A Risk-Benefit Analysis of Maintaining an Aerobic-Endurance Triathlon Training Program During Pregnancy: A Review

Une analyse des risques-avantages du maintien d'un programme de formation d'endurance triathlon aérobie pendant la grossesse: Un examen

Short title: A review of aerobic-endurance triathlon training during pregnancy.

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Keywords: pregnancy, exercise, triathlon, swimming, cycling, running, aerobic, endurance

Mots-clés: la grossesse, l'exercice, le triathlon, la natation, le cyclisme, la course, aérobie, endurance

SUMMARY

Objectives: Possible risks and benefits of an endurance-based triathlon training program during pregnancy were assessed. **News**: Vigorous exercise throughout the third trimester can lower birthweight by 400g , but other indices of fetal wellbeing are unaffected. Fetal heart rate increases during exercise, remaining within the normal range (120-160 beats·min^{-1}). Swimming, cycling and running do not affect fetal morbidity or mortality. Performance indices such as aerobic capacity can be maintained through continuation of training.
Prospects and projects: will aid the counselling of women during pregnancy. To date no research exists regarding triathlon training during pregnancy, future studies could investigate muti-sport training whilst pregnant. **Conclusion**: Pregnancy does not require complete cessation of triathlon training and can include each of the three sports. However, maternal heart rate (MHR) should not exceed 90% of maximal.

Objectifs: Les risques et les avantages possibles d'un programme de formation de triathlon à base d'endurance pendant la grossesse ont été évalués. **Actualités**: L'exercice vigoureux tout au long du troisième trimestre peut abaisser le poids de naissance par 400g, mais d'autres indices de bien-être fœtal ne sont pas affectés. Fœtal augmente la fréquence cardiaque pendant l'exercice, en restant dans la plage normale (120-160 battements · min-1). Natation, vélo et course n'affectent la morbidité ou la mortalité fœtale. indices de performance tels que la capacité aérobie peut être maintenue grâce à la poursuite de la formation.
Perspectives et projets: aidera à conseiller les femmes pendant la grossesse. À ce jour, il n'existe pas de recherche sur la formation au triathlon pendant la grossesse, des études futures seront menées lors de la pratique du muti sportif pendant la grossesse. **Conclusion**: Par conséquent la grossesse ne nécessite pas l'arrêt complet de la formation de triathlon et peut

inclure chacun des trois sports. Cependant, la fréquence cardiaque maternelle (MHR) ne doit pas dépasser 90% du maximum.

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SUMMARY

Possible risks and benefits of an endurance-based triathlon training program during pregnancy were assessed. Vigorous exercise throughout the third trimester can lower birthweight by 400g , but other indices of fetal wellbeing are unaffected. Fetal heart rate increases during exercise, remaining within the normal range (120-160 beats·min^{-1}). Swimming, cycling and running do not affect fetal morbidity or mortality. Performance indices such as aerobic capacity can be maintained through continuation of training. Therefore pregnancy does not require complete cessation of triathlon training and can include each of the three sports. However, maternal heart rate (MHR) should not exceed 90% of maximal.

Les risques et les avantages possibles d'un programme de formation de triathlon à base d'endurance pendant la grossesse ont été évalués. L'exercice vigoureux tout au long du troisième trimestre peut abaisser le poids de naissance par 400g, mais d'autres indices de bien-être fœtal ne sont pas affectés. Fœtal augmente la fréquence cardiaque pendant l'exercice, en restant dans la plage normale (120-160 battements · min-1). Natation, vélo et course n'affectent la morbidité ou la mortalité fœtale. indices de performance tels que la capacité aérobie peut être maintenue grâce à la poursuite de la formation. Par conséquent la grossesse ne nécessite pas l'arrêt complet de la formation de triathlon et peut inclure chacun des trois

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1. INTRODUCTION

Triathlon is an aerobic endurance sport involving sequential swimming (0.75–3.90km), cycling (20-180km) and running (10-42km) with distances varying according to event. A competitive triathlete must complete each section as fast as possible without accumulating fatigue and altering homeostasis. Aerobic-based training causes functional adaptations within the body including increased aerobic capacity, measured as the volume of oxygen utilised per minute ($\dot{V}O_{2max}$). A high $\dot{V}O_{2max}$ is seen as a hallmark characteristic of elite triathlon performance [1]. Elite female triathletes have treadmill $\dot{V}O_{2max}$ values of 65.6 $ml \cdot kg \cdot min^{-1}$, whilst cycling values are approximately 94-97% and swimming 64-86% of treadmill values [2, 3]. In a normal population of 20-29 year old female, mean treadmill $\dot{V}O_{2max}$ is 40.3 $ml \cdot kg \cdot min^{-1}$[4].

