# The effects of exercise during pregnancy on haemodynamics

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# The Effects of Exercise During Pregnancy on Haemodynamics

Submitted by

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## Extended abstract

During pregnancy the maternal body undergoes significant physiological changes, with some of the most profound changes occurring within the cardiovascular system. Many of the cardiovascular changes occur within the first month or two of pregnancy including an increase in blood volume, cardiac output, heart rate and stroke volume, which are all associated with a decrease in vascular resistance and systemic vascular tone. Maladaptive changes to these maternal haemodynamic processes can occur during gestation, increasing the risk of gestational hypertensive conditions. Regular exercise performed during pregnancy has been shown to reduce the risk of developing perinatal gestational hypertensive conditions. Further evidence on the exact parameters of exercise needed to explain these beneficial responses is required, within both uncomplicated and at-risk pregnancies.

Chapter 1 provides a general review of the literature on exercise in pregnancy, and introduces the thesis aims. The topics covered in the general literature review include: gestational hypertensive conditions of pregnancy and the short to long term maternal and foetal consequences; exercise guidelines in pregnancy; arterial function in pregnancy and the effects of exercise on arterial function in non-pregnant populations. The detailed methods for Studies 2, 3, 4 and 5 are outlined in Chapter 2. Further methods applicable to each of the specific studies are reported in the relevant chapters.

Chapter 3 comprises a systematic review and meta-analysis investigating the effects of aerobic and resistance exercise on blood pressure in uncomplicated and at-risk pregnancies. The findings showed that compared to usual care, aerobic and/or resistance exercise performed throughout uncomplicated pregnancy had no influence on blood pressure. In women who are at risk of, or diagnosed, with gestational hypertensive conditions during pregnancy, moderate to vigorous exercise during pregnancy improves blood pressure outcomes. Higher risk pregnancies may reduce their risk of future cardiovascular complications through regular exercise training during pregnancy.

Chapter 4 includes a case study which aimed to observe the acute effects of a submaximal graded exercise test on arterial stiffness and blood pressure longitudinally throughout pregnancy. A healthy pregnant woman was recruited from five weeks of gestation to perform

weekly submaximal graded exercise tests on the treadmill until 35 weeks of pregnancy. An aged matched non-pregnant control was recruited to perform weekly – fortnightly sessions over 30 weeks. The primary outcome measures included: arterial stiffness measured by pulse wave velocity (PWV) and pulse wave analysis (PWA), blood pressure (BP), and mean arterial pressure (MAP). The findings showed a gradual decrease in resting arterial stiffness throughout pregnancy, with the greatest response in PWV following exercise seen in the first trimester. Resting systolic (SBP), diastolic (DBP) and MAP all followed similar trends decreasing from trimester 1 (T1) to trimester 2 (T2), before increasing again in trimester 3 (T3). The findings lead us to speculate that the ability of the maternal cardiovascular system to adapt to submaximal exercise may decrease as gestation progresses, which led to the design of Chapter 5.

A cross-sectional analysis of 34 pregnant participants is included in Chapter 5, in which the immediate effects of vigorous intensity exercise at various gestational weeks on vascular function is assessed. Baseline submaximal testing data from the participants in Chapters 6 and 7 were analysed. Based on the findings from this study, it is suggested that the maternal body is able to adapt to stressful stimuli, with the cardiovascular system recovering quickly (within 10 minutes) following vigorous intensity exercise. Further research in pregnancy is warranted on the acute effects of vigorous exercise on arterial stiffness given the varied responses seen in this study.

Chapter 6 was designed to assess the feasibility of vigorous intensity interval training (VIIT), along with resistance training (RT) and reformer Pilates (PIL) in pregnancy. Most of the available research to date on the acute effects of exercise in pregnancy has focused on one type or intensity of exercise (e.g. walking/cycling at moderate intensity). Given the varied benefits derived from a balanced exercise program incorporating aerobic and resistance exercise, it is important to understand the acute physiological effects of these different modes. Pilates was identified as a low to moderate intensity mode of exercise which has a paucity of evidence in pregnancy despite its increase in popularity over the past decade. The three modes of exercise in this study proved feasible in the second and third trimesters of uncomplicated pregnancies. All participants were able to achieve the prescribed intensities for VIIT, RT and PIL, with VIIT perceived as more difficult later in gestation despite similar cardiovascular responses between modes. This could be due to an increase in fatigue and

discomfort associated with progressing gestation rather than an increased cardiovascular response.

A longitudinal crossover trial was employed in Chapter 7 which aimed to observe the effects of VIIT, RT and PIL on arterial stiffness and BP completed weekly throughout pregnancy. We specifically wanted to observe whether the acute response to these three modes of exercise changed as pregnancy progressed. Resting measures of arterial stiffness, BP and HR followed trends previously outlined in longitudinal studies of pregnancy. PWV was significantly higher immediately and 10 minutes following VIIT and RT, but only immediately post Pilates, indicating a greater response with more intense exercise. Similarly, significant increases in MAP and BP were seen following VIIT and RT but not Pilates. Despite these differences in arterial pressure, along with a greater increase in MHR with more intense exercise, foetal heart rate (FHR) responses remained similar and within normal clinical limits regardless of type of exercise or exercise intensity. The findings in Chapter 7 support VIIT as an apparently safe mode of exercise throughout gestation, with 229 VIIT sessions in 20 participants closely monitored across the course of the study.

A summary of the outcomes from all studies is provided in Chapter 8. This chapter discusses the practical implications of the thesis findings and makes recommendations for future research in this area. The thesis findings indicate that acute cardiovascular responses to exercise change as gestation increases. Further longitudinal research is imperative throughout pregnancy to facilitate the development of trimester-specific guidelines for exercise. While vigorous exercise seems to be safe and achievable during gestation, incorporating shorter bouts of higher intensities may enhance enjoyment and therefore adherence in pregnancy. Nonetheless, it is worth noting that it is hypothesised that engaging in higher intensity exercise during the later stages of pregnancy may not yield significantly greater benefits compared to moderate intensity workouts, due to alterations in resting cardiovascular measures.

## Declaration by author

This thesis contains no material that has been extracted in whole or in part from a thesis that I have submitted towards the award of any other degree or diploma in any other tertiary institution.

No other person's work has been used without due acknowledgment in the main text of the thesis.

All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees.

Courtney Giles

## Contributions by others to the thesis

The conception, design and editing of all sections of this thesis were contributed to by my supervisors Dr Kassia Beetham, Dr Jemima Spathis and Associate Professor Rich Johnston. All supervisors, including Associate Professor Michael Baker, contributed to the revision of the manuscript and chapters for final approval. Associate Professor Rich Johnston provided statistical advice on all Chapters 3-7. Kate Oxnard contributed to the data collection for Studies 4 and 5. Jade Kubler contributed to the data extraction and bias assessment in Study 1. Participants in the experimental studies were recruited through the ACU ELC, and Pear Exercise Physiology Clinic. Esme Soan contributed to the recruitment of participants through Pear Exercise Physiology Clinic.

## Individual contributions to the thesis

I contributed to the conception and design of all studies included in this thesis. For Study 1, I developed the search strategy, conducted the search and filtered through the results, analysed the included studies, performed bias assessments, extracted the data, performed the meta-analysis and wrote the paper. For Studies 2-5 I designed the protocol and advertising, recruited participants, delivered exercise sessions, collected and analysed outcome measures.

## Publications included in the thesis

One first author manuscript has been published in an international, peer-reviewed journal and is included in full in Chapter 3, with the journal formatted version provided in Appendix 1.

Giles C, Johnston R, Kubler J, Spathis J, Beetham K. The effects of aerobic and resistance exercise on blood pressure in uncomplicated and at risk pregnancies: A systematic review and meta-analysis. Womens Health (Lond). 2023;19:17455057231183573.

**Contributions by authors to the publication**

| Contributor | Contribution | Signature |
|---|---|---|
| Courtney Giles (Candidate) | Conception and design of study<br>Design of search terms and criteria<br>Revision of papers/data collection<br>Statistical analysis<br>Compilation of manuscript<br>**Total contribution (65%)** |  |
| Rich Johnston | Conception and design of study<br>Assistance with statistical analysis<br>Critical revision of manuscript<br>**Total contribution (5%)** |  |
| Jemima Spathis | Conception and design of study<br>Revision of papers/data collection<br>Critical revision of manuscript<br>**Total contribution (10%)** |  |
| Jade Kubler | Revision of papers/data collection<br>Critical revision of manuscript<br>**Total contribution (5%)** |  |
| Kassia Beetham | Conception and design of study<br>Design of search terms and criteria<br>Critical revision of manuscript<br>**Total contribution (15%)** |  |

**<u>Other publications during candidature</u>**

Beetham KS, Giles C, Noetel M, Clifton V, Jones JC, Naughton G. The effects of vigorous intensity exercise in the third trimester of pregnancy: a systematic review and meta-analysis. BMC Pregnancy Childbirth. 2019;19(1):281. https://doi.org/10.1186/s12884-019-2441-1

**Statement of appreciation**

I am very proud to have finished this thesis in such an important field of research. My passion for women's health has grown over the course of this degree, and I have been able to grow as both a researcher and an exercise physiologist. I am sincerely grateful to the Australian Catholic University for providing me with the opportunity to pursue and complete my PhD journey. The support and resources offered by ACU have been instrumental in shaping my academic growth and fostering an encouraging learning environment. I extend my gratitude to the School of Behavioural and Health Sciences for their support throughout my Master's degree to the completion of my doctoral studies.

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at ACU, and I look forward to continuing to learn from each of you as I progress in my academic career!

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**List of abbreviations and acronyms**

ABPM – Ambulatory blood pressure monitoring

ACSM – American College of Sports Medicine

ACU – Australian Catholic University

ACU HREC – Australian Catholic University Human Research Ethics Committee

AEP – accredited exercise physiologist

AKI – acute kidney injury

ALT – alanine aminotransferase

APGAR – appearance, pulse, grimace, activity, respiration

AST – aspartate aminotransferase

AIx – augmentation index

AP – augmentation pressure

BGL – blood glucose levels

BP – blood pressure

BMI – body mass index

baPWV – brachial-ankle pulse wave velocity

CO – cardiac output

CVD – cardiovascular disease

cfPWV – carotid-femoral pulse wave velocity

cm – centimetres

DBP – diastolic blood pressure

DIC – disseminated intravascular coagulation

ESSA – Exercise and Sports Science Australia

ELC – Exercise Lifestyle Clinic

FHR – foetal heart rate

FHx – family history

GDM – gestational diabetes mellitus

GHTN – gestational hypertension

GP – general practitioner

GW – gestational week

HBPM – home blood pressure monitoring

HDPs – hypertensive disorders of pregnancy

HELLP – Haemolysis, Elevated Liver enzymes and Low Platelet syndrome

HIIT – high intensity interval training

HR – heart rate

$HR_{max}$ – heart rate maximum

HRR – heart rate recovery

HTN – hypertension

Hx – history

ISSHP – International Society for the Study of Hypertension in Pregnancy

IUGR – intrauterine growth restriction

kg – kilograms

km – kilometres

LDH – lactate dehydrogenase

LMPA – light to moderate physical activity

LPA – light physical activity

MAP – mean arterial pressure

MeSH – Medical Subject headings

METs – metabolic equivalents

m – metres

$m.s^{-1}$ – meters per second.

MICT – moderate intensity continuous training

MPA – moderate physical activity

MVPA – moderate to vigorous physical activity

N/A – not applicable

NO – nitric oxide

NP – non-pregnant

NR – not reported

$O_2$ – Oxygen

OBGYN – obstetrician gynaecologist

PFMT – pelvic floor muscle training

PA – physical activity

PlGF – placental growth factor

PEH – post exercise hypotension

PE – pre-eclampsia

$PHR_{max}$ – age predicted heart rate maximum

PIL – reformer Pilates

PP – pulse pressure

PWA – pulse wave analysis

PWV – pulse wave velocity

RCT – randomised controlled trial

RPE – rating of perceived exertion

RM – repetition maximum

RT – resistance training

RoB 2 – Revised Cochrane risk of bias tool for randomised trials

SOMANZ – Society of Obstetric Medicine of Australia and New Zealand

SD – standard deviation

SV – standard variances

SV – stroke volume

SBP – systolic blood pressure

TPR – total peripheral resistance

T1 – trimester 1

T2 – trimester 2

T3 – trimester 3

T1DM – Type 1 diabetes mellitus

T2DM – Type 2 diabetes mellitus

UBF – uterine blood flow

VIIT – vigorous intensity interval training

VPA – vigorous physical activity

WHO – World Health Organisation

# Chapter 1. Introduction and general review of the literature

## 1.1 Introduction

### 1.1.1 Maternal adaptations in pregnancy

During pregnancy the human body undergoes significant physiological and anatomical adaptations (1-3). These changes involve every system of the body, with some of the most profound modifications occurring within the cardiovascular, haematological, endocrine and metabolic systems (Figure 1) (1, 3). There are known fluctuations in these changes across gestation, with most adaptations occurring to accommodate an increased demand from the developing foetus (2). Many of the physiological changes that occur throughout pregnancy can be attributed to the endocrine system, with an increase in the release of certain hormones triggering a cascade of adaptations throughout the body (3). For example, the release of relaxin from the corpus luteum and placenta helps mediate the release of nitric oxide (NO), which in turn has a systemic vasodilatory effect. This decrease in total peripheral resistance (TPR), helps maintain blood pressure (BP) in the presence of increased blood volume triggered by upregulation of the Renin Angiotensin Aldosterone system (4). Other major adaptations include: an increase in lung tidal volume and minute ventilation by 30-50% (5), increased maternal metabolic demand by 85-500 calories per day (6) and an increased activation of the prefrontal cortex responsible for increasing maternal nursing behaviour (2), just to name a few. It is essential that pregnant women's bodies are able to make these rapid adaptations in order to handle the increased physical and metabolic demands required for a successful live birth (1, 7). These rapid changes give rise to a greater opportunity for maladaptation to occur. Preventing maladaptive responses in pregnancy is vital in ensuring positive maternal and foetal outcomes.

### 1.1.2 Maternal cardiovascular adaptations in pregnancy

Many of the cardiovascular changes commence within the first month or two of pregnancy including an increase in blood volume, cardiac output (CO), resting maternal heart rate (HR) and stroke volume (SV) (2, 3). These measures reach a plateau near the start of the second trimester as seen in Figure 2 (8, 9). During pregnancy, blood volume has been shown to increase as much as 50% from pre pregnancy levels. With this there is a concurrent increase in cardiac output of 30-50%, from a rise in stroke volume and HR (7). However, BP does not usually increase during uncomplicated pregnancy due to an accompanying decrease in peripheral vascular resistance (25-30%) and systemic vascular tone, particularly within the uterine circulation (2, 7, 10).

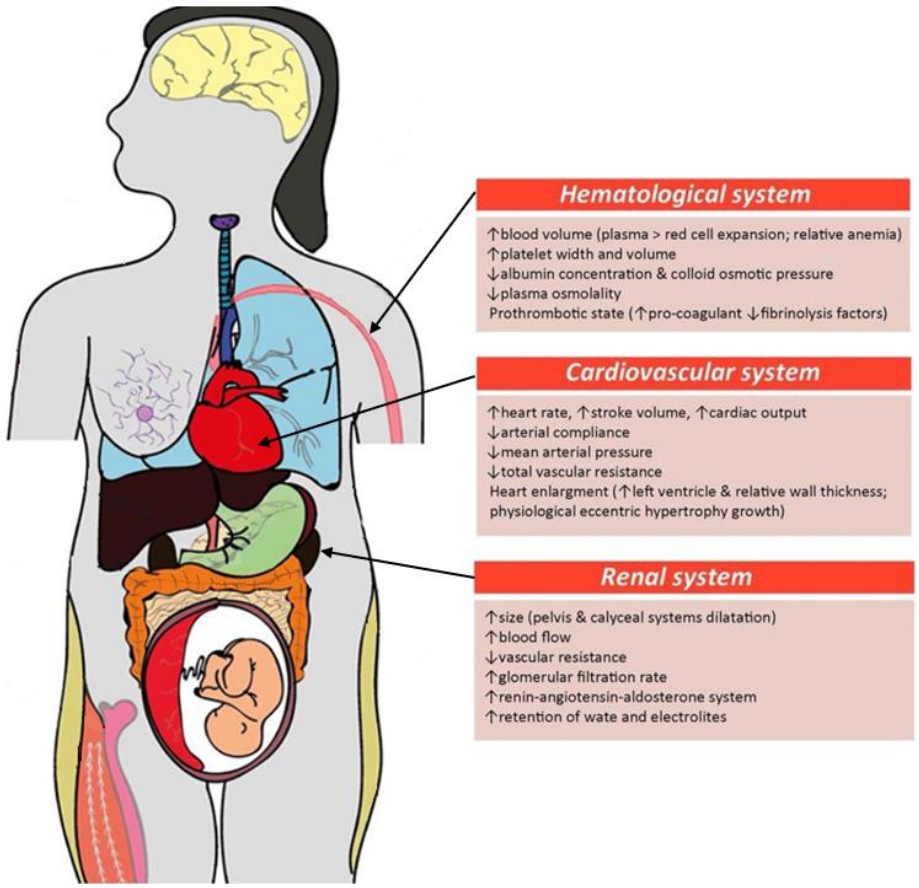



Figure 1. Schematic diagram highlighting the main physiological modifications in the maternal physiology in response to pregnancy adapted from (2)

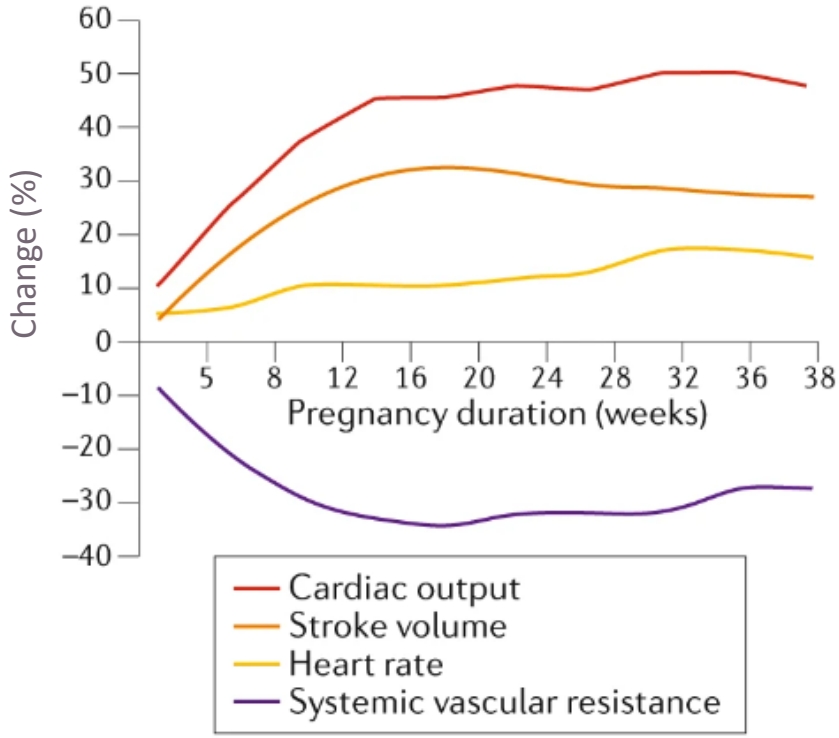



Figure 2. Haemodynamic changes throughout pregnancy based on data from (9) created by (8)

### 1.1.3 Blood pressure trends in pregnancy

During pregnancy, in response to vasoactive substances (e.g. NO), growth factors and haemodynamic stimuli, the structural components of blood vessel walls are altered through the dynamic process of vascular remodelling (10, 11). The structure and function of arteries are altered through remodelling to accommodate the increased blood volume and subsequent cardiac output, and to ensure that the endothelial shear rates (the force created when blood flow acts on the endothelium) remain within healthy limits (10, 12). A curvilinear reduction in BP associated with vascular remodelling and vasodilation has been observed in healthy pregnancies, with a nadir reached between the end of the first trimester and the beginning of the second trimester (10, 13). Systolic blood pressure (SBP) then rises on average by 5.6 mmHg by 40 weeks of gestation following the drop during trimester two. Diastolic blood pressure (DBP) reaches its lowest around 21 weeks but shows an overall increase from pre-pregnancy of 6.9 mmHg (13). *Figure 3* demonstrates the average SBP and DBP throughout gestation reported in a systematic review of 39 studies (13). These values, however, have been shown to differ between healthy and pathological pregnancies (11, 14). Where normal pregnancy is characterised by a low systemic vascular resistance and an increased CO, the adaptations are often reversed in hypertensive pregnancies (BP > 140/90 mmHg) (15). An increase in the stiffness of systemic arteries and higher total vascular resistance is typical of pregnancies complicated with pre-eclampsia (PE), with these changes persisting 6 months post-partum (15).

