active (Guthold et al., 2020) and only 4-15% of pregnant individuals meet the current recommendations of 150 min of moderate-intensity physical activity per week (Santo et al., 2017, Gjestland et al., 2013, Tornquist et al., 2023). Furthermore, postpartum physical activity and exercise volumes generally remain lower than pre-pregnancy levels (Hesketh et al., 2018, Tornquist et al., 2023), and females who have given birth have lower cardiorespiratory fitness than their age-matched counterparts (Rogers et al., 2020). Practical, enjoyable approaches are clearly needed to improve adherence to exercise before, during, and after pregnancy.

Herein we review and discuss the potential of interval training, including high-intensity interval training (HIIT) and sprint interval training (SIT), as an exercise modality to improve cardiometabolic health and pregnancy outcomes in reproductive-aged females. Our aim was not to contrast the effects of interval training with those of other types of exercise, such as moderate-intensity continuous training (MICT) or strength training, rather to draw attention to interval training as an alternative exercise option in this population. However, some of the studies we discuss have made comparisons between adaptations after interval training and other forms of exercise. The interval training terminology usually differentiates between two basic types of interval training at high exercise intensities: HIIT and SIT. HIIT, can be defined as 'near maximal' efforts performed at intensities that elicits ≥ 80% (but often 85-95%) of heart rate maximum (HRmax), whereas SIT is characterised by efforts performed at intensities at or above the workload that would elicit peak oxygen uptake (VO_2peak) (MacInnis and Gibala, 2017). Both HIIT and SIT induce similar, and at times greater, improvements in cardiometabolic health outcomes when compared with moderate-intensity continuous training (MICT) (Jelleyman et al., 2015, Campbell et al., 2019, Sabag et al., 2022).

HIIT, especially low-volume protocols, is a time-efficient exercise strategy that could counter the perceived 'time constraints' barrier to physical activity in the reproductive years (Coll et al., 2017). Studies also suggest that women perceive greater enjoyment during HIIT compared with during MICT, both when pregnant and not (Li et al., 2022, Wowdzia et al., 2022, Ong et al., 2016)

Interval training and cardiometabolic health in premenopausal females

Obesity and insulin resistance are associated with infertility and pregnancy complications (reviewed by (Muhammad et al., 2023)). Maternal cardiometabolic health at the beginning of pregnancy can also have a life-long influence on the health of the offspring (Moholdt and Hawley, 2020). For females who are planning a pregnancy, interval training can be a means to increase cardiorespiratory fitness, improve insulin sensitivity and reduce fat mass. Higgins and colleagues showed that 6 weeks with three weekly sessions of 30-sec 'all-out' sprints, repeated 5-7 times interspersed with 4 min low-intensity recovery, reduced total fat mass and increased VO_2peak more than MICT of equal estimated energy expenditure in young (~20 years old) women with overweight/obesity (Higgins et al., 2016). Similarly, Zhang and colleagues showed greater visceral fat reductions after three weekly sessions of interval training for 12 weeks (three separate protocols; two of which were isoenergetic to MICT) than after MICT in young women with obesity (Zhang et al., 2021). HIIT has also been shown to be equally effective as MICT in improving VO_2peak in women aged 18-30 years with obesity, even when the energy expenditure is markedly lower (~50%) and the time spent training is less than half that of MICT (Kong et al., 2016).

Interval training can improve insulin sensitivity, which is important pre-pregnancy since fasting blood glucose, blood insulin concentrations, and insulin resistance are independent pre-pregnancy predictors of gestational diabetes (GDM) (Alwash et al., 2023). Twelve weeks of interval training, both as SIT (80 x 6-sec cycling sprints interspersed with 9 sec rest), and HIIT (9 x 4-min cycling at 90% of VO_2peak interspersed with 3 min rest) were more effective than MICT in improving insulin sensitivity in young women with overweight/obesity (Sun et al., 2019b). However, fasting glucose levels decreased only after MICT. Another study showed 23% greater clamp-derived insulin sensitivity after a 10-week HIIT programme, with two weekly sessions of 4 x 4 min work-bouts at 85-95% of HRmax and one weekly session of 10 x 1 min with maximum effort, in women with overweight/obesity referred to assisted fertilisation (Kiel et al., 2018). In summary, interval training can be a time-efficient exercise option to increase pre-pregnancy insulin sensitivity in females with overweight/obesity, but continued research is needed to establish the effectiveness of interval training on insulin sensitivity in premenopausal females outside laboratory settings.