Pregnancy induces physiological changes that support fetal development, largely co-ordinated by hormonal changes [5]. Angiogenesis increases the vascular bed, providing support to the growing uterus and fetus. This requires an increase in blood volume, achieved by sodium and water retention and by stimulating thirst [6]. Sufficient oxygen delivery to the fetus is achieved by the action of progesterone, increasing chemosensitivity to CO_2, [7]. This stimulates respiratory drive at a lower level of CO_2. Urinary frequency increases, due to bladder smooth muscle relaxation and increased fluid intake [8]. An increased incidence of back pain due to anterior relocation of the centre of gravity may restrict activity [9].

A competitive triathlete planning to continue to train throughout pregnancy needs to consider the effects of exercise upon the fetus and the pregnant mother, plus whether swimming, cycling and running are safe to carry out during pregnancy.

In 2006 the Royal College of Obstetricians and Gynaecologists (RCOG) issued a statement on exercise during pregnancy [10]. The guidelines give an overview of the evidence on the effects of pregnancy adaptations upon physical activity, as well outlining the benefits of exercise during pregnancy. It is suggested that previously sedentary individuals limit their heart rate to 60-70% of maximal maternal heart rate (MHR), whilst active individuals limit themselves to 60-90%.

Redistribution of maternal blood flow to working muscles during exercise may cause transient reduction in blood flow to the fetus, potentially affecting birthweight and neurodevelopment [11].

A correlation between maternal heat exposure and increased incidence of neural tube defects (NTD) has been shown in women using hot tubs whilst pregnant [12]. Heat production increases during exercise due to increased respiration and energy release, therefore might impact upon fetal development.

During pregnancy, the effects of exercise upon the mother must also be considered as her body will be undergoing significant physiological adaptation, and in addition the placenta develops for adequate substrate delivery to the fetus [13, 14]. The relaxin-induced laxity of ligaments as well as the shift in centre of gravity may increase the likelihood of exercise induced injury [9].

Triathlon training programs are designed for an individual but some characteristics are universal; the focus being aerobic-based exercise at submaximal intensity. Duration will vary, although will typically be greater than 45 minutes.

In addition to the potential risks, training must provide a benefit with regards to maintaining adaptations that are characteristic of triathlon performance, as well as facilitating an effective resumption of pre-pregnancy training and return to competition after delivery.

Conducting a trial to study effects of triathlon training during pregnancy is not possible due to the international spread of elite triathlon and the number of female triathletes who conceive within a set timeframe. Elite athletes would be reluctant to follow a plan that deviates from their own for standardisation, or cease training to form a control group. Instead, a search of the literature was conducted. To date, there has been no specific research into the risks or benefits of triathlon training whilst pregnant. The aim of this research is to assimilate existing data on aerobic exercise during pregnancy to determine whether triathlon-specific training, including swimming, cycling and running at the necessary intensity, would be safe during pregnancy. Therefore training alterations can be implemented to reduce risk and maximise benefit.

2. METHODS

A United States National Library of Medicine National Institutes of Health, PubMed, search was conducted using the terms ‘exercise AND pregnancy’, which returned 3688 results. This was refined using the filters specifying studies conducted in English and in ‘humans only’, which returned 2601 results. To ensure that these studies were relevant to a risk-benefit analysis of triathlon training during pregnancy additional search terms were used. A search of ‘pregnancy AND swimming’ returned 123 results, ‘pregnancy AND cycling’ returned 403 and ‘pregnancy AND running’ returned 295. A search of ‘pregnancy AND triathlon’ returned zero results.

The results of the search were then read and irrelevant articles were removed, which returned 59 relevant results.

These papers were then categorised according to whether they addressed neonatal outcome, maternal outcome or exercise performance. Within each of these three sub-sections the information was collated. Where available, 95% confidence intervals (CI) have been given in addition to the data. Where mean values are given, plus or minus the standard error of the mean (SEM) has been given when available.