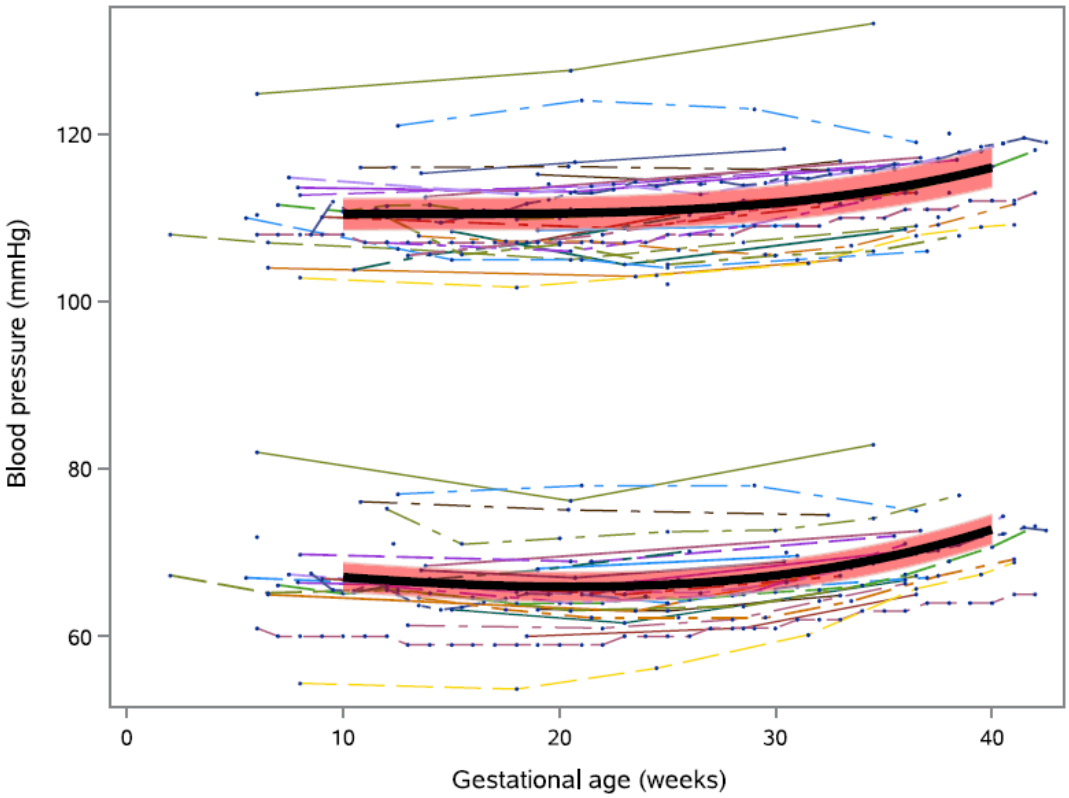



Figure 3. Mean BP (solid black line), with 95% CI (red band) by gestational age. Trajectories of individual studies are shown (thin lines) (13)

### 1.1.4 Hypertensive disorders of pregnancy

Hypertensive disorders of pregnancy encompass a range of diagnoses, including chronic hypertension, gestational hypertension (GHTN), PE and eclampsia (16). There are discrepancies in the literature on certain aspects of the classification, diagnosis, and treatment of gestational hypertensive conditions (17, 18). Defining these conditions is often difficult as they are characterised by a group of clinical features occurring together leading to diagnosis, rather than any one specific clinical feature (19). The discrepancy in classifications complicates research on the effects of gestational hypertensive conditions on maternal and foetal outcomes (17). The International Society for the Study of Hypertension in Pregnancy (ISSHP) (17) and the Society of Obstetric Medicine of Australia and New Zealand (SOMANZ) (18) provide very similar classifications of the different hypertensive disorders of pregnancy. Hypertension is broadly defined as SBP ≥ 140 mmHg and/or DBP ≥ 90 mmHg (18). *Table 1* outlines the classification of the hypertensive disorders of pregnancy provided by the ISSHP (17) and SOMANZ (18).

Table 1. Classification of hypertensive disorders of pregnancy (20)

| Type of hypertensive disorder | Definition |
|---|---|
| ***Pre-pregnancy or at < 20 weeks*** | |
| **Chronic hypertension** | Hypertension (SBP ≥ 140 and/or DBP ≥ 90 mmHg) detected pre-pregnancy or before 20 weeks' gestation |
| ***Essential*** | Hypertension without a known secondary cause |
| ***Secondary*** | Hypertension with a known secondary cause (e.g. renal disease) |
| **White-coat hypertension** | SBP ≥ 140 and/or DBP ≥ 90 mmHg when measured in the office or clinic, and BP < 135/85 mmHg using HBPM or ABPM readings |
| **Masked hypertension** | BP that is < 140/90 mmHg at a clinic/office visit, but ≥ 135/85 mmHg at other times outside the clinic/ office |
| ***≥20 weeks*** | |
| **Gestational hypertension** | Hypertension arising *de novo* at ≥ 20 weeks' gestation in the absence of proteinuria or other findings suggestive of pre-eclampsia |
| ***Transient gestational hypertension*** | Hypertension arising at ≥ 20 weeks' gestation in the clinic, which resolves with repeated BP readings |
| **Pre-eclampsia** ***De novo*** | Pre-eclampsia (de novo) is gestational hypertension accompanied by one or more of the following new-onset conditions at ≥ 20 weeks' gestation:<br>1. Proteinuria<br>2. Other maternal end-organ dysfunction, including:<br>- Neurological complications (e.g., eclampsia, altered mental status, blindness, stroke, clonus, severe headaches, or persistent visual scotomata)<br>- Pulmonary oedema<br>- Haematological complications (e.g., platelet count < 150,000/μL, DIC, haemolysis)<br>- AKI (such as creatinine ≥ 90 μmol/L or 1 mg/dL)<br>- Liver involvement (e.g., elevated transaminases such as ALT or AST > 40 IU/L) with or without right upper quadrant or epigastric abdominal pain)<br>3. Uteroplacental dysfunction (e.g., placental abruption, angiogenic imbalance, foetal growth restriction, abnormal umbilical artery Doppler waveform analysis, or intrauterine foetal death). |
| ***Superimposed on chronic hypertension*** | Among women with chronic hypertension, development of new proteinuria, another maternal organ dysfunction(s), or evidence of uteroplacental dysfunction (as above). |

ABPM = ambulatory 24-hour BP monitoring; AKI = acute kidney injury; ALT = alanine aminotransferase; AST = aspartate aminotransferase; BP = blood pressure; DBP = diastolic BP; DIC = disseminated intravascular coagulation; HBPM = home BP monitoring; HDPs = hypertensive disorders of pregnancy; SBP = systolic BP.

#### *1.1.4.1 Chronic hypertension*

Chronic hypertension in pregnancy is diagnosed when hypertension (SBP ≥ 140 mmHg and/or DBP ≥ 90 mmHg) is detected pre-pregnancy, or prior to 20 weeks of gestation (17, 18). It can be further classified as either essential (idiopathic – no known secondary cause) or secondary (known secondary cause e.g. renal disease) (17, 18). It is estimated that 3-5% of pregnancies worldwide are afflicted with chronic hypertension (20).

#### *1.1.4.2 White coat hypertension*

White Coat hypertension refers to an increased BP (≥ 140/90 mmHg) when measured in a clinical setting/in the presence of a clinician (e.g. GP, nurse), with normal BP readings found when assessed outside of clinical settings (e.g. home monitoring) (17, 18). The reported prevalence of white coat hypertension in pregnancy is inconsistent (21), with reports ranging from 4% (22, 23) to 30% (24).

#### *1.1.4.3 Masked hypertension*

Masked hypertension is essentially the opposite of white coat hypertension, with normal BP readings when assessed clinically (< 140/90mmHg) and raised BP when measured in a non-clinical setting (e.g. ambulatory or home monitoring) (17, 18). Around 30% of 'at risk' pregnancies are reportedly affected by masked hypertension, whilst the prevalence in normal pregnancies is unknown (25).

#### *1.1.4.4 Gestational hypertension*

Gestational hypertension is defined as hypertension (≥ 140/90 mmHg) arising after 20 weeks of pregnancy, without the presence of proteinuria, biochemical or haematological abnormalities (e.g., platelet count < 150,000/μL, DIC, haemolysis) (17, 26). These measurements need to be confirmed with repeated measures over the space of several hours to rule out white coat hypertension (18). These definitions are consistent with international guidelines and hypertension diagnosis criteria in non-pregnant populations (17, 18). Severe hypertension is classified as a SBP greater than or equal to 160 mmHg and/or a DBP greater than or equal to 110 mmHg, confirmed on repeated measures (17, 18). This condition is associated with an increased risk of maternal and foetal morbidity and mortality and requires urgent treatment so BP can be lowered promptly (18, 27).

#### *1.1.4.5 Pre-eclampsia*

Pre-eclampsia is a multi-system disorder involving the onset of GHTN and at least one other organ system and/or the foetus (18).

One or more of the following signs of new onset organ involvement are present in the diagnosis of PE as outlined by SOMANZ and ISSHP (17, 18):

- Renal involvement:
    - Significant proteinuria – spot urine protein/creatinine ratio ≥30mg/mmol. Proteinuria is the most recognised additional feature after hypertension but should not be considered mandatory to make the diagnosis of PE
    - Serum creatinine > 90 μmol/L, 1 mg/dL
- Liver involvement:
    - Raised serum transaminases (e.g. ALT or AST > 40IU/L from a normal baseline, in the absence of alternative diagnoses for such changes) with or without right upper quadrant or epigastric abdominal pain
- Haematological involvement:
    - Thrombocytopenia (< 150,000 μ/l)
    - Features of haemolysis: decreased haptoglobin with or without fragmented red cells, elevated lactate dehydrogenase (LDH)
    - Disseminated intravascular coagulation (in the absence of alternate diagnoses for such changes)
- Neurological involvement:
    - Seizure (eclampsia)
    - Features of cerebral irritability: hyperreflexia with sustained clonus, persistent headache, persistent visual disturbances (photopsia, scotomata, cortical blindness, posterior reversible encephalopathy syndrome, retinal vasospasm)
    - Cerebrovascular accident
- Pulmonary oedema
- Features of placental dysfunction

- Sonographic features of foetal growth restriction or deceleration in foetal growth trajectory associated with abnormal umbilical artery Dopplers or oligohydramnios (in the absence of alternate diagnoses for such changes).
- Liver involvement (elevated transaminases e.g. ALT or AST > 40IU/L) with or without right upper quadrant or epigastric abdominal pain)

International guidelines agree that the terms 'severe' and 'mild' should no longer be used in reference to PE in clinical settings, as all cases should be considered as potentially life-threatening (19).

### 1.1.5 Pregnancy specific conditions

PE and GHTN are pregnancy specific disorders that pose significant risks to both mums and infants. Indeed, elevated BP is the leading cause of maternal and foetal morbidity and mortality worldwide (28, 29). The exact cause of GHTN has not yet been established, but it is believed to develop early in pregnancy and is a precursor to the development of PE (29-31). The aetiology of PE is not yet fully understood, with placental dysfunction and poor uteroplacental perfusion due to immunologic changes proposed as contributing mechanisms (16, 29). Indeed, it is widely accepted that the pathogenesis of PE is complex, and likely multifactorial (16).

### 1.1.6 Classification of PE

The categorisation of PE by gestational age has been proposed, with 34 and 37 weeks of gestation used as cut off points (32). The timing of diagnosis may suggest different etiologic and pathophysiologic pathways through which the disease arises (32). *Table 2* provides the classification of PE according to gestational age provided by (32).

Table 2. Classification of pre-eclampsia according to gestational age

| Gestational Age | Terminology |
|---|---|
| **GA < 34 weeks** | Early-onset pre-eclampsia |
| **GA ≥ 34 weeks** | Late-onset pre-eclampsia |
| **GA < 37 weeks** | Preterm pre-eclampsia |
| **GA ≥ 37 weeks** | Term pre-eclampsia |

GA = gestational age

### 1.1.7 Incidence

The rates of GHTN and PE are estimated to be at an all-time high globally, with between 8-13% of all pregnancies effected by these conditions (26, 33). Rates of gestational hypertensive conditions have been on the rise over the past 30 years, alongside increasing rates of maternal obesity and an increase in maternal age within western societies (18, 33). Improved monitoring and detection of gestational hypertensive conditions has also become available, making it unclear whether the rates of women with these conditions are increasing at the rate that evidence has indicated, or whether cases that once would have been undetected are now being identified. Given the difficulties in defining PE, determining the incidence across different countries is a challenge for researchers (19, 34). There have been significant regional differences identified, with incidence rates as low as 0.4% being reported in Vietnam, whilst the condition is common in women with recent African ancestry (up to 10.5%) (19). Some preventative methods involving early screening in pregnancy have been identified (35), however despite decades of research on potential preventative methods, PE remains a leading cause of maternal and foetal morbidity and mortality globally (36). *Table 3* shows the reported prevalence of PE and GHTN across the different continents taken from a narrative review conducted in 2023 investigating maternal CVD following PE and GHTN (26).

Table 3. Range of reported prevalence (% of pregnancies) estimates for GHTN and PE

| Continent | Pre-eclampsia (% of pregnancies) | Gestational Hypertension (% of pregnancies) |
|---|---|---|
| **Africa** | 0.5-10.5 | 0.3-28.9 |
| **Asia** | 0.2-6.7 | 1.8-3.4 |
| **Australasia** | 2.6-9.2 | 5.7-8.2 |
| **Europe** | 1.6-5.2 | 0.9-5.8 |
| **North America** | 1.5-4.0 | 3.0-8.0 |
| **South America and the Caribbean** | 1.8-7.7 | None found |

### 1.1.8 Adverse effects

GHTN and PE have been associated with a range of maternal and foetal complications during pregnancy and birth including intrauterine growth restriction (IUGR), foetal micro and macrosomia, shoulder dystocia and birth injuries, respiratory distress syndrome and pre-term birth (33, 37, 38). PE accounts for at least 63,000 maternal deaths each year globally, with mortality rates highest in low-middle income countries (19). Higher rates of caesarean

deliveries have been seen in pre-eclamptic populations (18, 39), however this may be in part due to the fact that some doctors reportedly prefer to perform caesareans for women with PE despite a lack of evidence indicating that this improves maternal or foetal outcomes (40). The SOMANZ and ISSHP guidelines do not provide any recommendations on the method of birth (vaginal vs caesarean), only that from 37-weeks gestation delivery should be initiated (17, 18)

### 1.1.9 Long term consequences

Longitudinal data indicates that women who are diagnosed with PE in their first pregnancy are seven times more likely to develop the condition in subsequent pregnancies (41). The risk of developing PE in first pregnancies is around twice as high as developing PE for the first time in subsequent pregnancies (42). This protective effect of previous pregnancies is transient however, with evidence indicating that the risk of PE in second pregnancies increases as time since the first pregnancy increases, with greater intervals between pregnancies (> 10 years) resulting in a risk similar to nulliparous women (42). Some have hypothesised that this protective response may be due to repeated maternal exposure and adaptations to the partner's specific foreign antigens (42, 43). The vascular dysfunction that is associated with gestational hypertensive conditions is considered systemic and persistent resulting in a significantly increased risk of future CVD (7, 10, 29). The underlying mechanisms believed to contribute to the vascular dysfunction in PE are similar to those in non-pregnant populations with cardiovascular disease (CVD) (44). This may explain the association between PE and CVD risk later in life (16). PE has also been identified as an independent risk factor for future death due to CVD (hazard ratio: 2.14) (45), which increases further when PE is developed earlier in pregnancy or occurs in more than one pregnancy (7, 19, 26).

Lasting vascular damage may arise as a result of pregnancies complicated by GHTN, due to an increase in inflammatory stress, endothelial damage and coagulation dysregulation (26). Although the exact aetiology remains unclear, experts agree that the pathophysiology of PE occurring early in pregnancy (20-32 weeks) is different to PE developed late in gestation (> 32 weeks) (29). Greater changes in angiogenic factors have been found in women with early onset PE compared to late onset, with an early diagnosis suggesting more damage to the vascular system (26). In women who were diagnosed with PE, the prevalence of hypertension in the 10 years post diagnosis is three times higher than in women who

experience uncomplicated pregnancies (29, 34). Furthermore the survival rate for women with CVD (median age 56 years) 30 years following a PE diagnosis early in pregnancy is around 85.9%, compared to 98.3% in women who were diagnosed late in pregnancy, and 99.3% for women who did not experience PE (45).

In women previously diagnosed with PE, metabolic syndrome and obesity were found to be twice as prevalent 10 years post pregnancy (29). Women who experience PE are also at an increased risk of ischaemic heart disease (risk ratio = 1.86) and stroke (risk ratio = 2.26) in the 10-11 years following pregnancy (33, 46), likely due to subclinical vascular damage that occurs during PE (46). At least one third of infants born to pre-eclamptic mothers experience IUGR, subsequently resulting in an increased risk of diabetes, hypertension, obesity and other chronic diseases for the infant later in life (19, 34). However, the links between maternal PE and future CVD as a foetus are not as strong as in the mother (19).

### 1.1.10 Risk factors

There are a range of risk factors that have been identified for PE which can be seen in *Table 4* (27).

Table 4. Risk factors for PE (27)

| Risk Factor | Unadjusted Relative Risk [95% CI] |
|---|---|
| Nulliparity | 2.1 [1.9-2.4] |
| Multiple pregnancy | 2.9 [2.6-3.1] |
| Previous history of pre-eclampsia | 8.4 [7.1-9.9] |
| Family history of pre-eclampsia | 2.9 [1.7-4.9] |
| Overweight BMI 25-29.9 | 1.7 [1.2-2.4] |
| Obese BMI > 30 | 2.7 [1.7-4.4] |
| Age ≥40 | 2.0 [1.3-2.9] |
| Systolic BP > 130mmHg (before 20 weeks) | 2.4 [1.3-2.9] |
| Diastolic BP > 80mmHg (before 20 weeks) | 1.4 [1.0-1.9] |
| Antiphospholipid syndrome | 9.7 [4.3-21.8] |
| Pre-existing diabetes | 3.7 [3.1-4.3] |
| Other risk factors | Underlying renal disease<br>Chronic autoimmune disease<br>Interpregnancy interval > 10 years |

BMI = body mass index; BP = blood pressure; mmHg = millimetres of mercury

### 1.1.11 Treatment/management

Pre-eclampsia is a progressive disorder of pregnancy which worsens as pregnancy continues. Indeed, BP continues to rise throughout gestation, as does proteinuria and other relevant factors (27). This condition involves both the mother and foetus, with careful monitoring of both parties necessary following diagnosis (19). The only definitive treatment method currently available is delivery, with PE usually resolving in the days following birth (27). The timing of delivery is dependent on the gestational age at diagnosis, as well as the severity of the condition (27). From 37 weeks of gestation, immediate management occurs with diagnosis, in which delivery will usually be planned within 48 hours from diagnosis, once BP has been stabilized and corticosteroids have been administered to accelerate the maturity of the foetal pulmonary system (27). When diagnosis occurs between 24-36 weeks, management is considered expectant and involves palliation using antihypertensive medications to prolong the pregnancy if safely possible, to allow the foetus to mature further before delivery to increase chances of survival (19). There are strong links between foetal morbidity and mortality and gestational age at delivery, therefore the prolongation of pregnancy provides no maternal benefits but rather improves the foetal prognosis (27).

Evidence shows that between 25-41% of women who are diagnosed with PE at less than 34 weeks of gestation and who are managed expectantly develop significant morbidity including eclampsia, pulmonary oedema, placental abruption and Haemolysis, Elevated Liver enzymes and Low Platelet syndrome (HELLP) (27). When diagnosis occurs prior to 24 weeks of gestation, termination is likely the suggested course of action, with little benefit in prolonging the pregnancy once diagnosis of PE has occurred. With this early gestation there is high maternal morbidity rates (65-71%) and foetal mortality rates (> 80%) (27). Presented in *Table 5* is the delivery plan relative to the PE diagnosis at certain gestational weeks taken from the SOMANZ guidelines on the management of hypertensive disorders of pregnancy (27).

The management of gestational hypertension and PE involves the use of antihypertensive medications including oral methyldopa (centrally acting), oxprenolol (β Blocker), labetalol (β Blocker/mild vasodilator), and 2nd or 3rd line agents include hydralazine (vasodilator), nifedipine (Ca channel antagonist) and prazosin (α blocker) (17, 27). Monitoring of maternal BP and other markers as pregnancy progresses is vital in the early detection of PE (17).

Table 5. Timing of delivery and gestation at presentation of PE (27)

| Gestation at onset | Previable < $23^6$ weeks | 24-$31^6$ weeks | 32-$36^6$ weeks | 37+0 onwards |
|---|---|---|---|---|
| **Delivery plan** | Consult with Tertiary institution: likely to need termination of pregnancy or extreme preterm delivery. High risk patient. | Consult and transfer to Tertiary institution likely to need preterm delivery. Aim to prolong pregnancy where possible. | Aim to prolong pregnancy where possible, delivery in institution with appropriate Paediatric care. | Plan delivery on best day in best way |

### 1.1.12 Predicting PE

There is no set of first or second trimester tests that can accurately predict all cases of PE, however consideration of maternal risk factors (e.g. age, previous PE, body mass index (BMI)) as well as BP, mean arterial pressure (MAP), placental growth factor (PlGF) and doppler of the uterine artery (waveform analysis) can help identify women that may benefit from daily aspirin to prevent PE development early in pregnancy (17). Large studies involving general obstetric populations have found that these clinical measurements have only a moderate ability to predict PE, with only a third of PE cases accurately identified (47). BP is routinely measured throughout pregnancy as part of standard antenatal care in Australia. High BP readings are used as an indication as a potential early sign of hypertensive disorders (47). Several studies have reported on the use of second trimester BP in PE screening, with varying results ranging from 8-93% detection due to diverse methods of population screening and varying cutoff values used in determining a positive screening (47).

MAP has been suggested as another potential useful tool in determining PE risk early in pregnancy (47-49). MAP is the average arterial pressure throughout a cardiac cycle (systole and diastole), and is dependent on CO and total vascular resistance (50) Research has shown that MAP is more strongly indicative of PE risk than systolic and diastolic BP alone, with first and second trimester MAP being strongly associated with PE risk, independent of other maternal characteristics (47, 49, 51). MAP can provide insight on the overall exposure to a heightened pressure in a person, as it provides an average of the arterial BP throughout a single cardiac cycle (52). Despite these findings MAP was only able to weakly discriminate

between women who did and did not develop PE throughout pregnancy (51). Systematic evidence has found that arterial stiffness is a greater predictor of future cardiovascular events and hypertensive conditions throughout pregnancy than MAP or BP alone (53, 54).

## 1.2 Arterial function

Arterial function is considered an important factor in cardiovascular health and is recognised as a strong marker of risk of CVD in the general population (55, 56). Blood flow and BP oscillate throughout the arterial system due to the pulsatile nature of CO (55). The elasticity of arteries, particularly the aorta is considered an important factor in the body's ability to buffer these oscillatory changes in BP (55, 57). Arterial stiffness, endothelial function and arterial-wave reflection are the most common indices used to assess arterial function (55).