Interval training combined with dietary interventions

Combining interval training with dietary interventions is probably more advantageous for cardiometabolic health benefits than either strategy alone. Indeed, the combination of HIIT and time-restricted eating for 7 weeks induced greater reductions in body weight, fat mass, and visceral fat area than each of these interventions on their own in reproductive-aged women with body mass index ≥ 27 kg/m^2 (Haganes et al., 2022). The adherence to the HIIT protocol, which was identical to the protocol in (Kiel et al., 2018), was > 90% of the scheduled sessions for both the isolated HIIT group and the combined HIIT and time-restricted eating group. These results indicate that HIIT, either as a sole intervention or combined with time-restricted eating, is a feasible and efficient lifestyle intervention to improve cardiometabolic health in premenopausal females. However, a study from China reported improved VO_2peak but no additional effect of either MICT or HIIT added to a 4-week low-carbohydrate diet on body weight, fasting glucose, or lipid concentrations in young females with overweight/obesity (Sun et al., 2019a). Of note, the volume of HIIT in that study was very low, with each session comprising only 2.5 min of exercise (10 x 6 sec work-bouts interspersed with 9-sec rest periods). Still, HIIT induced a ~15% improvement in VO_2peak. The corresponding improvement after MICT (comprising 30 min at 50-60% of VO_2peak) was ~17%, again showing the time-efficiency of HIIT for comparable improvements in cardiorespiratory fitness (Sun et al., 2019a).

Interval training and bone health

HIIT can also improve bone metabolism in young females, who constitute a critical osteoporosis-prevention population. (Lu et al., 2022) showed that total bone mineral density increased by 8.5% after 8 weeks of HIIT (versus 5.5% after MICT) among sedentary but otherwise healthy females and that HIIT elicited greater changes in markers of bone metabolism (1,25-dihydroxyvitamin D_3, calcaneus broadband ultrasound attenuation, and calcaneus stiffness index). The HIIT programme consisted of three weekly sessions of treadmill running, including 6 x 3-min bouts of running at 80-90% of VO_2max, separated by 2-min active recovery at 30-40% of VO_2max (Lu et al., 2022). The reason for the superior osteogenic effect of HIIT is probably that impact force is a relevant element in the stimulation of bone metabolism (Santos et al., 2017).

The influence of oral contraceptives on adaptations to interval training

Women taking oral contraceptives may not get the same cardiometabolic adaptations to interval training, compared with women experiencing regular natural menstruation (Schaumberg et al., 2017, Schaumberg et al., 2020). An observational study showed that oral contraceptive users had lesser VO_2peak and peak cardiac output adaptations after a 4-week SIT programme, compared with women with normal menstruation (Schaumberg et al., 2017). The SIT protocol included three weekly cycling sessions of 10 x 1 min sprints at 100-120% of peak power output interspersed by 2 min of passive recovery. Although VO_2peak increased in both groups (8.5% in the oral contraceptive users and 13% in those with normal menstruation), the results indicated that oral contraceptives dampened physiological adaptations to SIT. As such, exogenous ovarian hormones may limit central adaptations of oxygen delivery, which has been demonstrated by a lesser improvement in pulmonary oxygen uptake kinetics during a square-wave step-transition cycle protocol in oral contraceptive users (Schaumberg et al., 2020). Interestingly, after a 4-week follow-up (detraining period), the oral contraceptive users had a lower decline in physiological and performance adaptations, compared with normal menstruating women (Schaumberg et al., 2017). The knowledge about how the menstrual cycle and hormonal contraceptives affect physical performance and adaptations to exercise training is still incomplete.

Interval training in polycystic ovary syndrome

Interval training has also been shown to improve some cardiometabolic health outcomes in individuals with polycystic ovary syndrome (PCOS). PCOS is the leading cause of anovulatory infertility and menstrual disorders, and individuals with PCOS are at an increased risk of obesity, insulin resistance, type 2 diabetes, dyslipidaemia, and cardiovascular diseases (Teede et al., 2018, Hoeger et al., 2021, Fazleen et al., 2018, Melo et al., 2015). PCOS is characterised by excess androgen production by the ovaries as well as the adrenal glands contributing to hyperandrogenism which presents as hirsutism, acne, androgenic alopecia, and/or increased amount of testosterone, menstrual irregularities, oligo/anovulation, and insulin resistance. Abnormal steroid metabolism resulting in increased cortisol production is also a feature of

PCOS (Tsilchorozidou et al., 2003, Rosenfield and Ehrmann, 2016). Lifestyle modification, including exercise and diet, is regarded as a cornerstone in PCOS management (Teede et al., 2018), with the evidence to date suggesting that HIIT at least can provide short-term benefits for symptom management (Santos et al., 2021, Patten et al., 2020).