3. RESULTS

3.1 Effects of maternal exercise upon fetal development

After 60 minutes of stationary cycling at 50-60% of $\dot{V}O_{2max}$, maximum mean rectal temperature in ten women at 25-35 weeks gestation was 37.8 °C, an increase of 0.6°C from the mean basal temperature recording [15]. In another study, rectal temperature measurements were taken during upright cycling at three different intensities and durations (mean HR between 138 to 156 beats·min^{-1}), where maximal increase was 0.4°C [16].

At greater intensity, exercise at 75% of $\dot{V}O_{2max}$ increases core body temperature by 1.3°C, to 38.5°C in non-pregnant subjects [15].

Indices of fetal well-being, including fetal heart rate (FHR), uterine artery pulsatility index (PI) and mean uterine artery volume blood flow, were measured in six pregnant Olympic-level endurance athletes (cross country skiing, duathlon, and long distance running) during five minutes of treadmill running, repeated three to five times [17]. Gestational age ranged from 23 weeks to 29 weeks, therefore normal ranges for PI and FHR were <1.5 and 110-160 beats.min^{-1} respectively. The FHR responses to percentage of maximal MHR are shown in figure 1.

The two episodes of fetal bradycardia corresponded with high umbilical artery PI (1.67 and 1.65), with a reduction of umbilical artery volume flow of 37% and 42% from basal levels. Measurements taken in ten minutes following cessation of exercise showed that FHR, umbilical artery PI and umbilical artery blood flow all returned to normal. Four of the mothers in this study gave birth between 39-41 weeks of gestation, birthweight in five out of six cases was > 3 kg. One infant was induced at 35 weeks due to pre-eclampsia, weighing 2.3 kg.

Effects of maternal exercise upon FHR are shown in table 1 [18]. FHR increased in response to exercise in all but one study. A drop of 30 beats·min^{-1} in FHR occurred after cessation of maximal exercise, but had returned to normal within 2 minutes.

In addition to a mean increase in FHR of 15 ± 11 beats·min^{-1} reported by Clapp et al., 1993, results showed a greater magnitude of FHR increase in response to exercise as gestational age increased. FHR increases 10 ± 8 beats·min^{-1} during early gestation and 20 ± 11 beats·min^{-1} during late gestation [19]. Measurements were taken in mothers who were 16-39 weeks pregnant.

A meta-analysis of 30 studies found weighted mean difference (WMD) in birthweight between infants born to endurance-exercising mothers, who continued exercise into the second trimester, and sedentary height- and weight-matched controls was not significant (WMD -56.8 g, CI – 165.9, 52.3g) [20]. When continued into the third trimester, the mean birthweight of infants born to endurance exercisers was found to be 212.2 (CI -275.5, -148.9) g less than those born to active controls, and 436.5 (CI -605.5, -267.5) g less than sedentary controls. Results from 4458 pregnant women showed that ≥ 3hours of sport per week during the second trimester gave a lower birthweight by 2 g, and by 9g if continued into the third trimester compared to women who did no sport, once adjusted for confounding variables such as body mass index and smoking [21]. When mothers carried out two or more of swimming, cycling, running, aerobics or dancing during the second trimester, adjusted difference in birthweight compared to sedentary controls was -10 g, and -61 g in the third trimester. With regards to intensity, moderate to heavy exercise in the second trimester corresponded to an adjusted increase in weight of 21 g and when continued into the third trimester a reduction of 23 g [21].

The neurodevelopment of infants born to mothers following a structured exercise protocol (n=188) was assessed using the Bayley Scales of Infant Development – III (BSID) and compared to controls (n=148).[22] No significant differences were found between the two groups. The BSID was used to assess neurodevelopment of 52 infants aged 361 ± 3 days old born to mothers who exercised regularly and 52 control infants [23]. There was no significant difference in psychomotor or mental scores between the groups.

3.2 Effects of exercise on the pregnant woman

Women who continued endurance-based exercise throughout pregnancy gave birth 2-8 days earlier than controls [20, 24]. A Cochrane review found that there was no statistically significant increased risk of preterm birth with maternal aerobic exercise [25].