### 1.2.1 Arterial stiffness

Arterial stiffness has increasingly been recognised as an independent predictor of CVD morbidity and mortality in healthy and clinical populations (56, 58). Stiffening of the arteries occurs with age, genetic predisposition and pathological processes including atherosclerosis (55). The gold standard non-invasive measurement of arterial stiffness is aortic pulse wave velocity (PWV), which is calculated by measuring the pulse pressure (PP) transit time as it moves between two sites along the arterial branches, e.g. the carotid and femoral arteries (56, 57). There is an inverse relationship between the pressure wave velocity and arterial elasticity and compliance, meaning with an increase in arterial stiffness an increase in transmission velocity occurs (55). Although aortic PWV is considered the gold standard measure, due to the large contribution from the thoracic and abdominal aorta in buffering, direct measurement of aortic PWV cannot be conducted without the use of expensive, non-portable techniques such as phase contrast magnetic resonance imaging (MRI) (59). As such, the carotid-femoral (cfPWV) is often used in place as a more practical non-invasive substitute (55). The cfPWV measurement is considered the most clinically relevant estimate of arterial stiffness as it is measured along the aortic and aorto-iliac pathway, with the aorta and its first branches being responsible for the most severe pathophysiological implications of arterial stiffness (54). There are multiple devices commonly used across the world to assess PWV including Sphygmocor® 2000 (AtCor Medical, Sydney, Australia), The Complior System® (Alam Medical, Pantin, France), Arteriograph® (Tensiomed, Budapest,

Hungary), Vicorder® (Skidmore Medical Ltd, Bristol, UK) and VaSera® VS-1000 (Fukuda Denshi, Tokyo, Japan) (55, 57, 60).

### 1.2.2 Arterial stiffness in uncomplicated pregnancy

In line with other pregnancy-induced changes to the cardiovascular system, all measures of arterial stiffness reportedly decrease early in healthy pregnancy before increasing towards the end of gestation, with PWV reaching its lowest point at 17 weeks, increasing to its peak at 35 weeks and then reducing again slightly prior to birth (55, 58). These changes in arterial stiffness are associated with a progressive decrease in TPR due to increased peripheral vasculature vasodilation, accommodating for an increase in blood volume (10). Guidelines suggest that in non-pregnant populations a cfPWV over $10m.s^{-1}$ is related to organ damage and cardiovascular events (55). Normal ranges for PWV in pregnancy have not been defined, however normograms derived from longitudinal data have been developed indicating the normal pattern with which PWV fluctuates throughout pregnancy, which can be viewed below in *Figure 4* (58). Establishing a framework for the analysis of arterial function during healthy pregnancy with normative value ranges should be an important goal for researchers. In combination with other risk factors, this may allow clinicians to identify pathological disturbances at an earlier stage in pregnancy, allowing earlier diagnosis of gestational hypertensive disorders (61).

### 1.2.3 Arterial wave reflection

Arterial wave reflection can be quantified by augmentation index (AIx) (55). AIx is another indirect measure of arterial stiffness, measuring pulse wave reflection, as opposed to PWV which measures the speed at which blood travels through the vasculature (62). During systole a forward-traveling pulse wave is generated by left ventricular ejection (55). When this pulse wave reaches sites of impedance (due to arterial taper or major bifurcations) a backwards-traveling reflected wave is generated, which superimposes on the forward-traveling wave. With normal arterial compliance, the reflected wave reaches the central arteries after the aortic valve has closed, so there is no effect on central systolic pressure (63). The speed at which these waves travel increases as arterial stiffness increases, resulting in an increase in amplitude of the forward wave and augmentation of the central systolic pressure, due to the reflected wave superimposing at an earlier time (55, 63). AIx is a composite measure, representing ratio of the pressure difference between the start of the first

wave and the start of a second reflected wave (54, 55). AIx is influenced by factors including arterial stiffness, HR, SV, the reflective properties of the arterial tree (reflected wave amplitude and reflectance point) and BP (53, 54, 62). AIx and PWV are two different measures of the properties of the arterial tree and therefore cannot be used interchangeably, even though they are correlated (54, 62).

Augmentation index is commonly estimated from the brachial, carotid, or radial artery, as it is challenging to obtain direct measurements from the central arteries like the ascending aorta without invasive measures (cardiac catheterization) (55). The most common approaches to measuring AIx is tonometry of either the radial or carotid artery with a high-fidelity probe (using the same devices previously mentioned to measure PWV), or using oscillometric devices which analyse brachial pressure waveforms via cuff inflation on the upper arm (brachial artery) (55). Due to the effects of HR on AIx, it is commonly standardised to a HR of 75bpm (AIx75) (55). Research indicates that within healthy pregnancies, AIx follows a similar trend to PWV - decreasing in the second trimester (3-15%), before rising again in the third trimester (10, 64). An increased risk of CVD has been associated with elevated AIx in non-pregnant populations, and it is considered an important indicator of increased afterload on the heart (10). *Figure 4* shows the relationship between gestational age and resting brachial and aortic AIx, PWV and central MAP in a longitudinal study of thirty low-risk pregnant women (58).

### 1.2.4 Arterial function in hypertensive pregnancies

As previously mentioned, maladaptive changes to maternal haemodynamics during gestation increases the risk of gestational hypertensive conditions significantly (11, 14). Studies investigating arterial function in pre-eclamptic pregnancies have shown that all parameters of arterial stiffness differ significantly from normotensive pregnancies (55). When women with normotensive, hypertensive and pre-eclamptic pregnancies were compared it was found that all measures of arterial stiffness were increased in the women with PE both during and after gestation (15, 55). One Norwegian study compared arterial stiffness in three groups: Group 1 consisted of 65 women with normal pregnancies (NP); Group 2 included 40 pregnant women who had been diagnosed with PE (PE) and Group 3 included nonpregnant women who had been diagnosed with PE in a previous pregnancy (PPEP) (15). In the two pregnant groups arterial stiffness was measured ‘at term’ (Gestational week (GW) NP = 36 ± 0; PE = 35 ± 5), and again 6 months post-partum, whilst the PPEP group was measured

three years post-partum. They found that women with PE had significantly stiffer arteries and higher total vascular resistance than the NP group both at term and 6 months post-partum, with evidence of a sustained increase in arterial stiffness 3 years post-partum in the PPEP group (15). Thus, it has been suggested that some of the adaptations that occur in the arterial wall throughout pre-eclamptic pregnancy (often attributed to changes in endothelial function) may be irreversible (15). It has been suggested that measurements of arterial function early in pregnancy may be useful in predicting PE and GHTN (38, 65), which may allow for the implementation of earlier treatment resulting in a decreased severity. One systematic review identified 14 studies that evaluated arterial stiffness via PWV and/or AIx prior to, during or following pre-eclamptic pregnancy with results consistently finding an increased cfPWV and AIx not just throughout gestation, but prior to disease onset, and up to 2-3 years postpartum (66).

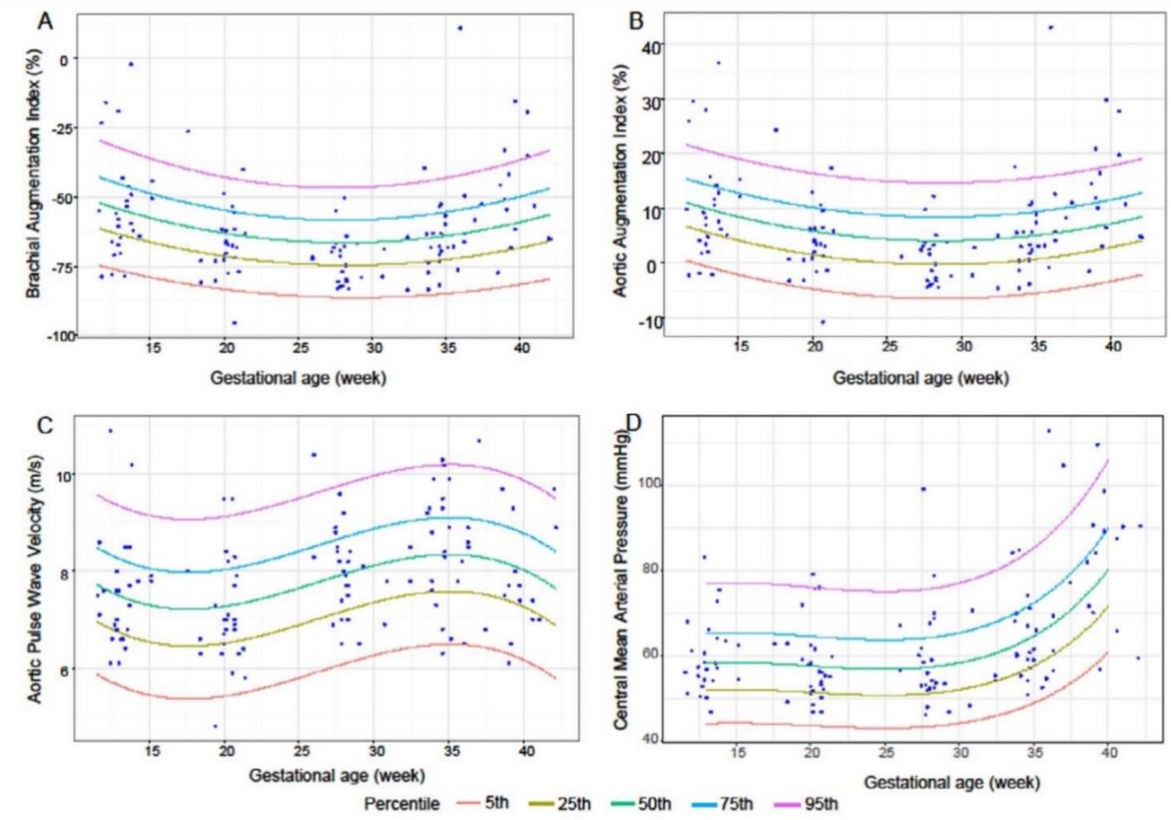



Figure 4. Relationship of gestational age with brachial augmentation index, aortic augmentation index, PWV, and central mean arterial pressure measurements in low-risk pregnancies (58)

## 1.3 Exercise

### 1.3.1 Exercise in pregnancy

Pregnancy represents a period of time in which maternal lifestyle factors including physical activity (PA) and diet play a substantial role in the health of not just the mother but also the growing foetus (67). Current PA guidelines for pregnant women recommend that all women without contraindication should aim to accumulate 150 to 300 minutes of moderate to vigorous intensity physical activity (MVPA) per week throughout pregnancy, in order to achieve clinically meaningful benefits (67, 68). In addition, it is recommended that this is achieved over most, if not all days of the week and that different modes of exercise including both aerobic and resistance training (RT) are incorporated (67). Pelvic floor muscle training has also been identified as an important aspect of prenatal exercise in order to improve pelvic floor musculoskeletal outcomes following pregnancy and childbirth (67, 69).

Following these guidelines has been associated with significant maternal and foetal benefits, including reduced risk of gestational diabetes (38%) (GDM), excessive gestational weight gain, gestational hypertension (39%) and pre-eclampsia (41%), urinary incontinence and lumbopelvic pain (33, 67, 70, 71). Despite these well evidenced benefits it is estimated that around only 30% of Australian pregnant women actually meet these guidelines throughout pregnancy (73). Previously there has been uncertainty and misinformation amongst obstetric care health professionals and pregnant women surrounding the safety of prenatal exercise, which has acted as a significant barrier to advising evidence-based recommendations for PA (67). Moreover, the risks associated with *not* meeting PA guidelines have not been appropriately emphasised to uncomplicated and at risk pregnant populations and obstetric care givers (67).

### 1.3.2 History of exercise guidelines in pregnancy

The conservative guidelines produced in the late 20$^{th}$ century were largely based on expert opinion rather than empirical evidence, as it is challenging to perform research investigating safe levels of exercise intensity during gestation (72-74). Some of the research that was available at the time investigated pregnancy outcomes with strenuous physical labour and undernutrition (75), and in other cases observed laboratory animals rather than humans (76). Despite this, there are few guidelines worldwide that actually recommend vigorous intensity exercise throughout gestation (77), with most still cautioning against higher intensities exceeding 80-90% of maximal heart rate ($HR_{max}$) due to the lack of high-quality evidence

regarding maternal and foetal health (72, 73). It has been hypothesised that the redistribution of blood flow to working muscles during high intensity exercise may result in foetal hypoxia and restricted growth due to a lack of oxygen and nutrient supply (72, 78, 79). A systematic review of 15 studies (n = 7848, uncomplicated pregnancies) found that despite the transient decreases in uteroplacental blood flow during vigorous intensity activity, exercising up to 90% of $HR_{max}$ appears safe for the mother and foetus in most healthy pregnancies, with no increased risk of adverse events/outcomes reported (miscarriage, incidence of small for gestational age births, low birth weight and prematurity) (80).

### 1.3.3 Exercise guidelines throughout pregnancy

Despite the significant cardiovascular adaptations that occur throughout gestation, pregnancy guidelines from across the world fail to provide trimester specific recommendations (77). Whilst research supports the general benefits of exercise during pregnancy, studies comparing the physiological responses to exercise in each trimester are lacking, thus limiting the ability to create evidence-based, trimester-specific recommendations. Current guidelines provide recommendations based on absolute values (i.e. 150-300 minutes) (73), however due to the nature of pregnancy, this volume can be challenging to achieve as gestation progresses given the increase in metabolic demands and physical discomforts associated with the later stages of pregnancy (81). Additionally, misinformation on the safety of exercise acts as a barrier with many women told to reduce their PA levels as pregnancy progresses, despite the well documented evidence showing the benefits of continued PA. Weekly PA *intensity* and *frequency* decrease as pregnancy progresses, along with an increase in sedentary behaviour (81, 82). As such this has been identified as an important gap in our knowledge, with developing trimester specific guidelines identified as a priority area for future research (77).

### 1.3.4 Exercise and blood pressure in non-pregnant populations

Aerobic exercise has been well evidenced to produce decreases in BP in non-pregnant populations (83). A position statement from Exercise and Sports Science Australia (ESSA) released in 2019 (83), reported that even at light intensities (50% $VO_{2max}$) aerobic exercise has been shown to elicit reductions in resting (84) and ambulatory BP (85) within normotensive and hypertensive individuals. Greater training effects on reducing BP (post intervention) are seen in populations with high initial BPs (83). It is important to note that a

dose-response relationship has been identified, with greater reductions in BP seen with higher intensities of exercise (83). Aerobic and RT have been identified by several governing bodies as the cornerstone of exercise-based management of BP in non-pregnant populations, with high intensity interval training (HIIT) and isometric RT offering effective alternative management strategies to conventional moderate intensity continuous training (MICT) (83, 86).

One meta-analysis of 65 studies investigated the acute effects of exercise (aerobic, resistance and/or combined) on BP and found an acute hypotensive response in the hours following exercise in non-pregnant populations of -4.8 mmHg SBP and -3.19 mmHg DBP (87). This study highlighted that the acute reduction in BP following a bout of exercise was significant regardless of baseline BP, PA level, gender, time of day, antihypertensive drug intake and type of exercise performed (87). This study does not specify for how long this post-exercise hypotensive response lasts, however it has been suggested that within hypertensive populations this response can last for up to 13 hours post exercise (88). It appears that the post exercise hypotensive response occurs independently of age, exercise intensity and duration (89). There is evidence showing that within healthy, recreationally active young adults, high dietary sodium intake (~6200mg/day) may augment acute BP responses to submaximal aerobic exercise (90). It was suggested that these augmented BP responses may be linked with a decrease in endothelial dependent vasodilation, however the mechanisms are not fully understood (90). This study raises the question of whether pregnancy, which also has a higher baseline blood volume level, would have similar dampening effects of acute BP responses to exercise.

### 1.3.5 Exercise and gestational hypertensive conditions

GHTN and PE have long been considered absolute and relative contraindications to exercise, with many women who experience these conditions advised against exercise due to the acute hypertensive effects of exercise (91). Indeed, transient increases in BP are expected with exercise (with recommended termination criteria > 250 mmHg systolic and > 115 mmHg diastolic in non-pregnant populations (92)) due to an increase in cardiac output that accompanies the increased oxygen requirements of the working muscles (92). More recently it has been suggested that clinical exercise guidelines surrounding pregnancy need to be reassessed to remove some of these barriers to exercise (91). Most of the well-known contraindications to exercise during pregnancy are based on expert opinion, and it has been

suggested that considering current empirical evidence on the significant benefits of antenatal exercise, that many of these proposed contraindications could be outdated (91). The limited research that is available on the acute effects of prenatal exercise in hypertensive pregnancies found no adverse effects on foetal heart rate (FHR), BP (range = 150-190 mmHg systolic, 100-115 mmHg diastolic (93)), uterine blood flow (UBF) and contractions or vaginal bleeding following moderate-vigorous intensity aerobic cycling (91, 94, 95). One randomised controlled trial (RCT) investigated maternal and perinatal outcomes in pregnant women with chronic hypertension or previous PE by comparing an exercise group (n = 56) that performed one session of moderate intensity cycling (20% above resting HR, < 140 bpm) per week to a non-exercising control group (n = 53) (96). They found that exercising at a controlled intensity under supervision does not affect mode of delivery, or appear to increase maternal or foetal risk (96). However, transient adverse effects in uteroplacental blood flow have been observed in women suffering from both PE and IUGR following a submaximal cycle test (91, 95). These deficits reportedly recovered within 30 seconds after exercise, with authors concluding that the exercise bouts were not harmful to the mother or foetus (97).

### 1.3.6 Exercise and arterial stiffness

***Acute exercise***

Differences in acute responses have been identified between PWV in the central and upper body to the lower body segments following exercise, with central and upper body PWV (measured proximal to the primary working muscles in most cases) increasing immediately post exercise (< 5 min) then decreasing to or below pre exercise levels, whilst lower limb PWV decreased immediately post exercise persisting into the recovery period (98). This finding demonstrates a complex relationship between the changes in arterial stiffness and acute aerobic stress, with segments of the arterial tree being affected differently based on their proximity to the working muscles and recovering in a time-dependant manner following the cessation of exercise (98). Arterial stiffness is intricately linked to various cardiovascular measures, particularly HR and BP and is a key biomarker of vascular health (55, (99). Systematic evidence in non-pregnant populations has suggested that the acute effects of exercise on PWV may be influenced by the effects of exercise on BP (100), however this relationship has not yet been investigated in pregnancy.

The timing of measurements post exercise appears significant in determining the acute response of the vasculature system, with varying results across systematic reviews within non-pregnant populations. One systematic review found no significant change in PWV following an acute bout of aerobic exercise in a population of healthy young adults up to 60 minutes post exercise (101). Conversely, another review investigated the effects of all types of exercise (aerobic, resistance, interval) on arterial stiffness in healthy participants at different time periods ranging from 0-14 to 60 minutes to 24 hours post exercise (100). They found a significant decrease in peripheral PWV up to 24 hours post exercise and a decrease in central PWV between 30-59 minutes post exercise (100). *Figure 5* shows the acute effects of exercise (all types) on total, central and peripheral PWV across different time periods following exercise (100).

***Regular exercise***

Regular exercise has been shown to have significant chronic effects on PWV and AIx in a range of non-pregnant populations (102). Different training modalities have shown varying effects on arterial stiffness (103). Aerobic exercise has shown the greatest effects when compared to RT or combined exercise, with larger effects seen in peripheral PWV (brachial-ankle PWV (baPWV)) than central (cfPWV) with aerobic exercise (102). Researchers suggest that this may be due to a greater release of NO in the exercising limbs due to greater shear stress rates (102).

There appears to be a relationship between exercise intensity and PWV/AIx response. Indeed, there are greater effects seen at higher absolute intensities (> 7 metabolic equivalents (METs)), rather than overall volume of exercise (frequency and duration) (102). Resistance exercise has shown varying effects on arterial stiffness dependant on the type and intensity, with chronic vigorous intensity resistance training (70-84% 1 repetition maximum (RM)) associated with an increase in arterial stiffness in both men and women (103, 104). Vigorous aerobic exercise is likely to result in sustained, moderate increases in BP, due to the mechanical compression of blood vessels and a strong exercise pressor reflex, whilst vigorous resistance exercise can elicit large, intermittent increases in BP (105). It has been suggested that this intermittent increase in pressure may increase PWV through a transient switch in load bearing from elastin to collagen fibres of arteries (101, 105). A combination of aerobic and RT has been shown to have either no effect or a slightly beneficial effect on arterial stiffness in normotensive and hypertensive participants (102, 103).

Increases in PWV as small as 1 $m.s^{-1}$ over time have been associated with an increased risk of cardiovascular events by 12-14% and 13-15% increase in CVD mortality (102). Meta-analytic data suggests that PWV may be reduced by regular aerobic exercise by approximately 0.6 $m.s^{-1}$,which correlates to an 8% decreased risk of cardiovascular events and a 9% reduction in the risk of CVD death (102). This highlights that even small changes in arterial function can have significant effects on health outcomes, particularly cardiovascular health.

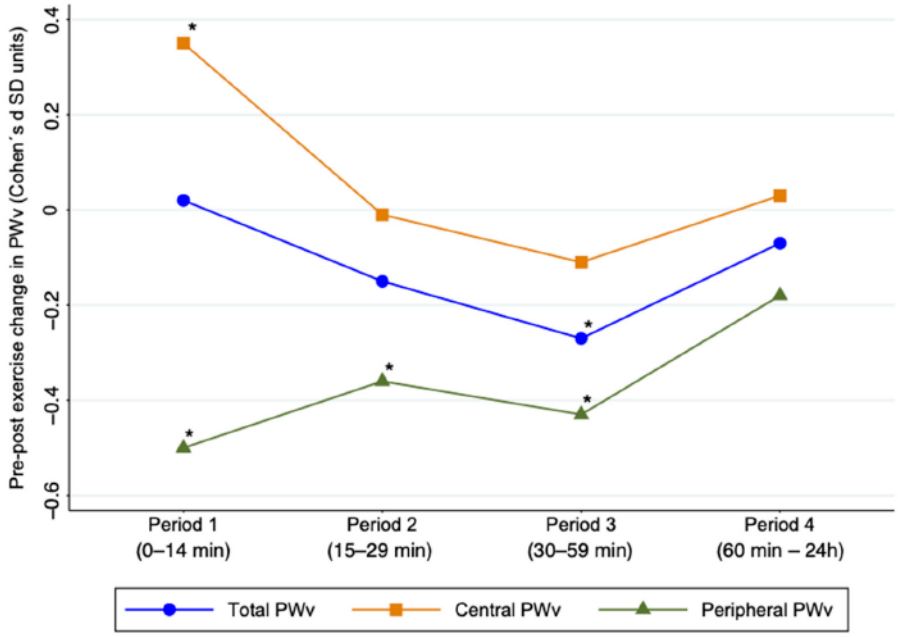



Figure 5. Acute effect of exercise on PWV by time period after exercise in non-pregnant healthy populations (100)

### 1.3.7 Exercise during pregnancy and arterial stiffness

There is limited research on the effects of exercise during pregnancy on measures of arterial stiffness. Previous research has found that regular MVPA may be associated with improvements in arterial stiffness during pregnancy (106, 107), however there is currently no research on the acute PWV responses following exercise. A non-randomised clinical trial conducted in 2012 compared baPWV in the second trimester and 1 month postpartum in an exercise group (n = 17) who performed thrice weekly exercise sessions (a combination of light-moderate intensity aerobic dance and resistance training), to a control group (n = 81) who performed no structured exercise sessions throughout gestation (107). They found that baPWV increased significantly from the second trimester to 1 month postpartum in the control group, whilst there was no significant change in baPWV between the second

trimester and 1 month after delivery in the exercise group (107). The authors concluded that regular exercise may prevent disturbances in arterial function during pregnancy (107). A pilot study looking at the effects of moderate-vigorous aerobic exercise on maternal and foetal vascular outcomes showed a trend for resting PWV to decrease in trimester 2 (T2), before increasing in trimester 3 (T3) as identified earlier in 1.2.2 (108). Trends showed a decline in middle cerebral artery velocity, which has been previously identified and attributed to a reduction in SBP and the vasodilation of downstream resistance vessels to help maintain a stable haemodynamic state (108). The limitations in these studies (lack of pre-pregnancy baseline vales, recruitment bias, low training/exercise stimulus) prevent any robust conclusions on PWV, however they do provide a rationale for future studies investigating the mechanisms of exercise on arterial function in pregnancy.