(Mohammadi et al., 2023) reported that an 8-week interval training programme consisting of three weekly sessions of 4 sets of 4-6 x 30-sec sprints at maximal aerobic velocity, resulted in significant reductions in body weight, fat percentage, insulin resistance (HOMA-IR), LDL, and total cholesterol levels, as well as increased estimated VO_2max. The 30-sec sprints were interspersed with 30 sec of moderate-intensity recovery, while the sets of four sprints were interspersed with 5 min passive recovery. In this study, testosterone and cortisol levels decreased significantly after SIT, compared with a no-exercise control group. In another study, 10 weeks of three weekly sessions of HIIT (two 4 x 4 min at 90-95% of HRmax and one 10 x 1 min at maximal intensity) improved insulin sensitivity (HOMA-IR) and VO_2peak (Almenning et al., 2015). Of note, these beneficial changes were evident without any significant changes in body weight, body composition, or reproductive hormones, compared with the no-exercise control group. However, a 16-week HIIT intervention, with two separate HIIT groups, one performing the 4 x 4 min protocol as described above and the other the 10 x 1 min protocol, did not induce any improvements in insulin sensitivity, body composition, VO_2peak, fat oxidation, endothelial function, or reproductive hormones (Kiel et al., 2022b, Kiel et al., 2022a, Lionett et al., 2021). The most likely reason for no effects of HIIT in this study was low adherence to the exercise protocol, with on average two sessions per week during the 16-week intervention period.

HIIT can also lead to added cardiometabolic benefits to alleviate PCOS symptoms on top of metformin therapy. (Samadi et al., 2019) showed that a 12-week aquatic 'Tabata-style' interval training programme accompanied by oral metformin improved body composition, estimated VO_2max, insulin resistance (HOMA-IR), hirsutism severity, and several sex-hormones relevant in PCOS pathology, compared with a control group of metformin only therapy. The training protocol in this study consisted of three weekly sessions with four 4-min bouts, each comprising eight rounds of 20-sec maximal effort work interspersed with 10 sec of rest. However, there were no added effect of HIIT on menstrual frequency, compared with the metformin-only control group.

Some randomised controlled trials (RCTs) have compared the effects of interval training with those of MICT on cardiometabolic outcomes in PCOS (Nasiri et al., 2022, Ribeiro et al., 2020, Patten et al., 2022). (Nasiri et al., 2022) reported similar improvements in body composition after 8 weeks of three weekly sessions of either HIIT or a combination of MICT and resistance training, but a greater increase in estimated VO_2max after HIIT. Their HIIT protocol was the same as in the study by (Mohammadi et al., 2023) above. The combination group undertook 25-40 min treadmill running at 60-70% of HR reserve, in addition to 30-40 min resistance training. In line with this, (Ribeiro et al., 2020) reported similar reductions in waist circumference without any change in body weight or testosterone levels after 16 weeks with three weekly sessions of progressive MICT or HIIT. The adherence was higher to HIIT (97%), which involved six to ten 2-min work-bouts progressing from 70% to 90% of HRmax, compared with MICT (85%), involving 30-50 min continuous walking/running at 65-80% of HRmax.

In contrast, (Patten et al., 2022) showed greater improvements in cardiometabolic and reproductive outcomes after 12 weeks of HIIT than after MICT. The HIIT protocol in this study consisted of twice weekly sessions of 12 x 1-min work bouts at 90-100% of HRpeak interspersed with 2 min low-intensity recovery and one weekly session of 8 x 4 min at 90-95% HRpeak interspersed with 2 min low-intensity recovery. The exercise protocols in this study were designed to match the minimum exercise recommendations, and the MICT consisted of three weekly sessions of 45 min continuous cycling at 60-75% of HRpeak. VO_2peak increased after both exercise protocols, but significantly more after HIIT than MICT (5.8 ml/kg/min versus 3.2 ml/kg/min), and only HIIT improved insulin sensitivity (Patten et al., 2022). Furthermore, menstrual cycle regulation improved after HIIT, independent of changes in body weight, fat mass or fat distribution.

In summary, HIIT has positive effects on several cardiometabolic and reproductive outcomes in PCOS, but with inconsistent evidence for effects on body composition, and metabolic and reproductive outcomes (hormone levels, menstrual cycle regulation). These inconsistencies can probably be attributed to the different phenotypes of PCOS and their response to exercise interventions. Differences in the duration and intensity of exercise, study sample size, and adherence rate may also contribute to varying outcomes.