No statistically significant difference in pregnancy induced changes in glucose sensitivity index was found between the control (baseline S^1 7.24 to 3.74) and the exercising group (baseline S^1 7.98 to 3.63) or in the acute insulin response [26]. Umbilical cord blood sample concentrations of insulin-like growth factors (IGF), IGF-I and IGF-II were significantly reduced in the offspring of exercising mothers (IGF-I, control group = 45ng/ml, exercise group = 32ng/ml and IGF-II, control group = 421ng/ml, exercise group = 371ng/ml). There was no difference in concentrations of leptin, plasma glucose, or insulin.

Maternal energy requirements throughout pregnancy increase from an additional 70 kcal·day^{-1} during the first trimester, 300 kcal·day^{-1} during the second and 450 kcal·day^{-1} during the third. [27]. Recommended weight gain during pregnancy is 11.5-16kg [13]. In addition to the energy demands of the fetus, aerobic exercise increases glucose metabolism and as such will further increase energy demand.

The effect of exercise on placental development has been studied using 11 women who continued running throughout pregnancy and 11 non-running controls that had been matched for diet, height and weight [28]. There were no significant differences in birth outcomes or total placental volume. Villous vascular volume (runners = 77, controls = 47, $p<0.05$), total dividing nuclei (runners 123, controls = 76, $p<0.01$) and proliferation index (runners = 29, controls = 45, $p<0.01$) were all significantly greater in the intervention group.

3.3 Triathlon Training Components

Triathlon poses a relatively unique challenge as the effects of swimming, cycling and running during pregnancy have to be considered.

Swimming

Hydrostatic force upon immersion in water causes increased circulating blood volume and cardiac output with a compensatory decline in MHR of approximately 10 beats·min^{-1} and blood pressure by approximately 10 mmHg [29]. Once out of the water there was no effect upon fetal heart rate [30]. Immersion also caused profound dieresis, which occurred without any change to serum osmolarity or sodium levels [31].

Women in their 25th week of pregnancy cycled at 70% of $\dot{V}O_{2max}$ on a stationary bike both on land and in water. Fetal tachycardia, FHR >160 beats·min^{-1} within 20 minutes of cessation occurred in six out of seven fetuses. When the bike was placed underwater, fetal tachycardia was observed in one fetus [32].

Shoulder deep submersion also affects the respiratory system, with significant reduction in forced vital capacity, maximum ventilatory capacity and expiratory reserve volume [33].

Cycling

Numerous studies into the effects of exercise during pregnancy have used cycling-based exercise interventions with no reports of adverse outcome upon mother or fetus [26, 34, 35]. A cohort study of 34,508 pregnancies in Norway showed that cycling was the second most popular form of exercise at 17 and 30 weeks of gestation, with 14.6% and 8.5% participation respectively [35].

No significant differences in cardiorespiratory responses to exercise when cycling upright compared to semi-supine for 12 minutes at a MHR of 135-145 beats·min^{-1} were found in women 34-38 weeks pregnant [36]. Table 2 shows the responses measured at rest and during the cycling exercise.

Running

An observational, cross sectional study of 110 competitive long distance runners showed that 71% continue to run whilst pregnant, at a lower intensity than pre-pregnancy[37]. However, only 31% continued into the third trimester. A 33 year old elite marathon runner continued to cover 107 ± 19 km·week^{-1} at 130-140 beats·min^{-1}, whilst pregnant with twins [38]. Training ceased three days before elective Caesarean section, with no health complications for mother or either infant. Running efficiency was affected, with mean running velocity decreasing from 4.00 m·s^{-1} (at a HR of 150 beats·min^{-1}) to 3.42 m·s^{-1}. Similarly, two long-distance runners each continued an un-altered programme of over 64 km·week^{-1} due to unawareness of pregnancy, before reducing the distance [39]. Both gave birth to healthy infants.

3.4 Performance benefits of exercise during pregnancy

A group of well conditioned recreational athletes maintained their pre-pregnancy exercise regime ± 10% throughout pregnancy and no difference in absolute $\dot{V}O_{2max}$ was measured between two months pre-conception (3083 ± 469 ml·min^{-1}) and six to eight weeks post-partum (3079 ± 416 ml·min^{-1}) [40]. By 16 weeks post-partum, the absolute $\dot{V}O_{2max}$ had significantly increased (3338 ± 452 ml·min^{-1}).