There is currently no research available on the effects of Pilates on arterial stiffness during pregnancy. Pilates is a popular mainstream form of lower intensity exercise amongst women, particularly in pregnancy. One RCT examining the effects of a 12-week Pilates intervention in the second and third trimesters on lower back and pelvic pain found differences in measures of mood, pain and disability in favour of the Pilates group compared to usual prenatal care (109). This supported the findings of an earlier study which found reduced pain levels in a group of pregnant women in the third trimester following Pilates exercise compared with a standard exercise regimen (110).

### 1.3.8 Interval exercise

Continuous moderate intensity exercise has long been the most commonly recommended type of exercise for adults with hypertension, however evidence suggests that interval training may elicit greater clinical benefits (111). Interval aerobic and resistance exercise training promotes fluctuations in shear and cardiovascular stress as participants vary between bouts of lower and higher exercise intensities (111). This type of exercise involves short to long bouts of higher intensity exercise, interspersed with recovery periods in which participants usually exercise at a light to moderate intensity (112). Due to these fluctuations in intensity, interval exercise provides greater stimulus for vascular adaptations than continuous exercise (112). Interval exercise training has been shown to have greater effects on functional exercise capacity and cardiorespiratory fitness than continuous exercise in both healthy and hypertensive populations (111). There is also evidence to suggest that whilst

continuous and interval training are both beneficial in reducing BP of hypertensive people, interval training may also reduce arterial stiffness in this same population (112).

There is a growing body of research supporting the use and safety of aerobic HIIT during pregnancy (113, 114). Historically, exercising at vigorous intensities and above has been advised against during pregnancy, however these restrictions have been removed from many international guidelines due to emerging research in this area (73). A systematic review of 12 studies found that the HIIT protocols used in pregnant populations varied substantially in terms of frequency, intensity (60% $VO_{2max}$ – self-reported maximum), type and duration, resulting in different exercise stimuli in the groups studied (113). The authors highlighted that despite this, HIIT programs were considered safe, and were well tolerated by pregnant participants regardless of the session structure (113). There were no acute or long-term detrimental effects of HIIT within the studied populations, with a number of health, functional and psychosocial benefits identified (113). It should be noted that whilst some studies report HIIT, the intensities sometimes prescribed actually fall within vigorous intensity (6-9 METs, 70-90% $HR_{max}$, rating of perceived exertion (RPE) 14-16) rather than high intensity (≥ 9 METs, ≥ 90% $HR_{max}$, RPE ≥17) based on Australian exercise intensity guidelines (115).

Another study comparing MICT and HIIT on maternal and foetal cardiovascular responses found that both sessions were well tolerated by the mother and foetus (72). Only one session of each type of exercise was performed in either the second or third trimester (72). The HIIT sessions in this study consisted of 10 x 1-minute bouts at 90% $HR_{max}$, interspersed with 1 minute of self-paced active recovery on an upright cycler ergometer for a total of 19 minutes, whilst the MICT sessions involved 30 minutes of continuous cycling at 64-76% $HR_{max}$ (72). The 15 participants (27.3 ± 3.5 weeks gestation, 33 ± 4 years of age) performed these sessions 48 hours apart, with maternal BP, HR, cerebral artery blood flow and respiration as well as UBF and FHR measured at rest and immediately following exercise. They found no differences in maternal cerebral blood velocities between sessions, and that FHR increased during exercise, but no difference was seen between HIIT (Δ +14 ± 7 bpm) and MICT (Δ +10 ± 10 bpm) (72). Similarly measures of UBF decreased with exercise but no difference was seen between HIIT and MICT (72). In addition, two studies have highlighted that pregnant women report greater levels of enjoyment with HIIT compared to MICT (114, 116).

Whilst these studies have identified that HIIT appears safe and well-tolerated by mothers, exercising at what is considered 'high intensity' may be challenging for some women, particularly those who are untrained. High intensity exercise is defined as "an intensity that cannot be sustained for longer than about 10 minutes" or ≥ 90% $HR_{max}$ or an RPE ≥ 17 (Borg's RPE scale (117)) (115). Vigorous intensity exercise, which is defined as "an intensity that may last up to about 30 minutes" or 70-90% $HR_{max}$ or an RPE 14-16 (115), may provide a more achievable threshold for interval training within pregnant women whilst providing similar cardiovascular benefits to HIIT. As such it is important to investigate the effects of vigorous intensity interval training (VIIT) in the pregnant population.

### 1.3.9 Barriers to exercise in pregnancy

Despite the well documented benefits of regular PA throughout gestation, most pregnant women (60-80%) fail to meet the recommended PA guidelines (118). Participation rates and the intensity of leisure time PA have been shown to decrease as gestation progresses, with this trend persisting into post-partum and beyond (119). The reasons behind the low levels of participation in PA are complex with several influencing factors (119). Sociodemographic factors including age, income, and education, along with race (races other than Caucasian are less likely to engage in PA during pregnancy) have been identified as mostly non-modifiable factors relating to PA participation levels (119). Personal, social and environmental factors are often cited as barriers to participation in PA throughout gestation, with lack of time, fatigue, pregnancy discomforts (pain, nausea, awkwardness due to weight gain) and fear of maternal/foetal harm amongst the most commonly reported (118).

As previously discussed, in order to meet exercise guidelines pregnant women without contraindication should be incorporating 150 to 300 minutes of moderate intensity or 75-150 minutes of vigorous intensity physical activity (VPA) per week, utilising both aerobic and resistance training (73). Given that lack of time is a barrier reported by many pregnant women, interval training may present a method to counter this barrier by incorporating shorter bouts of vigorous intensity exercise, providing a strong training stimulus in a short time (113). Resistance training during pregnancy helps build or maintain muscular strength and functional capacity, with some evidence to suggest that resistance training during pregnancy has been shown to strengthen the benefits conferred by aerobic training when used in combination (120). Given the pregnancy discomforts that many women report, some may find resistance training more comfortable than aerobic training. Pilates exercise is a

form of lower intensity resistance exercise amongst women, particularly in pregnancy, however the acute maternal and foetal responses to this type of exercise are not well understood. Given the popularity of Pilates throughout pregnancy, and the light intensity nature, this type of exercise may counter some of the perceived barriers surrounding fear of maternal/foetal harm.

### 1.3.10 Foetal response to exercise

It has been hypothesised that the redistribution of blood flow to working muscles during higher intensity exercise may result in foetal bradycardia, hypoxia and restricted growth due to a lack of oxygen and nutrient supply (72, 78, 79). Contrary to this belief, temporary reductions in uterine artery blood flow with maternal moderate-vigorous intensity exercise result in compensatory increases in FHR (121). A systematic review on the effects of prenatal exercise on FHR found that on average FHR increased by 6 bpm during maternal exercise and by 4 bpm following acute bouts of maternal exercise (121). FHR variability increases with gestational age (122), and is considered reflective of healthy foetal cardiac responsiveness when it is between 5-25 bpm. As such, acute increases in FHR of 4-6 bpm with maternal exercise is considered a normal response (121). Chronic prenatal exercise does not affect FHR or UBF, however has been shown to decrease umbilical blood flow (121). A study examining the relationship between PA and sitting time in pregnancy and placental morphology and blood flow found that PA volume was not associated with uteroplacental blood flow or placental morphology, however sedentary behaviour was (123). Excessive sitting (> 8 hours per day) during pregnancy may have negative effects on the placenta, with greater placental stiffness and lower placental growth found, independent of the amount of PA completed (123).

### 1.3.11 Chapter summary

The review of the literature in this chapter has identified the high prevalence of gestational hypertensive conditions, and the negative short- and long-term consequences associated with them. There is an identified lack of treatment options for these conditions and, given the prevalence, more research is needed to improve maternal and foetal health outcomes. Arterial stiffness has been identified as a potential predictive tool for these conditions throughout gestation, however there are currently no normative data provided for pregnant populations. Exercise is a well-accepted treatment method for hypertension within non-

pregnant populations, however historically pregnant women (particularly those with gestational hypertensive conditions) have been discouraged from exercising at intensities greater than light-moderate. Attitudes towards exercise during pregnancy are changing, with more and more evidence being produced emphasising the benefits of regular exercise throughout gestation. More recent evidence suggests that higher intensity interval exercise may provide a safe, enjoyable and time efficient option for pregnant women. Furthermore, higher intensity exercise has also been shown to be more effective in improving arterial function than low-moderate intensity exercise in non-pregnant populations (102). Therefore, it may be a promising option for future research in preventing gestational hypertensive conditions. More evidence is needed on the effects of different intensities of exercise throughout gestation, particularly on measures of cardiovascular function including BP, MAP and arterial stiffness.

## 1.4 Thesis aims

The specific aims of this thesis were:

1. To review the literature on all topics covered in the thesis including cardiovascular adaptations to pregnancy, exercise during pregnancy and the effects of exercise on measures of arterial stiffness (Chapter 1)
2. To systematically review and meta-analyse the effects of acute and chronic exercise in uncomplicated and at-risk pregnancies on BP and MAP (Chapter 3)
3. To observe the acute effects of a weekly submaximal exercise test on measures of arterial stiffness and BP throughout pregnancy (Chapter 4).
4. To observe the effects of a submaximal graded exercise (vigorous intensity) test during pregnancy on measures of vascular function including MAP and arterial stiffness. (Chapter 5)
5. To determine the feasibility of VIIT, RT and reformer Pilates in the second and third trimesters of pregnancy (Chapter 6)
6. To observe the acute effects of different types and intensities of exercise longitudinally throughout gestation on measures of arterial stiffness and BP (Chapter 7)

# Chapter 2. Extended Methods

## 2.1 Introduction

This chapter will outline the protocols and outcome measures used in the experimental studies (Study 2, 3, 4 and 5). *Table 6* provides a summary of each study with the associated protocols, outcome measures and equipment required for each. Figure 6 outlines the flow of participants recruited into each study. The exercise protocols will be described in more detail below.

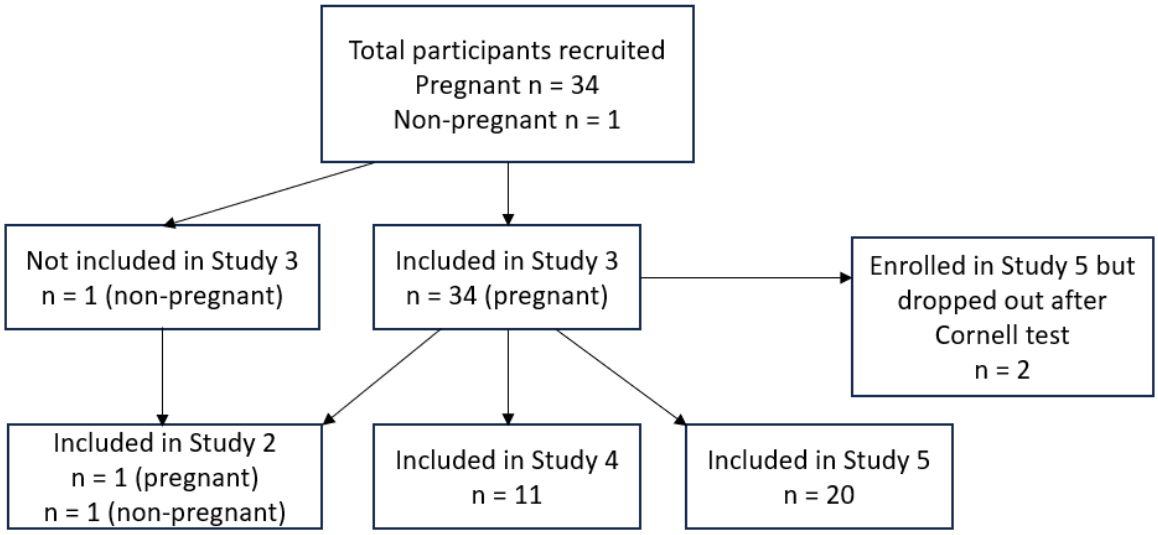



Figure 6. Flowchart of participant recruitment across the studies

## 2.2 Study 2

The aim of this study was to compare the acute effects of a submaximal graded exercise test on arterial stiffness and blood pressure (BP) completed weekly throughout gestation in a gravida three, singleton pregnancy to a non-pregnant control. Study 2 was a case series design (n = 2).

### 2.2.1 Study population

One participant (31 years, body mass index (BMI) 25.83kg/m$^2$, GW 5) with a history of two previous uncomplicated pregnancies to term, and one age-matched, non-pregnant participant with a history of two previous uncomplicated pregnancies to term (31 years, BMI 22.23kg/m$^2$) were recruited through the Exercise Lifestyle Clinic (ELC) at the Australian Catholic University (ACU) in Brisbane. The participant consent form is attached in Appendix 2. Both participants were considered healthy, with no current or previously diagnosed hypertensive conditions (chronic hypertension, gestational hypertension (GHTN),

or pre-eclampsia (PE)). Participants were not instructed on any exercise outside of the prescribed sessions, and were free to participate in other exercise during the study.

### 2.2.2 Study design

A case series design was implemented, with the pregnant participant performing once weekly submaximal graded exercise tests from five weeks up to 35 weeks of gestation. The age matched non-pregnant control completed 26 sessions in total, the first eight of which occurred weekly, followed by fortnightly sessions due to participant availability. All sessions were completed at the ACU ELC in Brisbane with accredited exercise physiologists (AEPs).

### 2.2.3 Ethics

This study protocol was approved by the Australian Catholic University Human Research Ethics Committee (ACU HREC), ethics register number: 2020-103H. Both participants gave written, informed consent to participate in this study.

## 2.3 Study 3

The aim of this study was to investigate the acute effects of a graded, submaximal exercise test on haemodynamics during pregnancy. Study 3 was a cross-sectional baseline trial (n = 34).

### 2.3.1 Study population

Thirty-four women with uncomplicated pregnancies were recruited prior to 36 weeks of gestation. Prior to enrolment participants were required to complete the pre-exercise screening tool for pregnancy developed by Exercise and Sports Science Australia (ESSA) (124), which screens for any general (including heart conditions, stroke, asthma, Type 1 (T1DM) or 2 diabetes mellitus (T2DM) etc.) and pregnancy specific contraindications (including incompetent cervix, placenta previa, PE) to exercise (Appendix 3). The participants were then asked to complete sections A and B of the PARmed-X for pregnancy (Canadian Society for Exercise Physiology), which is a PA readiness medical examination and have their health provider (GP/OBGYN/Midwife) complete section C and the attached Health Evaluation Form as medical clearance (Appendix 4) (125).

Participants were recruited through advertisements on social media, flyers placed around the ACU campus in Brisbane, as well as through Pear Exercise Physiology clinic – a women's health focused clinic located in Brisbane, Australia. The advertising materials can be viewed in Appendix 5.

***Inclusion/exclusion criteria***

Participants were aged between 18-40 years, non-smokers and had no absolute contra-indications to exercise upon enrolment (e.g., incompetent cervix, placenta previa, evidence of intra-uterine growth restriction (IUGR)). Women with well-controlled T1DM (relative contraindication to exercise (91)) or gestational diabetes mellitus (GDM) in this, or previous pregnancies were accepted into the study. Women who had been diagnosed with GHTN or PE in previous pregnancies were also accepted into the study.

### 2.3.2 Study design

A cross-sectional design was implemented with pregnant women recruited in any trimester of pregnancy (< 36 weeks gestation) to perform a single submaximal graded exercise test (up to 85% $HR_{max}$) following the Cornell protocol on the treadmill (*Table 10*). After obtaining written informed consent, participants completed the testing session at the ACU clinic in a fed state, having completed no strenuous PA in the previous 24 hours.

## 2.4 Study 4

The aim of this study was to investigate the feasibility of performing three different popular exercise modalities (resistance training (RT), aerobic – vigorous intensity interval training (VIIT), and reformer Pilates (PIL)) and observe the acute cardiovascular effects of each type of exercise during the second and third trimesters of pregnancy. Study 4 was a feasibility trial utilising a randomised crossover design (n = 11).

### 2.4.1 Study population

Eleven women with uncomplicated pregnancies were recruited in trimester 2 (T2) (n = 7, 20 ± 1.6 GW) and trimester 3 (T3) (n = 4, 29 ± 2.5 GW). Prior to commencement participants were required to complete the ESSA pre-screening tool and the PARmed-X described previously in 2.3.1. Participants were recruited through the advertisements outlined

previously in 2.3.1. Participants were not instructed on any exercise outside of the prescribed sessions, and were free to participate in other exercise as they liked.

***Inclusion/Exclusion criteria***

Participants were aged between 18-40 years, non-smokers and had no absolute contraindications to exercise upon enrolment (e.g., incompetent cervix, placenta previa, evidence of intrauterine growth restriction (IUGR)). Women with well controlled T1DM or GDM, or GHTN in this or previous pregnancies were accepted into the study. Women who had been diagnosed with PE in previous pregnancies were also accepted into the study.

### 2.4.2 Study design

A randomised crossover design was implemented with pregnant women recruited in T2 and T3 to complete four exercise sessions across four weeks in each trimester. All sessions were run by AEPs at the ACU ELC in Brisbane. After obtaining written informed consent, participants completed baseline testing (Cornell protocol) outlined in 2.7.1, before randomly performing one session each of VIIT, RT and PIL in each trimester across the subsequent three weeks. The order of sessions was randomly assigned for each participant using simple randomisation procedures (computerised random numbers), where VIIT = 1, RT = 2 and PIL = 3.

### 2.4.3 Ethics

This study protocol was approved by the ACU HREC, ethics register number: 2020-103H. All participants gave written, informed consent to participate in this study. The informed consent form and participant information letter for this study can be viewed in Appendix 6 and Appendix 7.

## 2.5 Study 5

The aim of this study was to observe the acute effects of a combined intervention of VIIT, RT and PIL on measures of arterial stiffness and BP throughout gestation. Study 5 was a longitudinal crossover trial (n = 22).

### 2.5.1 Study population

Twenty-two women with uncomplicated pregnancies were recruited to participate in the study. Prior to commencement participants were required to complete the ESSA pre-screening tool and the PARmed-X for pregnancy described previously in 2.3.1. Participants were recruited through the advertisements outlined previously in 2.3.1. Participants were not instructed on any exercise outside of the prescribed sessions, and were free to participate in other exercise during the study.

***Inclusion/Exclusion criteria***

Participants were aged between 18-40 years, were non-smokers and had no absolute contraindications to exercise upon enrolment (e.g., incompetent cervix, placenta previa, evidence of IUGR). Women with T1DM or a history of GDM, GHTN or PE diagnosed in previous pregnancies were accepted into the study if they were considered normotensive at the time of enrolment. If participants were diagnosed with GHTN or GDM during the study they were included in the study, due to the known benefits of regular exercise for these conditions. However, if women presented with signs or symptoms reflecting possible GHTN or GDM, further clearance from their treating medical professional was sought before continuing in the study.

### 2.5.2 Study design

A longitudinal randomised crossover design was implemented with pregnant women recruited in any trimester to perform three weekly sessions (one each of VIIT, RT and PIL) from enrolment up to 36 weeks of gestation. All sessions were run by AEPs at the ACU ELC in Brisbane. After obtaining written informed consent, participants completed baseline testing outlined in 2.7.1, before randomly performing one session each of VIIT, RT and PIL each week up to 36 weeks of gestation. The order of sessions was randomly assigned for each participant at the start of each week using simple randomisation procedures (computerised random numbers) where VIIT = 1, RT = 2 and PIL = 3. This study was designed to replicate a ‘real-world’ scenario in which pregnant women may aim to meet exercise guidelines during pregnancy, incorporating a range of exercise types and intensities into their weekly routine.

### 2.5.3 Ethics

This study protocol was approved by the ACU HREC, ethics register number: 2020-103H. All participants gave written, informed consent to participate in this study. The informed consent form and participant information letter for this study can be viewed in Appendix 8 and Appendix 9.