Interval training and female fertility

The effect of exercise on fertility outcomes, especially in females undergoing artificial reproductive techniques (ART) has been a disputable topic among researchers. A population-based cohort study reported that exercising for 4 hours or more per week before ART was negatively associated with live births compared with females not regularly engaged in physical activity (Morris et al., 2006). In line with this, some earlier epidemiological investigations showed that higher intensity and frequency of exercise increased risks of subfertility and infertility (Gudmundsdottir et al., 2009) and delayed time to spontaneous pregnancy (Wise et al., 2012). In contrast, others reported that physical activity before IVF had no effect (Gaskins et al., 2016) or beneficial effects (Kucuk et al., 2010, Rich-Edwards et al., 2002, Chavarro et al., 2007) on reproductive outcomes. The conflicting results across the studies regarding the effect of physical activity on fertility outcomes can perhaps be attributable to the type of infertility, classification system of exercise levels, recall bias of reporting lifetime exercise, and other confounders such as dietary habits and individual variabilities.

Several recent systematic reviews and meta-analyses concluded that physical activity before ART is associated with increased rates of clinical pregnancy and live births (Rao et al., 2018, Hakimi and Cameron, 2017, Mussawar et al., 2023). In an observational cohort study by (Palomba et al., 2014), physical activity before ART was associated with a 3-fold increase in clinical pregnancy and live births. They also showed that a minimum of 30 min of vigorous exercise 3 times per week significantly increased the chance of conception in females with obesity and PCOS (Palomba et al., 2008). However, data on the effect of HIIT on fertility outcomes are scarce. In a pilot RCT conducted by (Kiel et al., 2018), 3 weekly HIT sessions for 10 weeks improved cardiometabolic outcomes in females undergoing ART, but without any significant differences in fertility outcomes. Interestingly, in the trial on HIIT in PCOS mentioned above (Kiel et al., 2022b), eight participants (~20%) in the two HIIT groups, versus none in the control group, became pregnant during the 16-week intervention period or the follow-up at 12 months from baseline. Keeping the individual differences and the confounders in mind, more studies need to be performed on the role of HIIT on reproductive outcomes in females.

Interval training during pregnancy

Regular physical activity in pregnancy is well established to be safe and effective in improving health outcomes for both mother and baby (da Silva et al., 2017). Further, vigorous-intensity exercise, typically prescribed at intensities up to 85% of maternal HRmax (MHRmax), in the third trimester of pregnancy appears to be safe for most healthy pregnancies (Beetham et al., 2019). The upper limit of exercise intensity recommended during pregnancy has historically been increasing. It was generally accepted that bed rest or 'confinement' was appropriate in early 20th-century prenatal care. In 1985, the American College of Obstetricians and Gynecologists (ACOG) issued the first guidelines for physical activity during pregnancy, in which they warned pregnant individuals to keep MHR below 140 beats/min and not to exercise for more than 15 min at a time (ACOG, 1985). In 1994, the HR-based recommendation was removed, and women were advised to base their workouts on subjective feelings of tiredness (ACOG, 1994). From around 2003, there were several physical activity guidelines for pregnancy around the world, all of which agreed that moderate-intensity exercise appeared to be safe (ACOG, 2003, Davies et al., 2003). Finally, recent guidelines suggest either high-intensity exercise *only* in a monitored environment (Mottola et al., 2018) or only for those who have previously engaged in vigorous exercise (Bull et al., 2020). As such, HIIT has only been investigated in recent years by a handful of studies.

Acute effects of interval training during pregnancy

We are at an exciting time in exercise and pregnancy research, at which there is a growing interest in examining the feasibility, safety, and efficacy of higher-intensity exercise in pregnancy. Indeed, some recent investigations have assessed the acute maternal and fetal responses to HIIT during pregnancy (Wowdzia et al., 2022, Wowdzia et al., 2023, Anderson et al., 2021, Andersen et al., 2021). In a randomised, crossover study, Wowdzia and colleagues reported that HIIT (10 x 1 min work bouts at ≥ 90% MHRmax, interspersed with 1 min active recovery) and MICT (30 min at 64-76% of MHRmax) equally reduced post-exercise interstitial glucose levels in normoglycaemic pregnant individuals (Wowdzia et al., 2022). In patients with GDM, moderate-intensity postprandial interval walking, with alternating 3 min of slow and fast walking for 20 min, was effective in reducing postprandial glucose excursions (Andersen et al., 2021). In (non-pregnant) people with type 2 diabetes, a single session of high-intensity interval walking was superior to MICT matched for oxygen consumption, time, and perceived exertion in reducing postprandial blood glucose levels (Karstoft et al., 2014). Postprandial HIIT may therefore be an efficient option for improving glycaemic control in individuals with GDM, however, the potential for HIIT to reduce blood glucose levels in pregnant people with hyperglycaemia requires further study.