A study of women from a range of sporting backgrounds, from sedentary to high-level competitors, found no change in absolute $\dot{V}O_{2max}$ values through treadmill or cycle testing during each trimester and seven weeks post-partum [41]. No significant difference was found in $\dot{V}O_{2max}$ during pregnancy (table 3) in previously physically fit females who continued to train throughout pregnancy [42]. In addition, ventilatory equivalents for both O_2 ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$) decreased significantly compared to pregnancy levels when measured 12 weeks post-partum.

3.5 Post-partum considerations

Rapid resumption of exercise post-partum was achieved by an elite marathon runner whose mean running distance was 50 km·week^{-1}, four to eighteen weeks after giving birth, after which she averaged 98 km·week^{-1} [43].

Women who carried out exercise at >70% of maximal MHR for >45min (mean = 88min·day^{-1}) at least five times per week whilst breastfeeding, produced a greater volume of breastmilk with higher nutritional content, once adjusted for infant gender [44]. Maximal exercise immediately prior to breastfeeding increases the lactic acid content of the milk (from 0.67mmol·L^{-1} pre-exercise to 2.97mmol·L^{-1} 30 minutes after cessation) and affects the infant's acceptance [45]. This rise was associated with an increase in maternal perception that their infant was rejecting breastmilk.

4. DISCUSSION

There are no previous investigations into triathlon training during pregnancy. The aim of this review was to use pre-existing data to conclude whether it would be safe to continue training during pregnancy.

Birthweight is unaffected by aerobic exercise throughout the second trimester, but reduction of 212-437g occurred when vigorous exercise was continued into the third [20, 21]. However, the mean birthweight remained over 3000g in each of the six studies, therefore exercise does not reduce birthweight to 'low-birthweight'. No correlation exists between exercise and reduction in birthweight in infants who are born to mothers who did over 30 min of exercise daily, supporting the continuation of longer duration, sub-maximal exercise sessions. In infants born to exercising mothers, any difference in weight occurred due to reduced neonatal fat mass whilst crown-heel length and lean body mass were unchanged [20]. This suggests that maternal adaptations, such as increased insulin resistance, ensure that the fetus is supplied with adequate substrate for growth. The slight reductions that exist may be due to lower concentrations of IGF-I and IGF-II [26]. Continuation of triathlon training throughout the third trimester is unlikely to cause adverse neonatal outcome related to birthweight.

FHR monitoring provides a measure of fetal distress and well-being. If exercise severely restricted blood flow to the fetus it would suffer acute hypoxia and FHR would decrease [19]. FHR increased during both maximal and submaximal exercise and returned to basal measurements soon after cessation. This suggests that fetal well-being is not compromised by a reduction in blood flow and oxygen supply during exercise. Correlation between increased FHR response and gestational age is representative of a maturing response to a reduction in pO_2 [19]. The reduction in FHR reported in one study was a fetal response to a drop in MHR after maximal exercise. Exercising at intensities below 90% of MHR_{max} ensures umbilical artery blood flow remains above 50% of basal levels, thus avoiding fetal bradycardia [17]. Fetal morbidity and mortality was unaffected by the exercise interventions that investigated FHR responses [18].

Two studies have shown, using the Bayley Scales of Infant Development that exercising during pregnancy does not have any adverse effects upon neurodevelopment[22, 23].

Indices of fetal well-being both during and after pregnancy suggest that maternal physiology ensures continuous adequate oxygen and substrate delivery to the fetus. Birthweight, FHR and neurodevelopment would be affected if exercise caused substantial reduction in blood flow [11]. Therefore transient reduction in blood flow during aerobic exercise does not affect fetal or infant development. Maternal exercise >90% MHR_{max} did reduce umbilical blood flow over 50% and induced fetal bradycardia. However, triathlon is a sub-maximal sport and therefore training is unlikely to involve repeated maximal exertion.

Fetuses are vulnerable to temperature extremes as they have no thermoregulatory capability. Temperature in pregnant individuals should not exceed 38.9°C or rise more than 1.5°C above basal measurements [46]. However, maternal thermoregulation remains adequate to protect the fetus during exercise [16]. Therefore aerobic exercise is unlikely to cause neural tube defects through increased maternal temperature. Gestational age at delivery was slightly reduced in infants born to exercising mothers with an average ranging from 2-8 days earlier that non-exercising controls [20, 24]. This is unlikely to cause adverse neonatal outcome since infants are considered born at term within a 35 day period.