Table 6. Summary of study protocols

| Study | Design | Protocol | Frequency | Outcome Measures | | Exercise | Equipment |
|---|---|---|---|---|---|---|---|
| **S2 & S3** | **S2:** Case series, n = 2<br><br>**S3:** Cross-sectional, n = 34 | Cornell Protocol | **S2:** 1 x weekly<br><br>**S3:** 1 x | Resting, immediately post, 10 min post | BP (mmHg), MAP (mmHg), HR (bpm), FHR (bpm), PWV ($m.s^{-1}$), AIx (%), AIx75 (%), BGL ($mmol.L^{-1}$) | Treadmill | SphygmoCor Xcel<br>Aneroid Sphygmomanometer<br>Stethoscope<br>Wahoo HR chest strap<br>Foetal Doppler<br>Pulse oximeter<br>Smart phone<br>Glucometer, lancet and strips<br>RPE scale (6-20 Borg) |
| | | | | During exercise | HR (bpm), BP (mmHg), RPE, $O_2$ (%) | | |
| **S4 & S5** | **S4:** Feasibility, n = 11<br><br>**S5:** Longitudinal randomised cross-over, n = 22 | **Cornell Protocol**<br><br>**VIIT** - 4x4 = 4 min @ vig (14-16 RPE), 3 min @ mod (11-13 RPE) x 4<br><br>**RT** – 30-35 min @ mod (11-13 RPE)<br><br>**PIL** – 30-35 min @ light-mod (9-13 RPE) | **S4:** 3x/trimester<br><br>**S5:** 3x/week | Resting, immediately post, 10 min post | BP (mmHg), MAP (mmHg), HR (bpm), FHR (bpm), PWV ( $m.s^{-1}$), AIx (%), AIx75 (%) | **Cornell:** Treadmill<br>**VIIT:** Treadmill<br>**RT:** free weights, machine weights, kettlebells, medicine balls, exercise balls, TheraBand, mat<br>**PIL:** Reformer, Pilates ball | SphygmoCor Xcel<br>Aneroid Sphygmomanometer<br>Stethoscope<br>Wahoo HR chest strap<br>Foetal Doppler<br>Anthropometry tape measure<br>Smart phone |
| | | | | During exercise | HR (bpm), RPE (6-20 Borg), BP (mmHg) (VIIT only) | | |

S2 = Study 2, S3 = Study 3; S4 = Study 4; S5 = Study 5; mmHg = millimetres of mercury; HR = heart rate; bpm = beats per minute; BP = blood pressure; FHR = foetal heart rate; AIx = augmentation index; PWV = pulse wave velocity; BGL = blood glucose levels; RPE = rating of perceived exertion; $O_2$ = oxygen; VIIT = vigorous intensity interval training; RT = resistance training; PIL = Pilates

## 2.6 Outcome measures

All four experimental studies utilised the same resting and post-exercise outcome measures. The primary outcome measure across *Chapters 4, 6* and *7* was PWV, whilst secondary outcome measures included HR, BP, MAP, PWA, FHR and RPE. The primary outcome measure in *Chapter 5.* The effects of a submaximal graded exercise test on mean arterial pressure in pregnancy: A cross-sectional analysiswas MAP, whilst the secondary outcome measures included HR, BP, PWV, PWA, FHR and RPE. The timing of measures was the same across each study. Resting measures were taken following five minutes of semi-recumbent rest at a 15 degree incline from supine as this has angle been suggested to reliably reduce inferior vena cava compression (126). Following the submaximal exercise test and the VIIT sessions, participants were asked to safely but swiftly dismount the treadmill and assume a semi-recumbent position on a plinth (15-degree angle). Following the resistance and Pilates sessions, participants were instructed to complete five minutes of static stretching as a cool-down, before being asked to lay down in a semi-recumbent position on a plinth (15-degree angle). Once the participants laid down on the plinth the first set of post-exercise measures were started immediately, with measures taken between 1-5 minutes post-exercise. Whilst the SphygmoCor Xcel device performed the PWA measures, FHR was taken concurrently. The first PWV measurement was taken once the PWA was finished. Whilst the measures were not taken 'immediately' upon exercise cessation, they were taken as soon as possible, therefore 'immediately' has been used to describe the first measurement post exercise throughout the studies. Participants were asked to rest in this semi-recumbent position quietly for 10 minutes before the second set of post-exercise measures were taken.

Figure 7*7.* andFigure 8. present schematic representations of the measurement timing throughout the Cornell test and the three different modes of exercise.

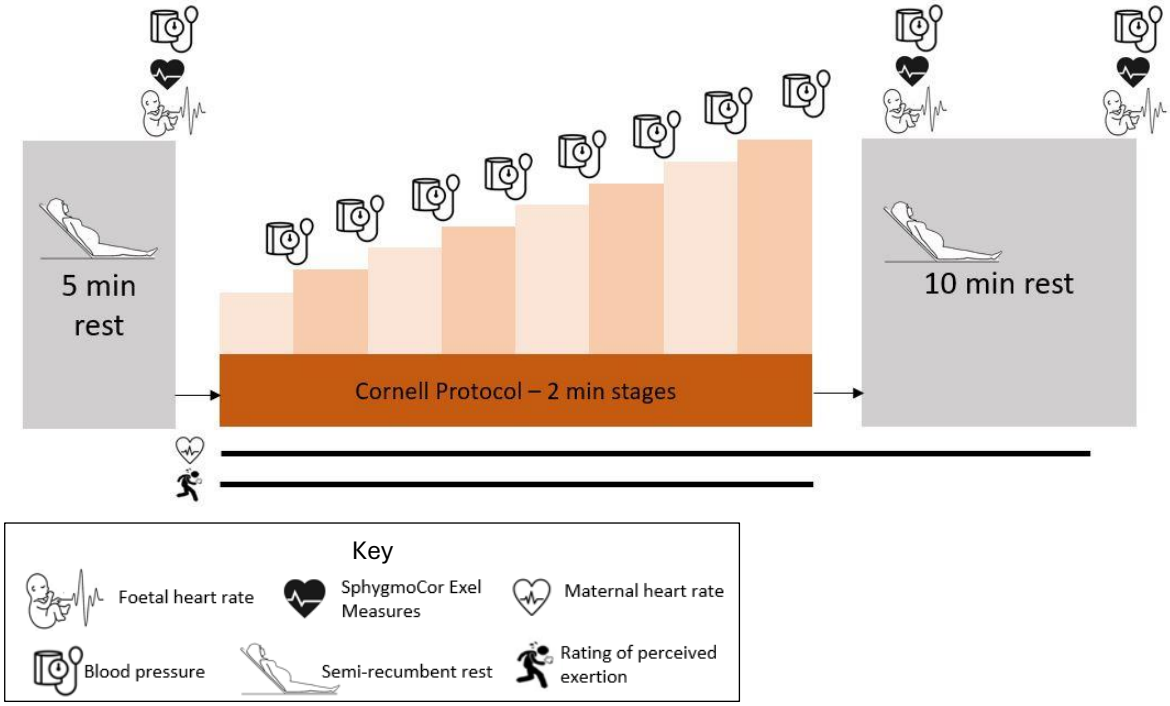



Figure 7. Timing of outcome measures in the Cornell Test

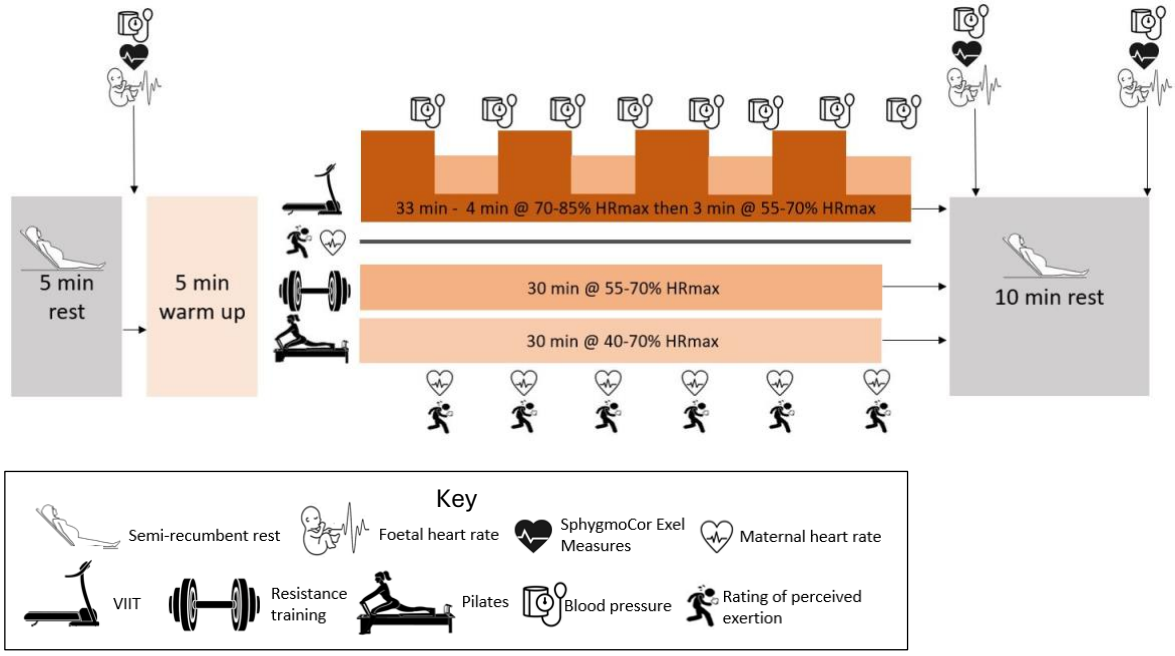



Figure 8. Timing of outcome measures in Studies 4 and 5

### 2.6.1 Blood pressure

Peripheral (brachial) BP was measured following 5 minutes of rest in the semi-recumbent position, with post-exercise measures taken immediately following exercise (1-2 minutes) and again 10 minutes post-exercise across all studies. Resting peripheral BP was measured using the SphygmoCor Xcel system via a pneumatic cuff placed around the upper arm. The cuff was inflated to measure the participant's brachial systolic (SBP) and diastolic pressure (DBP). These measures were also used in the calculation of pulse pressure (PP).

Brachial BP was measured manually during exercise at every exercise stage in Study 2 and 3, and at every stage of the VIIT treadmill sessions in Study 4 and 5. Exercising BP was measured on the treadmill to monitor the participants for any adverse responses given these sessions involved a higher intensity of exercise (up to 85% $HR_{max}$). This was performed using a standing aneroid sphygmomanometer and a stethoscope. The sphygmomanometers were checked before each use and re-zeroed if necessary. The sphygmomanometers were checked every 6 months by a trained laboratory technician employed at ACU. If any issues arose with the sphygmomanometers they were replaced, with all devices replaced every 2 years regardless of whether they had issues. Participants were instructed to hold the treadmill handrail on the contralateral side to reduce the risk of falling and imbalances whilst the BP measure was being undertaken. Termination criteria included SBP > 250 mmHg or DBP > 150 mmHg, which was based on non-pregnant populations guidelines (92).

All BP measurements were taken in accordance with the National Heart Foundation of Australia guidelines (127). The appropriate cuff size was selected for each participant based on the size of their arm, with the bladder length at least 80% and the width at least 40% of the circumferences of the mid-upper arm. Participants were required to wear sleeveless or loose-fitting shirts that could be rolled up to the shoulder without restricting blood flow when necessary. BP was determined using Korotkoff sounds, with SBP recorded as the first audible noise (Korotkoff Phase I), and DBP recorded as the last sound heard (Korotkoff Phase V). In instances where blood flow could be heard until the pressure reads near zero, the Korotkoff Phase IV was used to determine DBP.

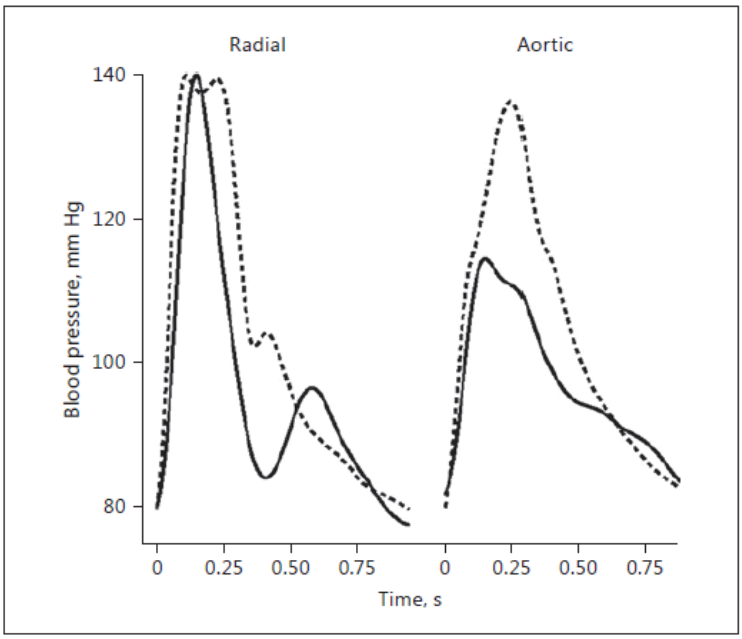



Figure 9. Peripheral and aortic BP waveforms taken from (58) showing the difference between brachial and aortic BP of two sample patients. Whilst the patients have similar brachial BPs, the magnitude of the aortic BP is markedly different.

### 2.6.2 Arterial stiffness

#### *2.6.2.1 Pulse wave analysis*

Resting PWA was conducted using an automatic device (SphygmoCor Xcel; AtCor Medical, Sydney, Australia) following 5 minutes of semi-recumbent rest. Post-exercise measures were taken again immediately post-exercise (1-2 minutes) and again 10 minutes post-exercise in all participants across the four studies.

Resting peripheral BP was measured as outlined in 2.6.1. Five seconds after the arm cuff was deflated, the PWA measure automatically began with the arm cuff reinflating to capture the peripheral waveform. A transfer function analysis within the SphygmoCor software was used to generate a central waveform, with central or aortic SBP and DBP (*Figure 9*), PP, and the magnitude of the forward and reflected waves estimated. Augmentation pressure (AP) provides a measure of the wave reflected back by the lower body and is calculated as the difference between the two peaks during systole. Augmentation index (AIx) is the ratio of AP to PP expressed as a percentage, which is influenced by HR. As such, this measure can be corrected to a HR of 75 beats per minute and is expressed as AIx75.

#### *2.6.2.2 Carotid-femoral pulse wave velocity*

Resting PWV was performed following 5 minutes of semi-recumbent rest, and again immediately (2-5 min) and 10 minutes following exercise in the semi recumbent position in all participants across the four studies. The first PWV measurement post exercise was taken once the PWA measurement was finished.

Carotid-femoral PWV (cfPWV) was measured using the SphygmoCor Xcel system (SphygmoCor, AtCor Medical, Sydney, Australia). Pulse waves were measured simultaneously at the carotid artery through a hand-held tonometer, and at the femoral artery through a low-pressure pneumatic cuff placed around the thigh (which remained partially inflated for 20-60 seconds). The distance between the carotid (c) and suprasternal notch (S) ($d_{sc}$), the sternal notch and the femoral cuff (fC) ($ds_{fC}$) and the inguinal fold (where tonometry would be applied to find the pulse) (fT) and the femoral cuff ($d_{fTfC}$) were then measured with a standard anthropometry tape (55, 59). To avoid an overestimation of the path length between the sternal notch and the femoral cuff due to pregnant abdomens, the tape measure was lifted off the body of the participant keeping a straight line parallel to the plinth, with the measurement taken in this position. Callipers have been recommended as another method to avoid this overestimation, however, were not available for these studies (55).

The tonometer was placed on the carotid artery and once a regular pulse wave was detected and the signal quality was valid, the thigh cuff automatically inflated to 80 mmHg which allowed the device to collect simultaneous carotid and femoral pulse waves. Once 10 seconds of valid carotid tonometer and femoral cuff signals were received by the device, a report screen appeared. The transit time (tt) between the feet of the two waves (carotid to femoral) was measured by the device. The cfPWV was then calculated by subtracting the contribution of the additional femoral segment to both the distance ($d_{fTfC}$) and the transit time proportional ($k_2$) to that distance. Transit time was further corrected ($k_1$) to adjust for the delay in the transmission of the pulse from the femoral cuff to the pressure transducer, as opposed to the carotid tonometer where the transducer was placed directly above the artery on the skin. These measures were performed in duplicate and an average was taken. When the two measures differed by more than 0.5 $m.s^{-1}$ a third measure was taken and the median of the three measures was used. The SphygmoCor device has been validated across a range of populations (59) and has previously been used within obstetric populations,

therefore was selected to ensure comparability with previous research (128). This device has been validated against invasive testing in non-pregnant populations, however not in pregnancy (55). The cardiovascular changes in pregnancy (e.g. HR changes) appear to be accounted for in the algorithm, with the algorithm designed to focus on wave propagation time between the two sites, minimising the impact of HR on the calculated PWV. Adaptations to the algorithm are therefore likely not necessary.

As shown in *Figure 10* the equation for PWV is:

$$cfPWV = \frac{(d_{sfC} - d_{sc} - d_{fTfC})}{(tt_{cfC} - k_1 - k_2 x d_{fTfC})}$$

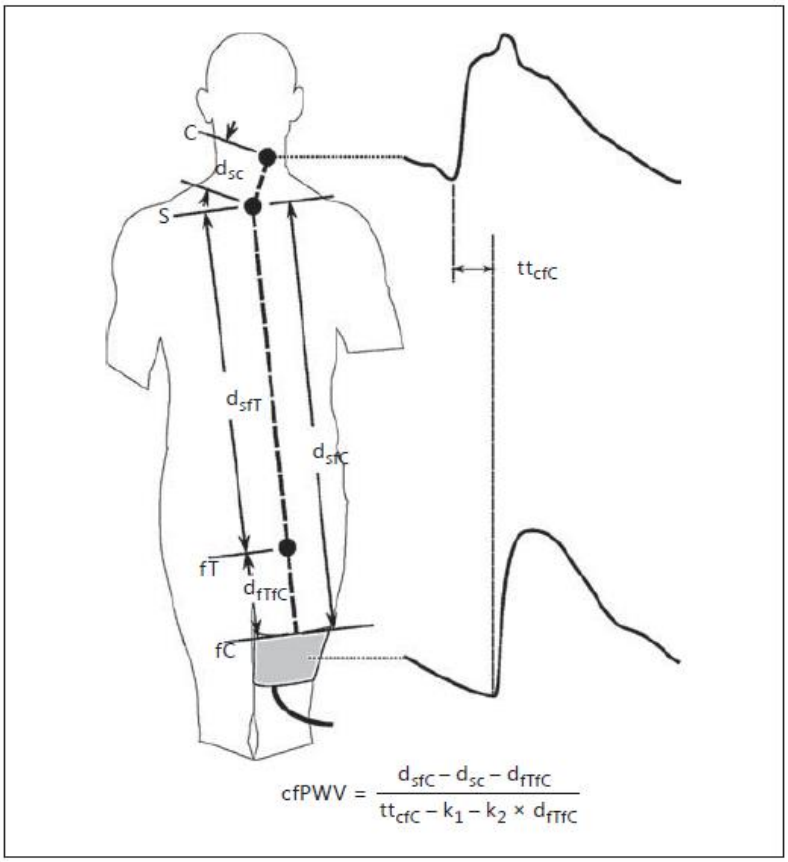



Figure 10. SphygmoCor XCEL carotid-femoral pulse wave velocity calculation (59)

### 2.6.3 Heart rate

Resting HR measurements were recorded following 5 minutes of supine rest. HR was constantly monitored throughout each of the exercise sessions and for 10 minutes following

exercise. HR was measured using photoplethysmography with a chest strap connected via Bluetooth to a phone application (Wahoo TICKR). Heart rate recovery (HRR) was observed by recording post-exercise HR 1-3 minutes following exercise sessions. Age predicted HR maximum ($PHR_{max}$) was calculated using the following equation (129):

$$220 - Age\ (years) = predicted\ maximum\ heart\ rate$$

The target HR/HR zones for each type of exercise were based on a position statement on exercise intensity terminology (115), and are outlined in *Table 7* .

Table 7. Exercise intensity

| Exercise protocol | Intensity | Objective measures | Subjective measures |
|---|---|---|---|
| **Cornell** | Submaximal graded test | ≤ 85% $PHR_{max}$ | RPE 17-19 |
| **Warm up (all types)** | Light | 40-55% $PHR_{max}$ | RPE 8-10 |
| **VIIT** | Work = vigorous<br>Recovery = moderate | 70 < 90% $PHR_{max}$<br>55 < 70% $PHR_{max}$ | RPE 14-16<br>RPE 11-13 |
| **RT** | Moderate | 55 < 70% $PHR_{max}$ | RPE 11-13 |
| **PIL** | Light – moderate | 40-70% $PHR_{max}$ | RPE 8-13 |
| **Cool down (RT & PIL)** | Light | 40-55% $PHR_{max}$ | RPE 8-10 |

VIIT = vigorous intensity interval training; RT = resistance training; PIL = Pilates; $PHR_{max}$ = age predicted heart rate maximum; RPE = rating of perceived exertion

### 2.6.4 Foetal heart rate

Foetal heart rate (FHR) was measured as a secondary measure using a basic 2Mhz foetal doppler (Edan Sonotrax) at rest and again post-exercise whilst the PWA measures were collected. Cardiotocography would have been ideal for measuring FHR post exercise as it would have provided a continuous recording of the FHR, however, was not available for these studies. A small amount of ultrasound gel (approximately 20 millilitres) was applied to the participants' abdomen to help transmit the ultrasound waves and improve the quality of the doppler signal. Once the heartbeat had been identified, the probe was held in position for approximately 20 seconds to ensure its stability. The measurement was recorded, and the gel was wiped off the participants' abdomens. Maternal HR and umbilical HR were assessed to ensure a true FHR reading was taken.

The ranges for FHR were (130):

- Normal FHR = 110-160 bpm
- Bradycardia = < 110 bpm
- Tachycardia = > 160 bpm

In the case of any FHR readings outside of the normal range, the AEPs followed protocols outlined by Queensland Health (130).

### 2.6.5 Timing of measures

The timing of post-exercise measures differed slightly across exercise modes, as the time taken from the cessation of exercise to when the first post-exercise measure (PWA) was taken varied from within 30 seconds (VIIT) to 1-2 minutes (RT, PIL). This was due to the proximity of the treadmill, reformer and RT area to where the SphygmoCor Xcel device was set up. On top of this, PWV measurements could not be taken until the PWA measurement had finished (approximately 1-2 minutes). This meant that the first PWV measurement occurred 2-3 minutes after the participant had ceased exercise. At times the PWV reading was more difficult to obtain, as the device is automatically triggered once the carotid tonometer detected a regular pulse wave with a valid signal quality. This can be potentially challenging due to increased adiposity around the carotid artery, along with involuntary movements from the participant that effect the signal quality (e.g. swallowing/coughing etc.). FHR was measured in the semi-recumbent position whilst the PWA measurement was simultaneously occurring at rest, within 30 seconds – 2 minutes post exercise and again 10 minutes post exercise.

### 2.6.6 Rating of perceived exertion

Participants reported their RPE using the Borg scale (117) throughout each session, as an additional subjective measure of exercise intensity (Appendix 10). RPE was reported at the end of every minute during the Cornell test and the VIIT sessions, whilst it was recorded at the end of every 5$^{th}$ minute during the RT and PIL sessions.

### 2.6.7 Oxygen saturation

Resting oxygen saturation was measured following 5 minutes of supine rest and throughout each exercise session for the pregnant participant in Study 2 using a finger pulse oximeter (Heal Force). The oximeter was placed on the contralateral arm to the BP cuff.