Blood flow is redirected to working muscles in periods of higher intensity exercise, and the historically conservative prescription of exercise intensity during pregnancy stems from worries about compromised well-being of the fetus at high exercise intensities. However, the fetus adapts to reduced blood flow by increasing its own HR, on average by 6 bpm (Skow et al., 2019). Such an increase is a beneficial adaptation which may help to optimise the fetal autonomic nervous system and placental function (Kubler et al., 2022, Bauer et al., 2020). Whether there is an upper limit of maternal exercise (i.e., a high volume and/or high intensity of exercise) for these beneficial fetal and placental adaptations is still not known.

A recent study from (Wowdzia et al., 2023) showed no indications of fetal distress after 10 x 1 min HIIT sessions at which the intensity was ≥ 90% MHRmax, with no signs of fetal bradycardia or changes in umbilical blood flow measures (Wowdzia et al., 2023). In line with this, a study by Anderson and colleagues demonstrated that HIIT performed as circuit-based resistance training did not influence fetal HR or umbilical flow indices (Anderson et al., 2021). In this study, pregnant participants in late second and early third trimesters completed 20-sec resistance training circuits with intensity up to 90% of MHRmax, interspersed with 60-sec recovery. However, a study in pregnant Olympic-level athletes showed transient fetal bradycardia and high umbilical artery pulsatility index when the participants exercised at > 90% of MHRmax for 5 min (Salvesen et al., 2012). The clinical significance of this finding is unclear, and an earlier study suggested no adverse effects on birth weight or placenta weight after a high-volume, high-intensity exercise regime during pregnancy (Kardel and Kase, 1998). These conflicting findings may be due to the duration of the work-bouts, and fetal well-being may be compromised during prolonged exercise at high intensity.

Effects of interval training interventions in pregnancy

There are only a few RCTs of the effects of regular interval training in pregnancy on maternal and infant outcomes. Halse and colleagues conducted an RCT comparing the effects of supervised interval training on a cycle ergometer, combined with unsupervised steady-state exercise, with a usual care group in pregnant participants with diet-controlled GDM (Halse et al., 2014, Halse et al., 2015). This study found that 6 weeks of three weekly interval training sessions of up to 45 min, including 15-60 sec bouts at 75-85% of age-predicted MHRmax interspersed with 2-min moderate-intensity recovery periods, improved aerobic fitness (Halse et al., 2015) and postprandial glucose concentrations (Halse et al., 2014) compared with a usual care group. No adverse events were reported in this study. Furthermore, Wang and colleagues showed that three weekly sessions of cycling SIT reduced the incidence of GDM for individuals with overweight/obesity (22% in the exercise group versus 41% in the control group) (Wang et al., 2017). The cycling exercise programme consisted of 3-5 repetitions of 30-sec sprints interspersed with 2 min recovery, was initiated in the first trimester, and continued until gestational week 37. In the latter study, the frequency of potential adverse events, such as miscarriage and fetal death did not differ between the exercise and control groups.

A recent study showed increased VO_2 at the anaerobic threshold, reduced fat mass and increased fat-free mass after an online 8-week HIIT intervention, compared with an education-only control group (Yu et al., 2022). There is no detailed description of the HIIT protocol, but the aim was that the participants exercised in work bouts with an intensity greater than the anaerobic threshold for as long as they felt comfortable (Yu et al., 2022). The authors did not observe any adverse effects during pregnancy, childbirth, or on neonatal outcomes. Interestingly, there was a greater dropout in the education-only group compared with the HIIT group (Yu et al., 2022). This finding aligns with other studies which indicate greater enjoyment and therefore adherence with interval training (Li et al., 2022, Wowdzia et al., 2023, Ong et al., 2016).