Triathlon training and pregnancy induce conflicting alterations to insulin resistance. Aerobic exercise leads to an increased sensitivity of insulin increasing glucose supply to working muscle [47]. In late pregnancy there is a shift towards insulin resistance with preferential delivery to the fetus [26]. Exercise-induced insulin sensitivity is overridden by maternal regulation to achieve optimal delivery to the fetus throughout pregnancy [26]. The increase in acute insulin response is also not affected by exercise during pregnancy, preventing fluctuations in blood glucose. However, reductions in umbilical cord concentration of the growth factors IGF-I and IGF-II are likely to down-regulate fetal growth and may be responsible for observed reductions in birth weight of infants born to mothers who continue to exercise during late pregnancy.

Maintaining an exercise programme whilst pregnant will combine the substrate demands placed upon the body by both exercise and the fetus. Maternal calorie intake must meet the demands of daily living, exercise and pregnancy to ensure appropriate weight gain and avoid fatigue and illness. If continuing triathlon training during pregnancy, calorie intake needs to include an additional 300 $kcal \cdot day^{-1}$ and 450 $kcal \cdot day^{-1}$.in the second and third trimesters respectively. In addition, any calories burned during aerobic exercise should be replaced to avoid negative energy balance.

There is an increase in cell proliferation in the placenta of mothers who continued to run throughout pregnancy [28]. The mechanism thought responsible is a transient reduction in placental blood flow during exercise stimulating the vascular endothelial growth factor (VEGF) system that promotes angiogenesis [14]. As a result of exercise, placental growth occurs and oxygen and substrate delivery is increased at rest.

A potential risk of exercising during pregnancy is that of musculoskeletal injury due to anatomical and biomechanical changes. Changes in centre of gravity puts strain on the lumbar vertebrae, whilst increased ligament laxity puts the knees at risk of injuries, including patello-femoral dysfunction [9]. The effects of anatomical changes are difficult to predict and so must be dealt with as they arise. Severe back pain may warrant cessation of running whilst patello-femoral dysfunction may restrict cycling.

Effective triathlon training will involve incorporating swimming, cycling and running. Swimming is popular during pregnancy, perhaps due to the bodyweight-supporting effects of the water, and has not been associated with adverse neonatal outcome. The enhanced thermal conductivity of water does mean that the water has to be at an optimum temperature (33.5°C - 35.5°C) as extremes of temperature will affect the pregnant female's ability to self-thermoregulate [29]. Therefore pregnant triathletes should be advised to swim in temperature controlled pools as opposed to lakes or the sea. Swimming may also be associated with favourable FHR responses.

Cycling has often been used as the modality for exercise intervention and has not been associated with harm to a fetus. Short duration semi-supine cycling had no effect on cardiorespiratory variables [38]. However over longer durations there may be risk of aortocaval compression.

Running distances as far as 107 km·week^{-1} whilst pregnant followed by uncomplicated delivery of a healthy infant have been reported [38]. Therefore continuation of running training as part of triathlon training is unlikely to be associated with any harm.

Individual training programs could incorporate all three modalities, with frequency, intensity and duration adjusted to the requirements of the mother as long as MHR remains below 90% of maximum.

Continuation of a training program may have aerobic performance benefits as it has been shown to aid maintenance of $\dot{V}O_{2max}$ from pre-pregnant levels. However, both studies failed to express relative $\dot{V}O_{2max}$ taking body weight into account. Had they done so, it is likely that a decrease in $\dot{V}O_{2max}$ would have been observed reflective of the steady maternal weight gain. Submaximal predictions based on expired gases measured in high level athletes showed no loss of aerobic fitness during pregnancy if training was continued [42]. Reduction in ventilatory equivalents seen post-partum is indicative of hyperventilation associated with pregnancy.

After giving birth, resumption of normal training can be achieved and may be more successful if the athlete maintains high self-efficacy, motivation and time-management [48]. Exercise does not lower the volume or nutritional content of breast milk, however breastfeeding should be avoided soon after maximal exercise [49]. Using a breast pump may also provide greater flexibility and aid comfort by reducing breast fullness whilst exercising [34].