### 2.6.8 Anthropometry

Anthropometric measures (height and weight) were conducted upon study entry for participants in Study 3, 4 and 5, with weight measured weekly for participants in Study 2. Height and pre-pregnancy bodyweight were self-reported by participants within the pre-exercise questionnaires. In Study 2 weight (in kilograms (kg)) was measured on the same scales at the same time of day each week (131).

### 2.6.9 BMI

Pre-pregnancy BMI was calculated for each participant at enrolment based on reported pre-pregnancy weight (kg) and height (centimetres (cm)). BMI was calculated using the standard equation:

$$BMI = kg/m^2$$

Where kg is the participants weight in kg and m is the participants height in metres. Pre-pregnancy BMI classifications were assessed according to World Health Organisation (WHO) BMI guidelines (*Table 8*) (132).

Table 8. BMI Classifications

| **BMI (kg/m$^2$)** | **Classification** |
|---|---|
| **< 18.5** | Underweight |
| **18.5-24.9** | Healthy Weight |
| **25.0-29.9** | Overweight |
| **30.0-34.9** | Obesity I |
| **35.0-39.9** | Obesity II |
| **≥ 40.0** | Obesity III |

### 2.6.10 Blood glucose

Blood glucose levels (BGL) were measured in the pregnant participant in Study 2 at rest and 5 minutes after each exercise session using a Glucometer (Accu-Chek). BGLs were also measured before and after exercise for any participants in Studies 3, 4 and 5 who had T1DM or who were diagnosed with GDM, to ensure they fell within safe limits (5-13.9 $mmol.L^{-1}$) (133). If BGLs fell outside of these limits, the protocol outlined by the American Diabetes Association was followed (133). BGLs are outlined in (*Table 9*) below.

Table 9. Classification of BGLs

| **BGL ($mmol.L^{-1}$)** | **Classification** |
|---|---|
| **< 4** | Hypoglycaemia – No exercise until treated |
| **4-5** | Low – Small dose of carbohydrates needed before exercising |
| **5-10** | Ideal – Safe to exercise |
| **10-14** | High – Gentle exercise advised |
| **> 14** | Hyperglycaemia – No exercise until treated |

### 2.6.11 Questionnaires

#### *2.6.11.1 Pre-enrolment questionnaire*

Participants in each study were asked to complete an online questionnaire designed by the research team prior to their first exercise session to gain demographic (age, ethnicity, marital status, employment status, postcode, number of children, level of education, employment status) and pregnancy (gestational week (GW), number of pregnancies, planned delivery type) data. The online program QualtricsXM (Qualtrics, Provo, UT) was used. The questionnaire can be viewed in Appendix 11.

#### *2.6.11.2 Post-delivery questionnaire*

A post-delivery questionnaire was provided to all participants within two months following reported due date. The online program QualtricsXM (Qualtrics, Provo, UT) was used. The questionnaire included questions on maternal birth outcomes (type of delivery, duration of labour, gestational age at delivery, complications, medical inventions used, time spent in hospital following delivery) and foetal birth outcomes (sex of baby, birth weight, birth length, head circumference, APGAR (appearance, pulse, grimace, activity, respiration) scores). The questionnaire also included ratings of enjoyment and motivation for each type

of exercise. As the questionnaire was provided up to two months after participation in the study had ended, recall on enjoyment and motivation levels for each type of exercise may have been impaired. The questionnaire can be viewed in Appendix 12.

### 2.6.12 Daily steps

The participants in Study 2 recorded their daily step count over the 7-8 month period with their own smartwatch (pregnant participant - Google WearOS, non-pregnant participant – FitBit Versa) (134). Each participants' watch was put on upon waking and removed when going to bed. Screenshots of the daily step count achieved were provided to the research team each week.

### 2.6.13 24-Hour food diary

Participants in Study 2 were required to report all food and drink intake over the 24 hours prior to each session in order to observe any predictors of change in vascular measures (e.g. sodium intake). The MyFitnessPal smartphone application was used to track diet, which provided a breakdown of calories, sodium, carbohydrates, fat and protein over the 24-hour period. Participants were asked to complete the food diary in MyFitnessPal upon waking the day prior to testing, and up until testing on the following day. An example food entry is shown in *Figure 11*.

### 2.6.14 Feasibility

The intensity of each session in Study 4 and 5 was determined based on $PHR_{max}$ (220 - age) and rating of perceived exertion (RPE) (129). The session was considered feasible if participants were able to achieve the target intensity. A post-delivery questionnaire was delivered which included ratings of enjoyment and motivation for each type of exercise. In the questionnaire participants were asked: "On a scale of 0-10 how much did you enjoy the VIIT/RT/PIL sessions?" and "On a scale of 0-10 how motivated were you to complete the VIIT/RT/PIL sessions?" Where 0 = not at all and 10 = extremely motivated. Participants were also asked to rank the three modes of exercise in order of first, second and third preference.

| Breakfast | Kilojoules kj | Carbs g | Fat g | Protein g | Sodium mg | Sugar g | |
|---|---|---|---|---|---|---|---|
| Coles Shortcut Bacon - Bacon , 60 gram | 432 | 1 | 6 | 10 | 624 | 0 | ⊖ |
| Fried egg, 1 large | 348 | 0 | 7 | 5 | 130 | 0 | ⊖ |
| Woolworths - English Muffin, 1 Muffin | 602 | 25 | 2 | 6 | 240 | 2 | ⊖ |
| Tomato Chutney - Tomato chutney, 5 g | 46 | 3 | 0 | 0 | 37 | 2 | ⊖ |
| Woolworths - Light Tasty Cheese Slices, 1 Slice | 297 | 0 | 5 | 6 | 131 | 0 | ⊖ |
| Add Food \| Quick Tools | 1,723 | 29 | 20 | 27 | 1,162 | 4 | |
| **Lunch** | | | | | | | |
| Woolworths - Creamy Kale Coleslaw Kit, 75 gram | 327 | 3 | 6 | 1 | 172 | 3 | ⊖ |
| Chicken Breast Fillet - Skinless Chicken Breast, 200 gr(3.5 ounces) | 1,381 | 0 | 7 | 62 | 148 | 0 | ⊖ |
| Homemade - Garlic Aoili, 1 Tbsp (15 g) | 356 | 1 | 8 | 0 | 80 | 0 | ⊖ |
| Helga's - Capsicum & Roasted Garlic Wrap, 70 gram | 879 | 34 | 6 | 5 | 280 | 2 | ⊖ |
| Add Food \| Quick Tools | 2,943 | 38 | 27 | 68 | 680 | 5 | |
| **Dinner** | | | | | | | |
| Chicken Panang Curry, 1 serving(s) | 2,214 | 47 | 19 | 35 | 1,180 | 6 | ⊖ |
| Add Food \| Quick Tools | 2,214 | 47 | 19 | 35 | 1,180 | 6 | |
| **Snacks** | | | | | | | |
| Banana - Large Banana, 1 piece | 506 | 31 | 0 | 2 | 1 | 17 | ⊖ |
| Green apple, 1 medium | 405 | 23 | 0 | 1 | 2 | 16 | ⊖ |
| Generic - Lebanese Cucumber, 200 g | 100 | 4 | 0 | 1 | 38 | 4 | ⊖ |
| Add Food \| Quick Tools | 1,011 | 58 | 0 | 4 | 41 | 37 | |
| Totals | 7,891 | 172 | 66 | 134 | 3,063 | 52 | |
| Your Daily Goal | 7,980 | 238 | 63 | 96 | 2,300 | 54 | |
| Remaining | 89 | 66 | -3 | -38 | -763 | 2 | |
| | Kilojoules kj | Carbs g | Fat g | Protein g | Sodium mg | Sugar g | |

Figure 11. Example of MyFitnessPal entry

## 2.7 Exercise protocols

### 2.7.1 Cornell treadmill protocol

The participants in Study 2 completed a graded submaximal exercise test once weekly on the treadmill following the Cornell protocol. The participants in Study 3 completed the Cornell protocol once upon enrolment into Study 4 or Study 5. This protocol was also used to estimate cardiorespiratory fitness and determine workloads in the VIIT protocols in Studies 4 and 5 based off HR responses.

The Cornell protocol consists of walking on a treadmill for up to eleven stages lasting 2 minutes each, that gradually increase in speed and gradient. The test was terminated once 85% of the participant's $PHR_{max}$ was reached, the participant indicated a desire to stop, or

the assessor identified any concerning signs or symptoms. Given the limited research available on the safety of high intensity exercise (>85%$HR_{max}$) during pregnancy whilst these studies were being designed, it was decided that the tests would be cut off at 85% $PHR_{max}$ as there was evidence showing that vigorous exercise (70-85% $HR_{max}$) is safe throughout the third trimester (80). Participants were instructed to avoid holding the handrail unless needed to briefly to steady themselves, particularly during the later stages of the test. This protocol has been used previously in pregnancy research (135, 136). The eleven stages are outlined in *Table 10* below.

Table 10. Cornell treadmill protocol

| **Cornell treadmill protocol** | | | |
|---|---|---|---|
| **Stage** | Minute | Speed km/hr | Gradient % |
| **1** | 2 | 2.74 | 0 |
| **2** | 4 | 2.74 | 5 |
| **3** | 6 | 2.74 | 10 |
| **4** | 8 | 3.38 | 11 |
| **5** | 10 | 4.02 | 12 |
| **6** | 12 | 4.82 | 13 |
| **7** | 14 | 5.47 | 14 |
| **8** | 16 | 6.11 | 15 |
| **9** | 18 | 6.76 | 16 |
| **10** | 20 | 7.4 | 17 |
| **11** | 22 | 8.05 | 18 |

### 2.7.2 Vigorous intensity interval training (VIIT) protocol

The 4 x 4 method of interval training was applied in this study (137)**.** The vigorous intensity interval sessions lasted 33 minutes in total and began with a light 5 minute warm up on a treadmill or cycle ergometer (9-11 RPE, 45-60% $HR_{max}$). The participants then performed four, four-minute intervals of vigorous intensity walking or cycling (RPE 14-16, 70-85% $PHR_{max}$) interspersed with four, three-minute intervals of moderate intensity walking or cycling (RPE 11-13, ~65% $HR_{max}$). Treadmill was the preferred mode of exercise in the VIIT sessions, however participants were given the option to perform these sessions on a cycle ergometer if they found the treadmill walking uncomfortable. Treadmill was selected over stationary cycling as a more functional movement performed in everyday life, also due

to the increased risk of sacroiliac joint pain during pregnancy, which can be exacerbated with cycling movements. Cycling was provided as an alternative option for participants in order to reduce the risk of drop-out. The treadmill gradient and speed were adjusted at each stage to increase/decrease HR to align with the prescribed intervals.

Participants in Study 4 performed one bout of VIIT in each trimester of pregnancy, whilst the participants in Study 5 participated in one bout of VIIT weekly for the duration of the study. Across all 229 VIIT sessions in Study 5, three were performed on a cycle ergometer (due to patient reported ankle pain and swelling, which was exacerbated with treadmill walking), equating to 1.3% of VIIT sessions. All VIIT sessions in Study 4 were performed on the treadmill. The workload for the VIIT intervals were calculated in metabolic equivalents (METs) using the treadmill speed and gradient in the following American College of Sports Medicine (ACSM) calculation (138):

$$((Speed\ (m/min) \times\ 0.1) + (\%incline * 1.8 \times (speed\ (m/min)) + 3.5)) \div 3.5$$

### 2.7.3 Resistance training protocol

The RT sessions ran for 35 minutes, beginning with a light 5-minute warm up involving dynamic stretches of each major muscle group, then 30 minutes of RT using bodyweight exercises, free weights, resistance bands and machine-based exercises (120). Each session was individualised in terms of exercises selected, however the structure of each session remained consistent. Exercises were performed in a tri-set, with each set including an upper body, lower body and trunk exercise. Each tri-set was performed 3-4 times, with 8-12 repetitions performed for each exercise. Due to increased ligament laxity during pregnancy and the increased risk of exertion induced musculoskeletal injury (120), a higher repetition range (~10) is prescribed, keeping the load to a moderate intensity throughout (RPE 11-13) by adjusting the weight or repetitions for each set. Intensity was prescribed based on RPE rather than %1RM as no initial strength testing session was conducted. Given the nature of pregnancy, programming was not progressive but rather adapted as gestation progressed to ensure each session remained within the threshold for moderate intensity (115). A cool down was included to make these sessions as 'real-world' as possible within a research setting. An example program is shown below in *Table 11*.

Table 11. Example resistance training program

| | Exercise | Target Muscle Group | Sets | Reps | Intensity |
|---|---|---|---|---|---|
| **Warm Up** | Leg Swings | Lower body | 1 | 10 | RPE: 8-10 |
| | Arm Circles | Upper body | 1 | 10 | RPE: 8-10 |
| | Banded crab walks | Lower body | 3 | 10 | RPE: 8-10 |
| **Tri-set 1** | Goblet squat | Lower body | 3-4 | 8-12 | RPE: 11-13 |
| | Chest Press | Upper body | 3-4 | 8-12 | RPE: 11-13 |
| | Shoulder taps | Trunk | 3-4 | 8-12 | RPE: 11-13 |
| **Tri-set 2** | Walking lunges | Lower body | 3-4 | 8-12 | RPE: 11-13 |
| | Seated row | Upper body | 3-4 | 8-12 | RPE: 11-13 |
| | Cable Palloff press | Trunk | 3-4 | 8-12 | RPE: 11-13 |
| **Cool Down** | Static stretching | Whole body | 1 | 1 x 20-30 seconds | RPE: 8-10 |

RPE = rating of perceived exertion

### 2.7.4 Reformer Pilates training protocol

The reformer Pilates sessions ran for 35 minutes, beginning with a light 5-minute warm up involving dynamic stretches of each major muscle group, then 30- minutes of light to moderate (RPE 8-13) exercises targeting each major muscle group performed on the reformer. Reformer Pilates was selected as it is a popular mode of exercise amongst women, particularly in pregnancy (139). Exercise intensity was maintained by adjusting the springs on the Reformer to increase or decrease the load, or by adjusting the repetitions based on RPE. Programming was not progressive but rather adapted as gestation progressed to ensure each session remained within the threshold for light-moderate intensity (115). Exercises performed in the supine position were avoided as a precaution, as supine rest has been associated with symptomatic hypotension in up to 10% of pregnant women due to vena cava compression (140). The sessions concluded with a 5-minute cool down involving light static

stretching to make these sessions as 'real-world' as possible within the research setting. An example program is shown below in *Table 12*.

Table 12. Example reformer Pilates program

| | Exercise | Target Muscle Group | Sets | Reps | Intensity |
|---|---|---|---|---|---|
| **Warm Up** | Leg Swings | Lower body | 1 | 10 | RPE: 8-10 |
| | Arm Circles | Upper body | 1 | 10 | RPE: 8-10 |
| **Series 1** | **Side lying leg series** | Lower body + trunk | 1-2 | 10-15 | RPE: 8-13 |
| | > SL press<br>> SL calf raise<br>> clams<br>> overs/unders<br>> hip adduction squeeze | | | | |
| **Series 2** | **Kneeling upper limb series** | Upper body + trunk | 1-2 | 10-15 | RPE: 8-13 |
| | > chest press<br>> chest fly<br>> windmills<br>> Palloff press<br>> sword pull<br>> row<br>> reverse fly | | | | |
| **Series 3** | **Trunk stability series** | Trunk | 1-2 | 10-15 | RPE: 8-13 |
| | > bird dog<br>> single arm sweeps<br>> 4pt kneeling SL press | | | | |
| **Cool Down** | Static stretching | Whole Body | 1 | 1 x 20-30 seconds | RPE: 8-10 |

SL = single leg; RPE = rating of perceived exertion

# Chapter 3. The effects of aerobic and resistance exercise on blood pressure in uncomplicated and at risk pregnancies: A systematic review and meta-analysis

This manuscript in this chapter has been published in an international, peer-reviewed journal *Women's Health.*

**Reference**

Giles C, Johnston R, Kubler J, Spathis J, Beetham K. The effects of aerobic and resistance exercise on blood pressure in uncomplicated and at risk pregnancies: A systematic review and meta-analysis. Womens Health (Lond). 2023;19:17455057231183573.

The publication has been formatted for the thesis within the current document, with the journal formatted version provided in Appendix 1.

## Abstract

### Background

Regular exercise performed during pregnancy has been shown to reduce the risk of developing perinatal gestational hypertensive conditions. Further evidence on the exact parameters of exercise needed to explain these beneficial responses is required, within both uncomplicated and at risk pregnancies. The aim of this systematic review and meta-analysis was to investigate the effects of aerobic and resistance exercise on blood pressure during pregnancy.

### Methods

An online search of six search engines was conducted up to February 2023. Randomised controlled trials, quasi-experimental, cohort and longitudinal studies were included. Studies included an acute exercise bout or intervention of land-based aerobic and/or resistance exercise during any trimester in uncomplicated and at risk pregnancies. Outcomes included mean arterial pressure (MAP), or systolic blood pressure (SBP) and diastolic blood pressure (DBP).

### Results

Following the removal of duplicates, 1538 articles were screened with fifty-nine studies meeting the inclusion criteria for the review (RCTs n = 34, clinical trials n = 19, cohort n = 5 and cross-sectional n = 2), and 21 studies included in the meta-analysis. A random effects model was used with mean difference calculated in mmHg. Overall, there were no statistically significant effects of exercise on resting blood pressure outcomes in pregnant women with normal blood pressure compared to control/usual care populations following intervention (SBP mean diff -1.54 mmHg (favours intervention), $p = 0.38$; DBP mean diff -2.25 mmHg (favours intervention), $p = 0.1$; MAP mean diff -1.75 mmHg (favours intervention), $p = 0.31$). In at risk pregnant women, both aerobic and combination exercise significantly reduced BP outcomes compared to control (SBP mean diff -3.91 mmHg, $p < 0.01$; DBP mean diff -2.9 mmHg, $p = 0.01$; MAP mean diff -2.38 mmHg, $p = 0.01$). Twenty-seven studies reported an acute increase in SBP and DBP during aerobic exercise, with no difference found between uncomplicated and at risk pregnancies.

**Conclusions**

Compared to usual care, aerobic and/or resistance exercise performed throughout uncomplicated pregnancy had no influence on blood pressure. Pregnant women with no diagnosed complications should be encouraged to exercise regularly due to the multitude of known benefits. In women who are at risk of, or diagnosed, with gestational hypertensive conditions during pregnancy, moderate to vigorous exercise during pregnancy improves blood pressure outcomes. Higher risk pregnancies may reduce their risk of future cardiovascular complications through regular exercise training during pregnancy.

Registration: CRD42020159998

## 3.1 Introduction

Pregnancy is a period characterised by significant physiological adaptations, particularly within the cardiovascular system (58). Maternal haemodynamic alterations within the cardiovascular system are evident from the first few weeks of gestation (14, 141). These rapid changes are necessary to ensure sufficient uteroplacental blood flow to transfer oxygen and nutrients from the mother to the foetus, to optimise foetal development (7, 11). An increase in heart rate (HR), cardiac output (CO), stroke volume (SV) and plasma volume are observed in healthy pregnancies and associated with a concomitant fall in total vascular resistance and systemic vascular tone (12, 142). Maladaptive changes to these maternal haemodynamic processes can occur during gestation, increasing the risk of gestational hypertensive conditions (11, 14).

Pre-eclampsia (PE) and gestational hypertension (GHTN) are pregnancy specific disorders that pose a significant risk to pregnant women, with the World Health Organisation (WHO) recognizing these conditions amongst the leading causes of maternal and foetal morbidity and mortality worldwide, along with haemorrhage and sepsis (28, 29, 143). The exact cause of GHTN and PE are not well established, however it has been identified that hypertensive conditions that present prior to 20 weeks of gestation (chronic HTN, GHTN) often advance to PE (29-31, 144). The vascular dysfunction that is associated with gestational hypertensive conditions is considered systemic and persistent resulting in a significantly increased risk of future cardiovascular disease (CVD) (7, 10, 29). Infants born following pre-eclamptic pregnancy have also been shown to be at an increased risk for childhood obesity and CVD later in life (19, 30) Other clinical conditions such as gestational diabetes (GDM) and overweight/obesity significantly increase the risk of developing hypertensive conditions in pregnancy (27).

There is convincing evidence that both acute and long-term aerobic, and resistance, exercise, from light to vigorous intensity, lowers resting blood pressure (BP) in both hypertensive and normotensive non-pregnant populations (83, 87, 145). Regular PA has been shown to positively enhance metabolic and musculoskeletal changes associated with pregnancy, however the mechanisms of prenatal exercise on BP are not yet well understood (10, 146). Two recent systematic reviews looked at the effects of prenatal exercise on measures of cardiovascular health including BP, and found that resting blood pressure was reduced following prenatal exercise interventions (147). Further, the risk of developing major clinical

conditions such as GHTN, PE and GDM is significantly reduced in women who engaged in regular prenatal exercise (33). There is however a lack of understanding surrounding the effects of different types and intensities of prenatal exercise on maternal blood pressure (10), as well as whether uncomplicated and at risk populations respond differently to prenatal exercise. Further evidence on the exact parameters of exercise needed to elucidate these beneficial responses is required.

The primary aim of this systematic review and meta-analysis is to determine the effects of acute and long-term aerobic exercise, resistance exercise and a combination of both, on blood pressure outcomes in uncomplicated and at risk pregnant populations. It is hypothesised that acute bouts of aerobic exercise will result in post exercise hypotensive responses, and that long-term aerobic exercise during pregnancy will reduce blood pressure and help prevent the onset of gestational hypertensive disorders, particularly within populations who are at increased risk of these conditions.

## 3.2 Methods

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (148). The review was registered with PROSPERO (International Prospective Register for Systematic Reviews) under the registration number CRD42020159998 (149).

### 3.2.1 Search strategy

Six online search engines (CINAHL, Cochrane, Embase, Medline, PubMed, Web of Science) were used to search databases up to February 2023. Standardised search terms were established with pregnant women as the population, aerobic or resistance exercise as the intervention, and MAP or BP as the primary outcome measures. All synonymous terms that may be used to describe the population, intervention and outcome were included. Medical Subject headings (MeSH), truncation and Boolean operators were used to ensure that all relevant articles were found in the database searches. Filters were applied to ensure searches were limited to studies on humans and reported in English. The reference lists of included articles were screened to ensure that any relevant studies missed in the database searches could be included in the review. The complete search strategy for each search engine can be viewed in Appendix 13.