Interval training prescription during pregnancy

Some individuals develop medical conditions during pregnancy for which exercise, particularly high-intensity exercise, is not recommended. Some countries recommend using a screening tool, such as the Get Active Questionnaire for Pregnancy from Canada (Canadian Society for Exercise Physiology, 2021), to screen for any absolute or relative contraindications to exercise. It also seems pertinent to suggest, that until further evidence becomes available, the duration of work-bouts with intensity > 90% of MHR should be ≤ 1 min. There are several ways intensity can be measured in pregnancy. Cardiovascular parameters change in pregnancy, for example, resting HR increases throughout gestation. However, maximum HR drops only slightly during pregnancy (~4 bpm) (Lotgering et al., 1991), and therefore using a percentage of MHRmax is suitable in pregnancy. However, not all women will have access to

HR monitors or know their HR max, in which case rating of perceived exertion (RPE), or the ’talk-test’, can be suitable. All these measures rate the relative intensity of the exercise, even with increasing body weight and increased dyspnoea throughout gestation. As such, the absolute workload may decrease as pregnancy progresses but still provides the same physiological stimulus to the body. Some form of HIIT can thus continue through to the end of the third trimester of pregnancy for most women.

Interval training in the postpartum period

The postpartum period, sometimes referred to as the ‘fourth trimester’, is the time after delivery when the pregnancy-related physiologic changes are returning to the non-pregnant state. The World Health Organization 2020 guidelines on physical activity and sedentary behaviour recommend that postpartum females should be physically active for at least 150 min/week, with moderate intensity (Bull et al., 2020). According to the Physical Activity Guidelines for Americans (U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, 2018), only individuals who already do vigorous-intensity aerobic exercise, can continue doing so after their pregnancy. The research underlying these recommendations is very limited and often based on expert opinion or consensus rather than empirical evidence. Moderate-to-vigorous physical activity generally declines in pregnancy and remains low postpartum (Hesketh et al., 2018, Borodulin et al., 2009). Consequently, cardiorespiratory fitness is lower postpartum compared with age-matched females who have not given birth (Armitage and Smart, 2012, Rogers et al., 2020). Since HIIT can be an efficient exercise mode for rapid improvements in cardiorespiratory fitness, such training could have a place after pregnancy to prevent a decline in fitness (**Figure 1**). We could, however, not find any studies on the effect of HIIT in the postpartum period, on maternal health outcomes or breast milk composition. Nevertheless, current expert opinions suggest a gradual start and subsequent progression of HIIT postpartum (Bø et al., 2017, Deering et al., 2020).

There are few exercise guidelines specifically for lactating people and little knowledge about the impact of exercise on breast milk composition. Based on a few observational studies (Lovelady et al., 1990, Fly et al., 1998) and one RCT (Dewey et al., 1994), the consensus seems to be that exercise does not affect milk production, composition, or infant growth (ACOG, 2020, Bane, 2015). However, some studies indicate that there is a transient increase in lactate concentrations in breast milk after high-intensity exercise (Carey et al., 1997, Wallace and Rabin, 1991). Based on these findings, it has been discussed whether increased lactate concentrations may alter the taste of breast milk, and thus reduce the infants' acceptance of the milk after high-intensity exercise (Larson-Meyer, 2002). However, (Wright et al., 2002) showed that high-intensity exercise did not impede infant acceptance of breast milk postexercise. An ongoing RCT will determine the effect of maternal HIIT on breastmilk composition in lactating people with overweight/obesity (Moholdt et al., 2023).

Concluding remarks and future perspectives

Although females are less likely than males to be included in exercise training studies (Anderson et al., 2023), emerging evidence suggests that regular physical activity undertaken as HIIT improves cardiometabolic and reproductive outcomes in reproductive-aged females spanning different life stages (**Graphical Abstract**). As such, HIIT has been shown to be beneficial in females with obesity, PCOS, diabetes, and GDM. Several guidelines suggest that moderate to vigorous activity has beneficial effects in females undergoing ART, even if HIIT is most often not mentioned specifically in such guidelines. Furthermore, evidence to date suggests that HIIT may be a suitable option also in pregnancy, yet we need more evidence of the safety of HIIT to confidently integrate it into physical activity guidelines for pregnant individuals. Recent studies also show that at least some HIIT protocols are well tolerated by the fetus. Additional research is needed on HIIT in pregnancy to provide reassurance and support to individuals who wish to participate in this type of exercise, without fear of harming themselves or their baby. Indeed, conservative advice on exercise during pregnancy may increase the fear of exercise and lead to lower levels of physical activity and reduced psychological well-being (Coll et al., 2017). Moreover, maintaining a high level of training during pregnancy may also assist with a faster return to exercise training in the postpartum period. There is a particular paucity of research on HIIT in the postpartum period, and this should be a fruitful topic for further studies. Finally, supervised HIIT may also provide a more time-efficient and enjoyable option for women who may otherwise not meet PA guidelines.

Take home message

- Physical activity levels remain low in many reproductive-aged females.
- Interval training can be an alternative exercise option, that is time-efficient and provides multiple health benefits.