Limitations exist as data has not been collected from triathletes but has been reported from results in a variety of participant backgrounds, from previously sedentary to elite endurance athletes. Consideration has been made for all aspects of triathlon training. Technique adopted by triathletes whilst running, swimming or cycling does not differ, therefore it can be assumed if no adverse effects occur in females from other sporting backgrounds, it is likely to be true for triathletes. Some of the training interventions were of short duration, whereas women who compete at long distance triathlon may wish to incorporate long-duration sessions. Data from numerous sources was used with a range of exercise interventions, including case studies. The most effective methodology would have been obtaining data from triathletes themselves but as discussed in the introduction, there are difficulties with regards to data collection within this study population.

In conclusion, based on the available evidence, endurance-based swimming, cycling and running training are unlikely to pose a substantial risk to the mother or fetus and therefore cessation is not warranted. However, to protect against fetal bradycardia, intensity of sessions should be maintained below 90% of maximal MHR. Reduction in birthweight is correlated with vigorous exercise in the third trimester so reduction of exercise intensity after 29 weeks of gestation should be considered, especially if the fetus is judged small for its gestational age by an obstetrician. Exercise will not compromise fetal well-being provided nutritional and energy intake is adequate and may provide some benefits. Given the performance-predictive value of $\dot{V}O_{2max}$ in triathlon [1], if hoping to continue to train with a successful return to competition post-partum it would be advisable to maintain a training program that addresses maintenance of $\dot{V}O_{2max}$. Studies have shown that $\dot{V}O_{2max}$ can be maintained if training is continued [41].

The RCOG recommends that an elite athlete be overseen by an obstetrician with knowledge of the effects of strenuous exercise. This should be adhered to in the case high-level triathlon training. If any contra-indicated conditions arise during pregnancy then training must stop for the sake of maternal and fetal health.

Disclosure of interests

The authors declare that they have no conflicts of interest.

Contribution to authorship

A.V.H proposed the concept of the review, whilst E.L.H decided upon triathlon. E.L.H performed the literature review and wrote the paper whilst A.V.H supervised the project, aided the interpretation of results and provided editing help. Both authors approved the final version.