### 3.2.2 Eligibility criteria

The types of studies eligible to be included in this review were randomised controlled trials (RCTs), quasi-experimental, cohort, longitudinal, case-control or non-randomised intervention studies. To be eligible for inclusion in the review, studies needed to be peer-reviewed articles including: 1) pregnant women completing either an acute bout or an intervention of land-based aerobic or resistance exercise during any trimester, and 2) maternal MAP or SBP/DBP reported as either a primary or secondary outcome measure. To be included in the meta-analysis, studies required the above listed criteria, along with a comparator/control group treated with standard prenatal care. Studies that reported on water-based activities were excluded due to the thermal effects of both warm and cold-water immersion on the cardiovascular system (150). Only primary studies were included in the review, to ensure that data from these studies were only taken into consideration once. Both uncomplicated and at risk pregnant populations were included.

### 3.2.3 Definitions

The methodologies of the articles were reviewed in detail to determine whether the exercise intervention included in the study met the criteria for land-based aerobic, resistance or combination exercise. The American College of Sports Medicine (ACSM) defines aerobic exercise as any activity that uses large muscle groups, is rhythmic in nature and can be maintained continuously, whilst resistance exercise involves exercising muscles against an external load or resistance in order to improve muscular fitness (151). Studies including aerobic or resistance land-based exercise at any intensity were included (115). Acute exercise is defined as a single bout of exercise following which researchers observed any changes between pre and post exercise outcome measures. Exercise interventions are defined as repeated bouts of exercise across a period of time (in this case ≥ three weeks) following which researchers observed any changes between pre and post intervention outcome measures. The intensity of exercise was determined based on percentage of heart rate max (%$HR_{max}$) and rating of perceived exertion (RPE) on the Borg Scale and rated as light (40-55% $HR_{max}$, RPE: 8-10), moderate (55-70% $HR_{max}$, RPE: 11-13), vigorous (70- < 90% $HR_{max}$, RPE 14-16) or high (≥ 90% $HR_{max}$, RPE: > 17) (115). In this review an at risk pregnancy is defined as one with diagnosed conditions that increase the pregnant woman's risk of developing gestational hypertensive conditions, including but not limited to: GDM, overweight/obesity, chronic hypertension, and/or previous pre-eclampsia (27). Uncomplicated pregnancies are defined as those with no pre-existing medical comorbidities

(e.g. HTN, type 2 diabetes) and no pre-existing or new-onset obstetric complications (e.g. PE, GDM) (152).

### 3.2.4 Assessment of risk of bias

The Cochrane Risk of Bias for Randomised Controlled Trials tool was used to assess the risk of bias in the RCTs and randomised clinical trials (*Table 13*) (153). This assessment tool allowed the authors to assess the bias in each study as low, high or unclear across six domains including: selection bias, reporting bias, detection bias, performance bias, attrition bias and other bias. Based on the scores in each domain an overall risk of bias score was generated as low, unclear or high risk.

The Newcastle-Ottawa Scale was used to assess the cohort and case control studies (*Table 14* and *15*). Eight questions are used to assess quality based on comparability, selection, outcomes for the cohort studies and exposure for the case-control studies (80). A total of the scores out of nine is then calculated to provide an overall quality assessment. Three reviewers (CG, JS and JK) conducted the bias assessments separately and discussed any discrepancies to come to a consensus.

The Revised Cochrane risk of bias tool for randomised trials (RoB 2) with additional considerations for crossover trials was used to assess the bias present in the crossover trial (*Table 16*) (154). This tool assesses risk of bias across five domains including: 1) randomization process, 2) deviations from intended intervention, 3) missing outcome data, 4) measurement of the outcome and 5) reporting of results. Each domain is judged as low, some concern, or high risk, and then an overall risk of bias is determined. In order to determine the risk of bias in non-randomised single-arm clinical trials, five questions were selected from the Newcastle-Ottawa scale, which has been previously described as a method of assessing these studies (*Table 17*) (155).

### 3.2.5 Data collection process

The results from the database searches were exported to EndNote X9 for the screening process. Duplicates were removed, and the titles and abstracts were screened by CG. The full texts of the included articles were retrieved for screening and reviewed in full by CG and JK. The data extracted from the studies was screened separately by two reviewers (CG

& JK) to ensure the studies met the eligibility criteria. A third reviewer (JS) provided an evaluation if there were any discrepancies. The following information was extracted from the studies: study design, sample size, year and location, participant characteristics, intervention and control conditions, SBP, DBP and MAP (calculated) as well as information used to conduct the risk of bias assessment.

### 3.2.6 Statistical analysis

The primary outcomes in this study were the impact of exercise during pregnancy on SBP, DBP and MAP. Meta-analyses were conducted for all instances in which two or more studies reported data on comparable outcomes, interventions, participants and comparators as recommended by Ioannidis et al. (156) Only two studies reported MAP as an outcome measure, therefore the SBP and DBP reported in each of the studies was used to calculate the MAP for the control and exercising groups using the equation (157):

$$\frac{SBP+(2DBP)}{3} = MAP.$$

The sample standard deviation for each of the calculated MAPs was found using the standard variances (SV) for each measure. The following equations were used, where SD1 is the SBP standard deviation (SD) and SD2 is the DBP SD:

$$SD1^2 = SV1$$
$$SD2^2 = SV2$$
$$\frac{SV1 + (2SV2)}{3} = MAP\ SV$$
$$\sqrt{MAP\ SV} = MAP\ SD$$

The software Review Manager 5 (RevMan V5, The Cochrane Collaboration) was utilised to run random effects meta-analysis using the DerSimonian and Laird method to estimate between-study variance. Meta-analyses were conducted separately for each outcome – SBP, DBP and MAP. Subgroup analysis was performed to determine any effect of exercise type on outcome measures. As all resting blood pressure measures were recorded in mmHg, unstandardised mean differences were calculated for these continuous outcomes within each study. Standard variance was used to calculate the standard deviation when these were not

reported by studies. Heterogeneity between studies was then assessed based on the $I^2$ value for each analysis, with an $I^2$ value between 30-60% considered moderate, and any value higher than 60% considered substantial heterogeneity.(158) Leave-one-out analysis was performed to determine the effect of each study on the heterogeneity.

## 3.3 Results

### 3.3.1 Study selection

The screening process of the studies can be viewed in *Figure 12*. In the initial search 2,055 articles were identified (CINAHL: 216, Cochrane: 1072, Embase: 107, Medline: 441, PubMed: 115, Web of Science: 104). Filters were applied, duplicates were removed and the titles and abstracts were screened for eligibility. Full texts were screened, and 59 articles were found to be eligible for the review. There were 32 exercise intervention studies and 27 acute exercise studies. Four of the intervention studies also reported acute responses to exercise. The types of studies included were RCTs (n = 33), clinical trials (n = 19), cohort (n = 5) and cross-sectional (n = 2). Eight intervention studies were included in the review that discussed BP, however did not report either pre or post SBP, DBP or MAP values, or did not include a control/comparator group (159-166). These studies were not included in the meta-analysis, along with one study which failed to report SD for SBP or DBP (167), leaving 21 intervention studies in the statistical analysis. In the 27 acute studies the gestational age at the time of the study, modality of exercise, and whether the final outcome measure was measured at rest or during exercise varied considerably, therefore the acute studies were not included in the meta-analysis and are narratively presented. Six studies were excluded as they included water-based activities rather than land-based aerobic or resistance exercise (168-173). These aquatic-based studies did not fit within the inclusion criteria for this review, however this is an important area of research given that swimming is a popular, low impact exercise during pregnancy.

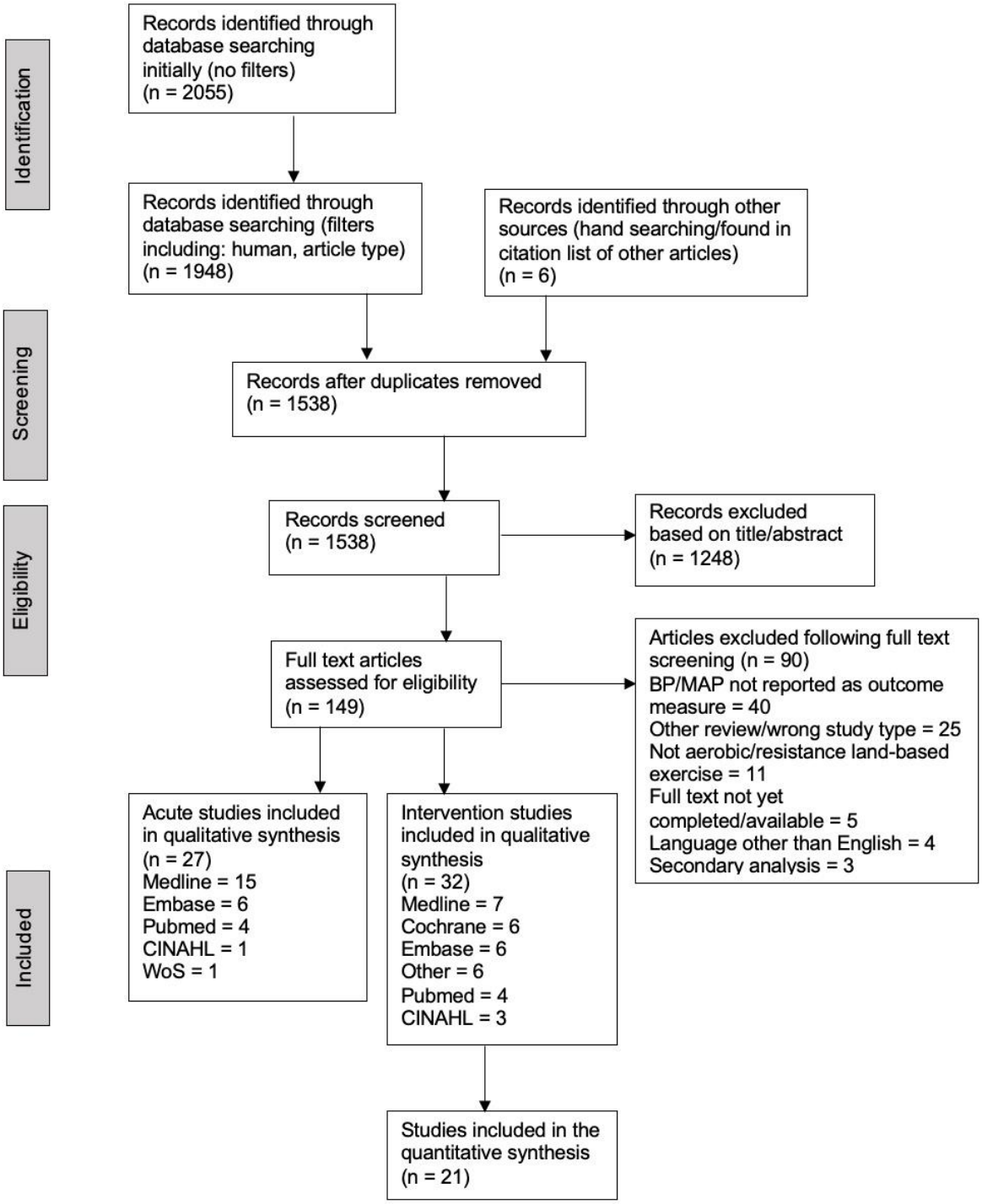



Figure 12. PRISMA Flow chart

### 3.3.2 Risk of bias

The risk of bias can be viewed in *Table 13, 14, 15, 16* and *17*. Overall, the risk of bias in the RCTs and randomised clinical trials was low, with 27 (71%) studies assessed as low risk (36, 96, 116, 146, 157, 159-162, 164, 165, 174-189), ten (27%) studies classified as unclear (108, 167, 189-195), and one (2%) study considered high risk (196) (*Table 13*). The cohort (93, 95, 197-201) and case control studies (202-207) were all classified as low (71%) to moderate (29%) risk of bias (*Table 14* and *15*), as were the two crossover studies (*Table 16*) (208, 209). One (15%) of the single-arm clinical trials was found to have an unclear risk of bias (210), whilst the other six (85%) studies were deemed to be low risk (*Table 17*) (163, 166, 211-214).

Table 13. Assessment of risk of bias in randomised control studies using Cochrane risk of bias tool

| | Selection Bias | Selection Bias | Reporting Bias | Other Bias | Performance Bias | Detection Bias | Attrition Bias | Overall |
|---|---|---|---|---|---|---|---|---|
| **Amorim, 2018, Brazil** | L | L | L | L | L | U | U | L |
| **Babbar, 2016, USA** | L | L | L | L | L | L | L | L |
| **Bahadoran, 2015 Iran** | U | H | U | U | U | U | U | U |
| **Barakat, 2011, Spain** | L | U | U | U | L | L | L | L |
| **Barakat, 2012, Spain** | L | L | U | U | L | L | L | L |
| **Barakat, 2014, Spain** | L | L | U | U | U | L | L | L |
| **Boparai, 2021, Canada** | L | L | L | L | L | L | U | L |
| **Brislane, 2021, UK** | H | H | L | U | L | L | U | U |
| **Brun, 2011, Canada** | U | U | U | U | L | L | U | U |
| **Carpenter, 2015, UK** | H | U | U | U | U | L | U | U |
| **Carpenter, 2017, UK** | H | U | U | U | L | U | U | U |
| **Daniel, 2015, Nigeria** | L | U | U | L | L | L | U | L |
| **de Oliveria, 2012, Brazil** | L | L | L | L | L | L | L | L |
| **Erkkola, 1976, Finland** | U | U | U | L | L | L | U | U |
| **Fernández-Buhigas, 2020, Spain** | L | L | U | U | L | L | U | L |
| **Garnaes, 2016, Norway** | L | L | L | L | L | L | L | L |
| **Guelfi, 2016, Australia** | L | L | L | U | L | L | U | L |
| **Haakstad, 2016, Norway** | L | L | L | L | L | L | L | L |
| **Halse, 2015, Australia** | L | L | L | L | U | L | U | L |
| **Huifen, 2022, China** | L | L | L | L | L | L | L | L |
| **Kasawara, 2013, Brazil** | L | L | L | L | L | L | L | L |
| **Khoram, 2019, Iran** | L | L | L | L | U | L | L | L |
| **Kim, 2018, Korea** | L | L | L | L | L | L | L | L |
| **Nascimento, 2011, Brazil** | L | L | L | L | L | L | L | L |
| **Perales, 2016, Spain** | L | L | L | L | L | L | L | L |
| **Petrov Fieril, 2015, Sweden** | L | L | L | L | L | L | L | L |
| **Pijpers, 1984, Netherlands** | U | U | U | U | U | L | U | U |
| **Ramirez-Velez, 2011, Columbia** | L | L | L | L | L | L | L | L |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Rodríguez-Díaz, 2017, Spain** | L | L | L | U | L | L | L | L |
| **Seneviratne, 2015, New Zealand** | L | L | L | L | L | U | L | L |
| **Silva-Jose, 2021, Spain** | L | L | L | L | L | L | L | L |
| **Sklempe Kokic, 2018, Croatia** | U | U | U | U | L | L | U | U |
| **Stutzman, 2010, Canada** | H | H | L | L | L | L | U | L |
| **Vladimirov, 2015, Poland** | L | L | U | U | U | L | L | L |
| **Webb, 1994, Canada** | H | H | H | H | U | U | U | H |
| **Yeo, 2000, USA** | U | U | L | U | L | U | L | U |
| **Yeo, 2008, USA** | U | U | L | L | L | U | L | L |

Table 14. Assessment of risk of bias in cohort studies using Newcastle-Ottawa scale

| | Representativeness | Selection | Ascertainment of exposure | Demonstration that outcome of interest was not present at start | Study controls for relevant primary confounder | Study controls for other secondary confounders | Assessment of outcome | Was follow up long enough for outcomes to occur | Adequacy of follow up of cohorts | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Pivarnik, 1993, USA** | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 6 |
| **Rafla, 1999, UK** | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 5 |
| **Rafla, 2000, UK** | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 6 |
| **Rauramo, 1988, Finland** | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 6 |
| **Rauramo, 1988, Finland** | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 4 |
| **Sady, 1990, USA** | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 4 |
| **Santos, 2016, Brazil** | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 6 |

Table 15. Assessment of risk of bias in case-control studies using Newcastle-Ottawa scale

| | *Adequate case definition* | *Representativeness of the Cases* | *Selection of Controls* | *Definition of Controls* | *Comparability of Cases and Controls on the basis of the Design or Analysis* | *Ascertainment of Exposure* | *Non-Response Rate* | *Total* |
|---|---|---|---|---|---|---|---|---|
| **Avery, 1999, Canada** | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| **Bgeginski, 2015, Brazil** | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 6 |
| **Meah, 2021, Canada** | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 6 |
| **Meah, 2021, Canada** | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 6 |
| **O'Neill, 1993, Australia** | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 5 |
| **Purdy, 2019, Canada** | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 5 |

Table 16. Assessment of risk of bias in crossover trials using ROB-2 Tool

| | Randomisation process | Period/Carryover effects | Effect of assignment to intervention | Adhering to intervention | Missing outcome data | Measurement of the outcome | Selection of the reported result | Total |
|---|---|---|---|---|---|---|---|---|
| **Petrov Fieril, 2016, Sweden** | H | L | L | L | L | L | L | L |
| **de Oliveria, 2014, Brazil** | SC | L | L | L | L | L | L | L |

Table 17. Assessment of risk of bias in single-arm clinical trials

| | Q1 | Q2 | Q3 | Q4 | Q5 | Total |
|---|---|---|---|---|---|---|
| **Bisson, 2014, Canada** | L | L | L | L | U | L |
| **Ferriera, 2014, Brazil** | L | L | L | L | L | L |
| **Jeffreys, 2006, USA** | L | L | L | L | U | L |
| **Morrow et al. (1989)** | H | L | L | L | U | L |
| **O'Connor et al. (2011)** | L | L | L | L | L | L |
| **O'Neill et al. (2006)** | L | U | L | L | L | L |
| **van Doorn et al. (1992)** | U | U | L | U | U | U |

### 3.3.3 Characteristics of acute and long-term exercise interventions

The characteristics of the participants included in the intervention and acute studies can be found in *Table 18* and *Table 19* respectively. The designs of the exercise interventions and acute studies can be viewed in *Table 20* and *Table 21* respectively.