- Recent studies indicate that high-intensity interval training is safe also during pregnancy.
- More research is needed to establish the safety and efficacy of interval training during pregnancy and postpartum.

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Competing interests

The authors declare there are no competing interests.

Data availability

This manuscript does not report data.

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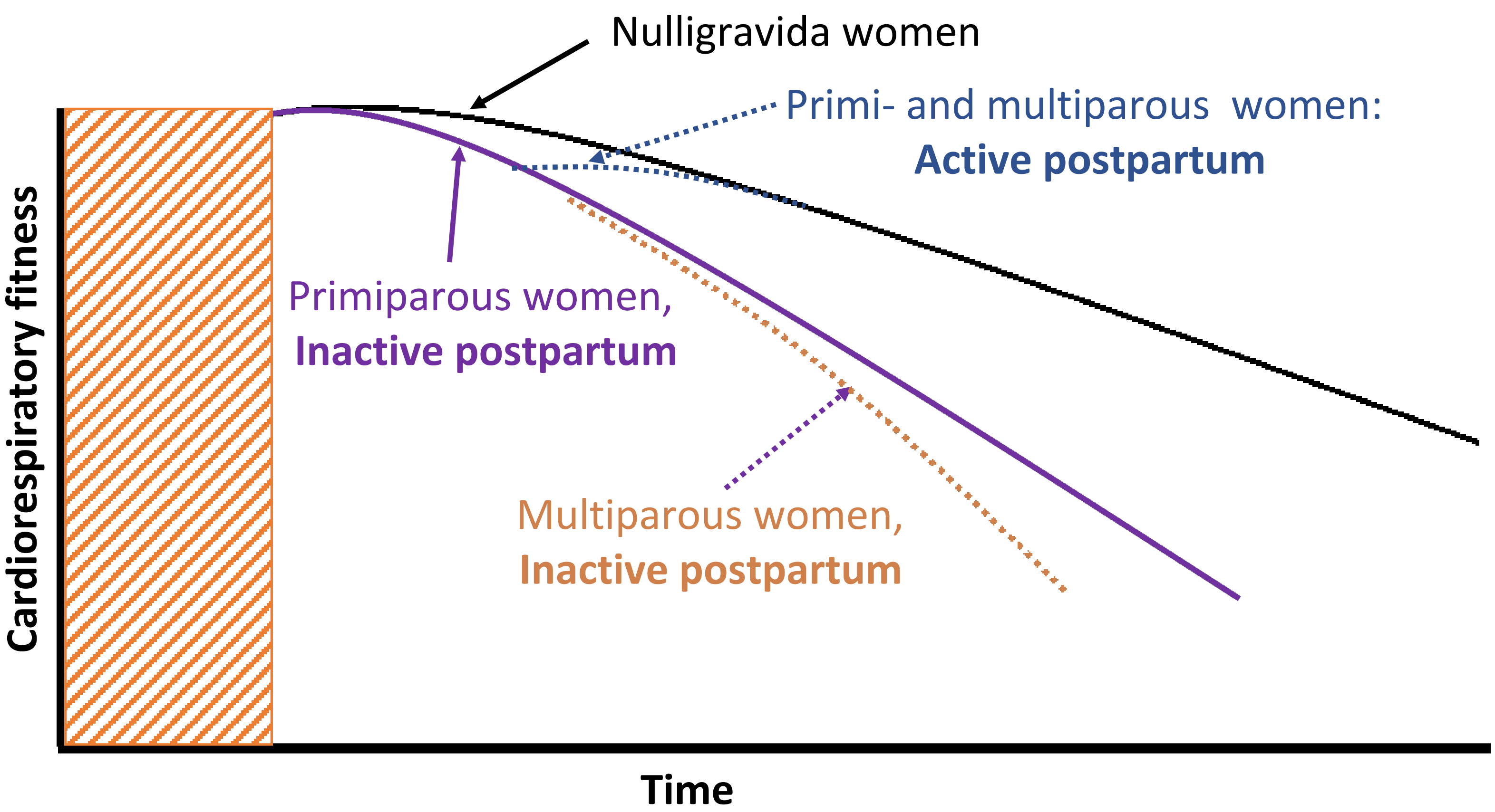
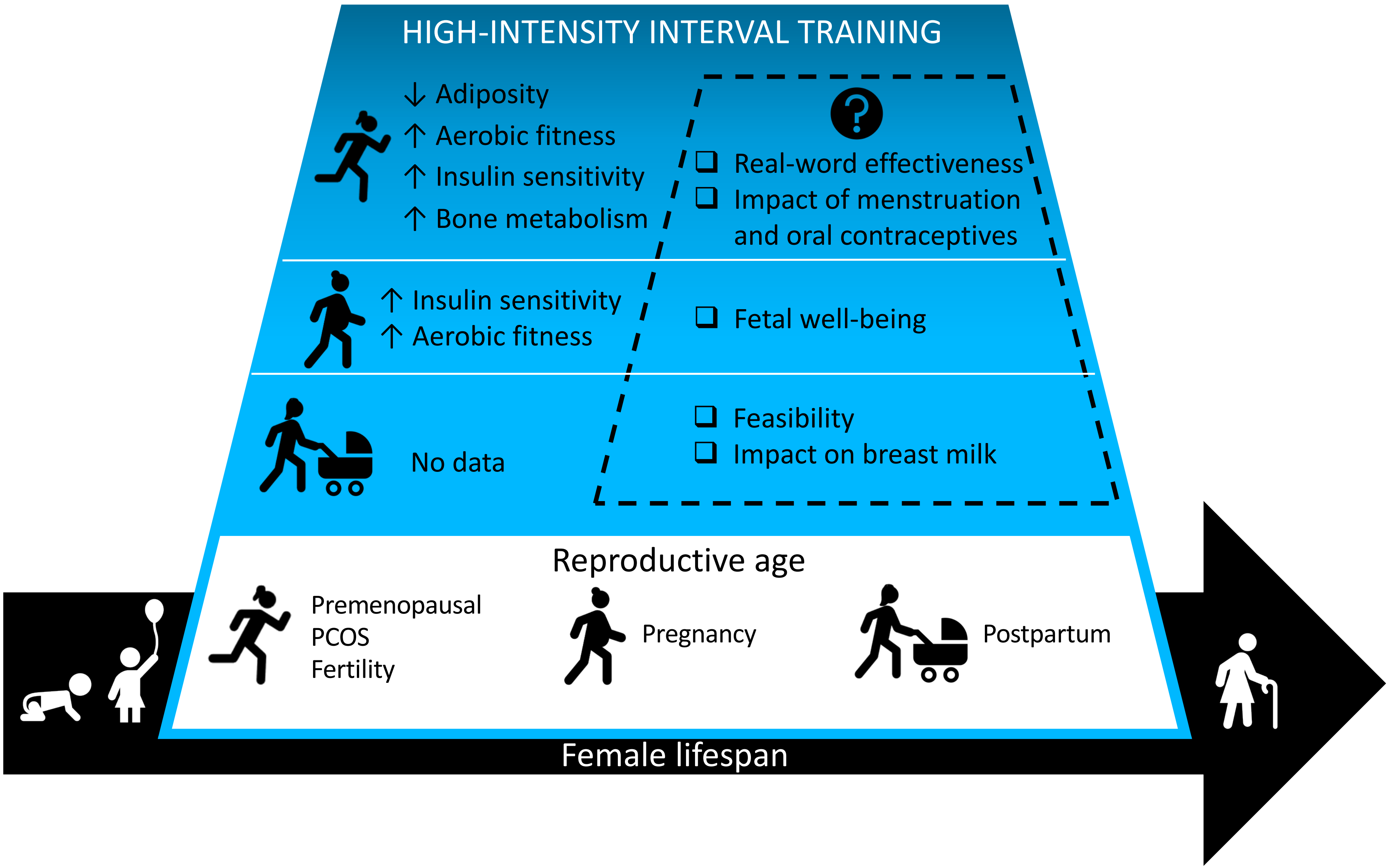
Figure legends

Graphical Abstract. Cardiometabolic effects of high-intensity interval training during the reproductive years in females. There are still some knowledge gaps to be filled.

Figure 1. The theoretical slopes of cardiorespiratory fitness during female lifespan under several different conditions: Nulligravida individuals (never pregnant), primiparous (has given birth once), and multiparous (has given birth more than once).



Nulligravida women
Primi- and multiparous women:
Active postpartum
Primiparous women,
Inactive postpartum
Multiparous women,
Inactive postpartum
Cardiorespiratory fitness
Time


HIGH-INTENSITY INTERVAL TRAINING
↓ Adiposity
↑ Aerobic fitness
↑ Insulin sensitivity
↑ Bone metabolism
❑ Real-word effectiveness
❑ Impact of menstruation and oral contraceptives
↑ Insulin sensitivity
↑ Aerobic fitness
❑ Fetal well-being
No data
❑ Feasibility
❑ Impact on breast milk
Reproductive age
Premenopausal
PCOS
Fertility
Pregnancy
Postpartum
Female lifespan