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Illustrations

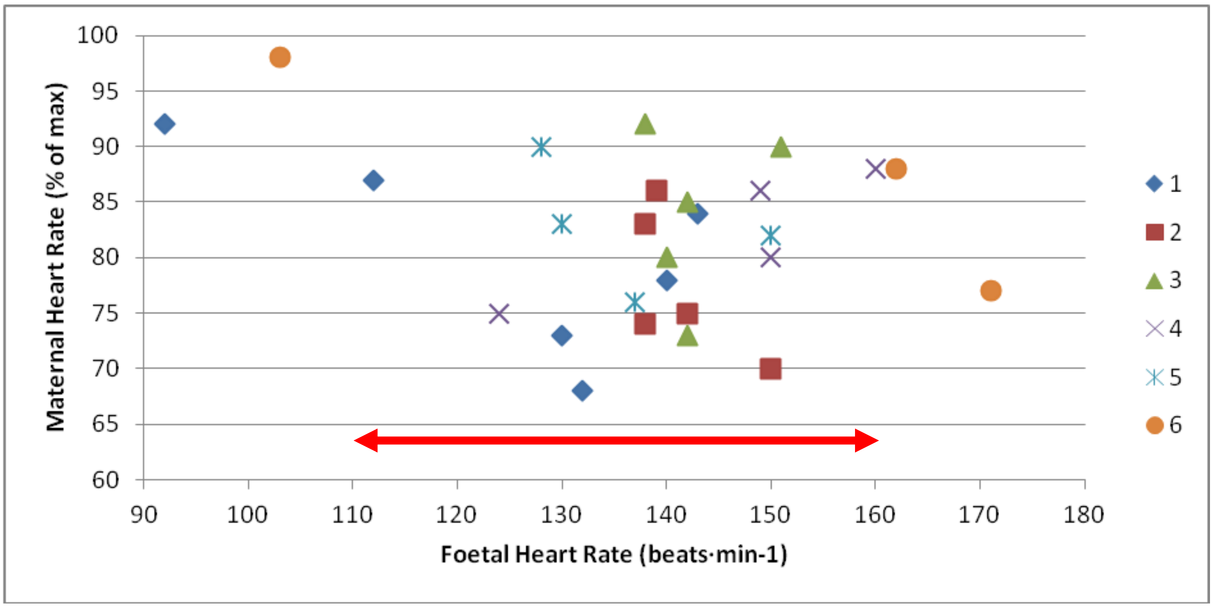

Figure 1. Fetal heart rate (FHR) at different levels of maternal activity, monitored by percentage of maximal maternal heart rate (MHR) during treadmill running. The red arrow indicates the normal FHR range for gestational age. Two examples of fetal bradycardia and two cases of fetal tachycardia were observed, three from the same subject. The red arrow indicates the normal range for fetal heart rate. Adapted from Salvesen et al., 2012 [17]

Author	Number of trained/ control participants	Intensity /duration	Time in pregnancy	Effects on FHR and/or blood flow
Clapp et al., 1993 **[19]**	120 various sports	≤70% $\dot{V}O_{2max}$/ 20min	16-39th g.w	↑ FHR 15 ± 11 beats·min^{-1} at 60% of $\dot{V}$O2max
Webb, 1994 **[50]**	22/16 bicycling	70%$\dot{V}O_{2max}$/ 25 min	2nd and 3rd trimester	↑ FHR 3-7 beats·min^{-1}

Van Doorn et al., 1992][51]	33 bicycling	$\dot{V}O_{2max}$/ until $\dot{V}O_{2max}$ reached	16th, 25th, 35th g.w and 7 wk post-partum	↑ FHR 4 beats·min^{-1}
Watson et al., 1991[52]	13 bicycling, swimming	$\dot{V}O_{2max}$/45 min	25th and 35th g.w	↓ FHR 30 beats·min^{-1} in 15%for less than 2 min.
Erkkola et al., 1992 [53]	8 bicycling	HR ≤ 170 beats·min^{-1}	25-38th g.w	Increased utero-placental resistance resulting in ↓ blood flow
MacPhail et al., 2000 [54]	23 cycle ergometer	$\dot{V}O_{2max}$/ until $\dot{V}O_{2max}$ reached	31-38th g.w	FHR 6 beats·min^{-1}greater 10-20min after exercise compared with 0-10 min after exercise.

g.w = gestational week

Table 1. Details of studies conducted to investigate FHR responses to maternal exercise. Adapted from Rieman & Kanstrup Hansen, 2000 [18]

	Rest		Exercise	
	Semi-Supine (n=27)	Upright (n=23)	Semi-Supine (n=7)	Upright (n=23)
Maternal HR (beats.min^{-1})	85	84	137	142

O2 Consumption ($mL.min^{-1}$)	207	260	1163	1247
Minute ventilation ($L.min^{-1}$)	9.4	8.3	38.1	37.3
Respiratory rate ($breaths.min^{-1}$)	16	12	25	21
Cardiac output ($L.min^{-1}$)	6.3	5.9	11.3	12.3
Stroke volume (mL)	76	71	82	89
Systolic BP (mmHg)	110	107	157	146
Diastolic BP (mmHg)	68	70	75	78

Table 2. The maternal cardiorespiratory responses to cycling measured at rest and during 12 minutes of cycling. Adapted from O'Neill, 2006 [36].

	25^{th} gestational week	36^{th} gestational week	12 weeks post-partum
HR ($beats \cdot min^{-1}$)	138 ± 3	138 ± 7	139 ± 3
$\dot{V}O_2$ ($ml \cdot min^{-1}$)	1447 ± 256	1388 ± 224	1532 ± 192
$\dot{V}_E/\dot{V}O_2$	32.7 ± 4.3	33.3 ± 3.5	29.4 ± 5.9*
$\dot{V}_E/VCO_2$	33.7 ± 4.3	34.6 ± 3.6	29.7 ± 4.0*

* significantly different ($P < 0.01$) compared to other gestational ages.

Table 3. Mean cardiorespiratory data from 11 physically active women during submaximal cycle ergometer testing. Measurements were taken during the second and third trimester of pregnancy and 12 weeks post-partum. Adapted from Pivarnik et al., 1993 [42]