Table 18. Characteristics of participants in intervention studies

| Author, Year, Country | Population Uncomplicated (U) or at risk (Clinical conditions) | Subjects (n) | | | GA *Week* | Baseline Measures | | | | | Control | | | | | Outcomes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total n = | Int | Co | | Age *years* | BMI *kg/m² or Weight (kg)* | SBP *mmHg* | DBP *mmHg* | MAP *mmHg* | Age *years* | BMI *kg/m² or Weight (kg)* | SBP *mmHg* | DBP *mmHg* | MAP *mmHg* | |
| **RCTs** | | | | | | | | | | | | | | | | |
| **Barakat, 2011, Spain** | U | 67 | 34 | 33 | 6-9 | 31 ± 3 | 23.9 ± 3 | NR | NR | NR | 30 ± 3 | 24.8 ± 4 | NR | NR | NR | No sig differences |
| **Barakat, 2012, Spain** | U | 290 | 152 | 138 | 6-9 | 31.4 ± 3.2 | 24 ± 4.3 | NR | NR | NR | 31.7 ± 4.5 | 23.6 ± 4 | NR | NR | NR | No sig differences |
| **Barakat, 2014, Spain** | U | 200 | 107 | 93 | 9-13 | 31.57 ± 3.87 | 23.78 ± 4.4 | NR | NR | NR | 31.51 ± 3.92 | 24.09 ± 4.32 | NR | NR | NR | No sig differences |
| **Boparai, 2021, Canada** | U | 27 | 16 | 11 | 16-20 | 32.6 ± 0.9 | 28.9 ± 6.6 | 115 ± 12 | 66 ± 9 | 85 ± 9 | 31 ± 0.7 | 25.5 ± 3 | 107 ± 11 | 64 ± 9 | 81 ± 8 | Int: ↓ SBP Con: ↑ SBP |
| **Brislane, 2021, UK** | U | 18 | 7 | 11 | < 12 | 33 ± 4 | 23 ± 3 | 99 ± 6 | 60 ± 8 | Calc. 73 ± 8.54 | 33 ± 3 | 24 ± 3 | 103 ± 12 | 60 ± 6 | Calc. 74.33 ± 8.49 | No sig changes |
| **Carpenter, 2015, UK** | U | 50 | 34 | 16 | 20 | 26.4 ± 1.3 | NR | 105.8 ± 1.9 | 72.3 ± 2.8 | Calc. 80.6 ± 7.34 | 24.6 ± 0.7 | NR | 109 ± 1.7 | 70.6 ± 1.2 | Calc. 83.4 ± 7.75 | Int: ↑ SBP, DBP |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carpenter, 2017, UK** | U | 51 | 16 | 35 | 20 | 19-24 n = 3 25-29 n = 4 30-34 n = 6 35-39 n = 2 40+ n = 1 | 18.5-24.9 n = 8; 25-29.9 n = 2; >30 n = 6 | 105.8 ± 1.9 | NR | NR | 19-24 n = 2 25-29 n = 12 30-34 n = 12 35-39 n = 5 | 18.5-24.9 n = 23; 25-29.9 n = 6; >30 n = 6 | 109 ± 1.7 | NR | NR | No sig differences |
| **Daniel, 2015, Nigeria** | At risk (GDM) | 30 | 15 | 15 | 24-28 | 32 ± 3.43 | 82.77 ± 14.62 kg | 108.67 ± 8.84 | 77.4 ± 11.54 | Calc. 87.82 ±10.72 | 32.93 ± 4.61 | 85.23 ± 8.14 kg | 110.67 ± 7.68 | 76.48 ±10.63 | Calc. 87.88 ± 9.75 | Int: ↓ SBP, DBP |
| **de Oliveria, 2012, Brazil** | U | 187 | 125 | 62 | 13-20 | 24 ± 4 | 25 ± 5.5 | NR | NR | NR | 23.5 ± 3.5 | 24 ± 5.4 | NR | NR | NR | No sig differences |
| **Erkkola, 1976, Finland** | U | 62 | 30 | 32 | 10-14 | 23.6 ± 1.7 | 57.5 ± 6.4 | 126.8 ± 14.1 | 76.2 ± 9.1 | Calc. 93.07 ± 11.02 | 23.2 ± 1.7 | 58.4 ± 6 | 124.4 ± 12.4 | 74.4 ± 7.7 | Calc. 91.07 ± 9.53 | No sig differences |
| **Fernández-Buhigas, 2020, Spain** | U | 92 | 41 | 51 | < 16 | 33.17 ± 3.19 | 22.81 ± 3.54 | 120.54 ± 10.56 | 72.65 ± 8.7 | Calc. 88.61 ± 9.34 | 32.63 ± 4.66 | 23.8 ± 5.09 | 119.51 ± 11.26 | 73.05 ± 7.2 | Calc. 88.54 ± 8.76 | No sig differences |
| **Garnæs, 2016, Norway** | At risk (Obese BMI >28kg/m$^2$) | 74 | 38 | 36 | 12-18 | 31.3 ± 3.8 | 33.9 ± 3.8 | 126.3 ± 20.9 | 75.0 ± 10.0 | Calc. 92.1 ± 9.6 | 31.4 ± 4.7 | 35.1 ± 4.6 | 127.9 ± 12.9 | 78.0 ± 8.4 | Calc. 94.63 ± 9.73 | Con: ↑ SBP |
| **Guelfi, 2016, Australia** | At risk (History of GDM) | 157 | 81 | 76 | < 14 | 33.6 ± 4.1 | 26.3 ± 5.1 | 106 ± 11 | 63 ± 8 | Calc. 77.33 ± 8.79 | 33.8 ± 3.9 | 25.7 ± 5.4 | 106 ± 13 | 64 ± 9 | Calc. 78 ± 10.5 | No sig differences |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Haakstad, 2016, Norway** | U | 61 | 35 | 26 | 12-24 | 31.5 ± 3.1 | 22.9 ± 3.2 | 115 ± 12 | 66 ± 7 | Calc. 82.33 ± 8.98 | 29.4 ± 3.8 | 23.0 ± 3.1 | 115 ± 10 | 67 ± 9 | Calc. 83 ± 9.35 | Con: ↑ SBP, DBP |
| **Halse, 2015, Australia** | At risk (GDM) | 40 | 20 | 20 | 26-30 | 34 ± 5 | 25.2 ± 6.7 | 107 ± 17 | 66 ± 11 | Calc. 79.67 ± 8.93 | 32 ± 3 | 26.4 ± 7.1 | 110 ± 7 | 70 ± 9 | Calc. 83.33 ± 8.39 | No sig differences |
| **Huifen, 2022, China** | At risk (GDM) | 89 | 43 | 46 | 28.02 ± 2.01 | 31.84 ± 5.19 | 23.03 ± 5.22 | 121.37 ± 15.83 | 75.63 ± 8.96 | Calc. 90.90 ± 11.71 | 31.35 ± 4.72 | 21.98 ± 2.96 | 119.8 ± 17.47 | 75.65 ± 10.86 | Calc. 90.37 ± 13.4 | Int: ↓ SBP, DBP |
| **Kasawara, 2013, Brazil** | At risk (chronic HTN/previous PE) | 109 | 56 | 53 | 12-20 | <19 n = 1; 20-29 n = 21; 30-39 n = 27; ≥ 40 n = 9 | 18.5-24.9 n = 4 25-29.9 n = 13 30-39.9 n = 26 ≥40 n = 15 | 116 ± 16.9 | 74.6 ± 15 | Calc. 88.4 ± 14.42 | <19 n = 1; 20-29 n = 20; 30-39 n = 31; ≥ 40 n = 6 | 18.5–24.9 n = 6; 25–29.9 n = 11; 30–39.9 n = 31; ≥ 40 n = 10 | 120.6 ± 13.9 | 77.1 ± 13.2 | Calc. 91.6 ± 13.44 | No sig changes |
| **Khoram, 2019, Iran** | At risk (chronic HTN, previous PE, Hx of GHT, FHx of HTN | 72 | 36 | 36 | 14 | 31.91 ± 4.62 | 27.36 ± 3.64 | NR | NR | NR | 31 ± 5.29 | 34.97 ± 4.77 | NR | NR | NR | Int: ↓ SBP. DBP |
| **Nascimento, 2011, Brazil** | At risk (Overweight/ Obese BMI >26kg/m$^2$) | 80 | 39 | 41 | 14-24 | 29.7 ± 6.8 | 34.8 ± 6.6 | NR | NR | NR | 30.9 ± 5.9 | 36.4 ± 6.9 | NR | NR | NR | No sig changes |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Perales, 2016, Spain** | U | 241 | 121 | 120 | 9-11 | 31 ± 4 | 23.8 ± 4.2 | 115.5 ± 13.0 | 65.0 ± 10.3 | Calc. 81.83 ± 11.27 | 31 ± 4 | 25.1 ± 4.7 | 115.6 ± 12.4 | 66.9 ± 11.4 | Calc. 83.1 ± 11.96 | No sig changes |
| **Petrov Fieri, 2015, Sweden** | U | 72 | 38 | 34 | 13 | 30.8 ± 3.6 | 22.6 ± 2.5 | 109 ± 18.8 | 66.2 ± 8.3 | Calc. 80.47 ± 12.8 | 30.6 ± 3.4 | 23.0 ± 2.6) | 111 ± 10.5 | 63.7 ± 7.7 | Calc. 79.47 ± 8.73 | No sig changes |
| **Ramirez-Velez, 2011, Columbia** | U | 50 | 24 | 36 | 16-20 | 19.5 ± 2.3 | NR | 110.2 ± 10.6 | 66.3 ± 10.4 | 81.0 ± 9.6 | 19.5 ± 2.3 | NR | 109.8 ± 11.4 | 64.5 ± 6.8 | 79.6 ± 7.9 | No sig changes |
| **Rodríguez-Díaz, 2017, Spain** | U | 105 | 50 | 55 | 26-28 | 32.87 ± 4.46 | 28.79 ± 4.27 | 108.72 ± 10.37 | 65.63 ± 7.33 | Calc. 79.99 ± 8.47 | 31.52 ± 4.95 | 26.78 ± 5.04 | 107.18 ± 10.08 | 65.16 ± 6.34 | Calc. 79.17 ± 7.79 | Int: ↓ SBP, DBP |
| **Seneviratne, 2015, New Zealand** | At risk (Overweight/ Obese BMI >25kg/m$^2$) | 75 | 38 | 37 | 20 | 31.6 ± 4.6 | 32.1 ± 4.4 | 113.2 ± 12.2 | 67.8 ± 8.3 | Calc. 82.93 ± 9.11 | 31.1 ± 5.2 | 34.1 ± 5.9 | 118.5 ± 9.8 | 70.0 ± 8.7 | Calc. 86.17 ± 9.28 | No sig changes |
| **Stutzman, 2010, Canada** | U & at risk (Overweight/ Obese BMI >25kg/m$^2$) | 22 | 11 | 11 | 18-22 | 30.4 ± 4.2 | 22.2 ± 1.7 | 111 ± 12 | 76 ± 11 | Calc. 87.67 ± 11.34 | 20.9 ± 2.3 | 25.8 ± 3 | 109 ± 7 | 74 ± 4 | Calc. 85.67 ± 5.2 | No sig changes |
| | | | | | | 30.6 ± 5.5 | 28.8 ± 6.9 | 114 ± 14 | 75 ± 10 | Calc. 88 ± 11.49 | 30.6 ± 4 | 26.2 ± 5.6 | 107 ± 8 | 72 ± 4 | Calc. 83.67 ± 5.66 | Con: ↑ SBP, DBP |
| **Vladimirov, Poland, 2015** | At risk (Anaemia) | 88 | 50 | 38 | 20-27 | 25 ± 4.3 | NR | 135.91 ± 3.9 | 83.09 ± 3.49 | Calc. 100.7 ± 10.03 | 25 ± 4.3 | NR | 136.32 ± 2.8 | 82.8 ± 4.93 | Calc. 100.64 ± 4.34 | Int: ↓ SBP, DBP |
| **Yeo, 2000, USA** | At risk (mild hypertension, | 16 | 8 | 8 | 18 | 30 ± 5.4 | NR | 109 | 69 | Calc. 82.3 | 30 ± 5.4 | NR | 109 | 69 | Calc. 82.3 | No sig changes |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hx of GHT, FHx of HTN) | | | | | | | | | | | | | | |
| **Clinical Trials** | | | | | | | | | | | | | | | |
| **Yeo, 2008, USA** | At risk (previous PE) | 79 | 41 | 38 | 18 | NR | NR | 106 | 62 | Calc. 76.67 ± 8.61 | NR | NR | 106 | 62 | Calc. 76.67 ± 8.26 | Con: ↑ SBP |
| **Ferriera, 2014, Brazil** | U | 27 | 27 | 0 | 18 | 23.3 | 23.4 | 108.0 ± 13.5 | 66.8 ± 10.1 | NR | N/A | N/A | N/A | N/A | N/A | No sig changes |
| **O'Connor, 2011, USA** | U | 32 | 32 | 0 | 21-25 | 29 ± 4 | 76 ± 2 kg | 166 ± 6 | 113.5 ± 8.4 | 71.9 ± 6.8 | N/A | N/A | N/A | N/A | N/A | No sig changes |
| **Silva-Jose, 2021, Spain** | U | 72 | 31 | 41 | 8-10 | 32.29 ± 6.36 | 22.61 ± 3.22 | 110.55 ± 12.13 | 71 ± 7.41 | NR | 33.93 ± 4.49 | 23.06 ±7.8 | 110.76 ± 13.3 | 72.95 ± 8.07 | NR | No sig differences |
| **Quasi-experimental Controlled Trial** | | | | | | | | | | | | | | | |
| **Bahadoran, 2015 Iran** | U | 88 | 29 | 59 | 18-22 | 26.1 ± 3.27 | 23.9 ± 3.37 | 107.9 ± 10.39 | 69.3 ± 8.31 | Calc. 81.5 ± 8.15 | 27.0 ± 3.57 | 22.9 ± 2.97 | 106.9 ± 12.30 | 67.0 ± 6.77 | Calc. 80.3 ± 9 | No sig changes |

RCT = randomised control trial; GA = gestational age; PA = physical activity; NR = not reported; GDM = gestational diabetes mellitus; HTN = hypertension; BMI = body mass index; PE = preeclampsia; Hx = history; FHx = family history; GHTN = gestational hypertension; Con = control group; Int = intervention group; Ex = exercising; Calc = calculated

Table 19. Characteristics of participants in the acute studies

| Author, Year, Country | Population Uncomplicated (U) or at risk (clinical conditions) | Subjects (n) | | | Recruitment *GA weeks* | Age, BMI, SBP, DBP | | | | Control Age, BMI, SBP, DBP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Int | Con | | Age *years* | BMI *kg/m² or Weight (kg)* | SBP *mmHg* | DBP *mmHg* | Age *years* | BMI *kg/m² or Weight (kg)* | SBP *mmHg* | DBP *mmHg* |
| **RCTs** | | | | | | | | | | | | | |
| **Babbar, 2016, USA** | U | 46 | 23 | 23 | 28-36 | 25.5 ± 4.4 | 26.5 ± 6.1 | 108 ± 12 | 70.7 ± 6.9 | 25.4 ± 4.6 | 25.1 ± 6.7 | 106.4 ± 6.3 | 69.3 ± 4.7 |
| **Brun, 2011, Canada** | At risk (GDM) | 11 | 6 | 5 | 31 ± 3.5 | 30 ± 3.8 | NR | 116 ± 4 | 74 ± 4 | 30 ± 3.8 | NR | 115 ± 3 | 71 ± 2.5 |
| **Kim, 2018, Korea** | At risk | 45 | 23 | 22 | >24 | 32.22 ± 2.58 | NR | 107.39 ± 11.37 | 67.83 ± 9.02 | 31.50 ± 4.48 | NR | 107.73 ± 10.20 | 66.36 ± 10.93 |
| **Pijpers, 1984, Netherlands** | U | 23 | 11 | 12 | 34-38 | 26.1 | 66.1 kg | 114.0 ± 6.8 | 65.7 ± 4.0 | 26.1 | 66.1 kg | 119.2 ± 8.9 | 72.4 ± 6.9 |
| **Sklempe Kokic, 2018, Croatia** | At risk (GDM) | 18 | 9 | 9 | 25.6 ± 5.2 | 32.8 ± 3.8 | 24.4 ± 4.9 | 112.1 ± 7.1 | 71.2 ± 6 | NA | NA | NA | NA |
| **Webb, 1994, Canada** | U | 38 | 22 | 16 | 14-18 | 30.2 ± 0.9 | 68.7 ± 2.5 kg | 145 ± 3 | 74 ± 1 | 29.1 ± 0.9 | 63.3 ± 1.2 kg | 143 ± 2 | 75 ± 1 |
| **Clinical Trials** | | | | | | | | | | | | | |
| **Amorim 2018, Brazil** | U | 120 | 120 | N/A | 34-38 | Bike | | | | NA | NA | NA | NA |
| | | | | | | 25 ± 6.4 | 32.2 ± 10.6 | 110 | 70 | | | | |
| | | | | | | Treadmill | | | | | | | |
| | | | | | | 25.2 ± 6.4 | 33.5 ± 8.7 | 112 | 70 | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Avery, 1999, Canada** | U | 24 | 12 | NPC 12 | 30-32 | 29 ± 1 | 70 ± 3 kg | NR | NR | 29 ± 2 | 62 ± 2 kg | | |
| **Bgeginski, 2015, Brazil** | U | 20 | 10 | NPC 10 | 22-24 | 25.3 ± 4.44 | 23.53 ± 2.48 | NR | NR | 25.2 ± 3.73 | 23.57 ± 2.59 | NR | NR |
| **Jeffreys, 2006, USA** | U | 14 | 14 | NA | 31 ± 2 | 34 ± 3 | 24.5 ± 2.8 | 110 ± 12 | 67 ± 10 | NA | NA | NA | NA |
| **Meah, 2021, Canada** | U | 30 | 15 | NPC 15 | 22.9 ± 5.9 | 33 ± 3 | 75 ± 27 | 109 ± 15 | 71 ± 10 | NPC 32 ± 8 | NPC 64 ± 8 | NPC 106 ± 9 | NPC 71 ± 7 |
| **Meah, 2021, Canada** | U | 45 | 14 | NPC 18 PPC 13 | 22-26 | 32±3 | 26 ± 4 | 109 ± 8 | 63 ± 5 | NPC 28 + 4 PPC 33 ± 2 | NPC 23 ± 4 PPC 23 ± 4 | NPC 113 ± 7 PPC 105 ± 6 | NPC 68 ± 6 PPC 61 ± 4 |
| **Morrow, 1989, Canada** | U | 15 | 15 | N/A | 36-41 | NR | NR | NR | NR | NA | NA | NA | NA |
| **O'Neill, 2006, Aus** | U | 50 | 50 | N/A | 34-40 | Semi recumbent | | | | NA | NA | NA | NA |
| | | | | | | 30 ± 5 | 71 ± 9 | 110 ± 9 | 68 ± 8 | | | | |
| | | | | | | Upright | | | | | | | |
| | | | | | | 30 ± 4 | 69 ± 5 | 107 ± 8 | 70 ± 6 | | | | |
| **O'Neill, 1993, Aus** | U | 39 | 39 | N/A | 23-28 | Trained | | | | NA | NA | NA | NA |
| | | | | | | 30.1 ± 2.9 | 68.1 ± 6 | 105.6 ± 7 | 66 ± 6.6 | | | | |
| | | | | | | Sedentary | | | | | | | |
| | | | | | | 29.8 ± 3.4 | 65.2 ± 6.3 kg | 101.9 ± 8.4 | 64.8 ± 4.5 | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Purdy, 2019, Canada** | U | 37 | 17 | 20 | T1, T2, T3 | T1 | | | | 28 ± 6 | 28.8 ± 3.4 | 112 ± 8 | 74 ± 7 |
| | | | | | | 31 ± 4 | 23.4 ± 2.2 | 113 ± 10 | 69 ± 7 | | | | |
| | | | | | | T2 | | | | | | | |
| | | | | | | 31 ± 4 | 23.0 ± 2.8 | 107 ± 9 | 66 ± 7 | | | | |
| | | | | | | T3 | | | | | | | |
| | | | | | | 32 ± 4 | 23.1 ± 2.6 | 108 ± 5 | 68 ± 7 | | | | |
| **van Doorn, 1992, USA** | U | 33 | 33 | N/A | 16 | 30.9 ± 0.7 | 86 ± 1.7 kg | 110 ± 1.8 | 73 ± 1.2 | NA | NA | NA | NA |
| **Crossover Trials** | | | | | | | | | | | | | |
| **Petrov Fieril, 2016, Sweden** | U | 20 | 20 | N/A | 21 | Aerobic | | | | NA | NA | NA | NA |
| | | | | | | 32.9 ± 4.3 | 20.0 ± 1.8 | 104 ± 13 | 67 ± 6 | | | | |
| | | | | | | Resistance | | | | | | | |
| | | | | | | 32.9 ± 4.3 | 20.0 ± 1.8 | 105 ± 8 | 66 ± 4 | | | | |
| **de Oliveria, 2014, Brazil** | U | 8 | 8 | 8 | 12-20 | NR | NR | 102 ± 6 | 59.8 ± 6 | NR | NR | 102 ± 10 | 57 ± 10 |
| **Cohort** | | | | | | | | | | | | | |
| **Bisson, 2014, Canada** | U | 61 | 61 | N/A | 12-15 | 30 ± 4.5 | 23.4 ± 4.2 | 102.9 ± 9.4 | 65.1 ± 8.4 | NA | NA | NA | NA |
| **Pivarnik, 1993, USA** | U | 16 | 10 | 6 | 24-26 | 29 ± 5 | 65.1 ± 8.9 | SBP & DBP = NR MAP = 84 ± 7 | | 29 ± 4 | 65.4 ± 4.4 | NR | MAP = 85 ± 7 |
| **Rafla, 1999, UK** | U | 143 | 143 | N/A | 36-40 | 25.5 | 66 kg | 112 | 67 | NA | NA | NA | NA |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rafla, 2000, UK** | At risk (PIH) | 17 | 17 | N/A | 26-40 | A26 | NR | 149 | 102 | NA | NA | NA | NA |
| **Rauramo, 1988, Finland** | At risk (PE (n=13), DM (n=10), Cholestasis (n=8)) | 50 | 31 | 19 | 32-40 | PE | | | | 26 ± 3 | 70 ± 12 | 112 ± 8 | 78 ± 7 |
| | | | | | | 27 ± 4 | 71 ± 8 | 140 ± 6 | 98 ± 5 | | | | |
| | | | | | | DM | | | | | | | |
| | | | | | | 27 ± 5 | 72 ± 9 | 118 ± 10 | 77 ± 8 | | | | |
| | | | | | | Chol | | | | | | | |
| | | | | | | 28 ± 4 | 74 ± 13 | 116 ± 9 | 76 ± 7 | | | | |
| **Rauramo, 1988, Finland** | U | 25 | 25 | NA | 32-38 | 26 ± 3 | 60 ± 12 | 112 ± 8 | NR | NA | NA | NA | NA |
| **Sady, 1990, USA** | U | 45 | 45 | NA | 20-34 | 22 -37 | 69.9 ± 11.19 | NR | NR | NA | NA | NA | NA |
| **Santos, 2016, Brazil** | U | 28 | 28 | NA | 30.51±3.3 | 26 ± 6.9 | 23.7 ± 3.2 | SBP & DB = NR MAP = 81.4 ± 9.6 | | NA | NA | NA | NA |

PIH = pregnancy induced hypertension; PE = preeclampsia; DM = diabetes mellitus; GDM = gestational diabetes mellitus; NR = not reported; T1/2/3 = trimester 1/2/3; Con = control; Int = intervention; GA = gestational age; chol = cholestasis; SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; U = uncomplicated; NPC = non-pregnant control; PPC = post-partum control

Table 20. Design of the intervention studies

| Author | Mode | Frequency (times/week) | Duration (min) | Intensity | Length (weeks) | Supervision | Control |
|---|---|---|---|---|---|---|---|
| **Bahadoran et al. 2015** | Walking | 3-5 | 30-45 | LMPA | 20 | Unsupervised | Routine care |
| **Barakat et al. 2011** | Walking, core, stretches & aerobic dance | 3 | 35-45 | LMPA | 29-33 | Supervised | Not specified |
| **Barakat et al. 2012** | Walking, core, stretches & aerobic dance | 3 | 40-45 | LMPA | 29-33 | Supervised | Not specified |
| **Barakat et al. 2014** | Aerobic dance & resistance ex. | 3 | 55-60 | LMPA | 27-31 | Supervised | No exercise |
| **Boparai et al. 2021** | Treadmill/cycle ergometer/elliptical | 3-4 | 25-40 | MPA | 15-19 | Partially supervised | Routine care |
| **Brislane et al. 2021** | Cycle ergometer | 3-4 | 15-30 | MPA | 26 | Partially supervised | Routine care |
| **Carpenter et al. 2015** | Recumbent cycle ergometer | 1 | 30-45 | LMPA | 20 | Supervised | Continued usual PA habits |
| **Carpenter et al. 2017** | Aerobic & resistance ex. + pelvic floor | 1 | 20 | MPA | 20 | Supervised | Continued usual PA habits |
| **Daniel et al. 2015** | Low impact aerobic dance | 2-3 | 45-60 | MPA | 8 | Supervised | Continued usual PA habits |
| **de Oliveria et al. 2012** | Walking | 3 | 15+ | MPA | 18-25 | Supervised | Routine care |
| **Erkkola et al. 1976** | All types | 3 | 60 | MVPA | 24-28 | Unsupervised | Routine care |
| **Fernández-Buhigas et al. 2020** | Aerobic & resistance ex. + pelvic floor & balance | 3 | 60 | LMPA | 23-27 | Supervised | Continued usual PA habits |
| **Ferriera et al. 2014** | PFMT | 1 | 35 | LMPA | 18 | Supervised | No control |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Garnaes et al. 2016** | Treadmill walking & resistance ex. | 3 | 60 | VPA | 16-25 | Supervised | Continued usual PA habits |
| **Guelfi et al. 2016** | Cycle ergometer | 3 | 20-60 | MVPA | 14 | Supervised | Routine care |
| **Haakstad et al. 2016** | Aerobic dance & resistance ex. | 1 | 60 | MPA | 12 | Supervised | Continued usual PA habits |
| **Halse et al. 2015** | Cycle ergometer | 3-5 | 25-45 | MVPA | 5-7 | Supervised | Routine care |
| **Huifen et al. 2022** | Resistance ex. | 3 | 50-60 | MPA | > 6 | Supervised | Routine care |
| **Kasawara et al. 2013** | Cycle ergometer | 1 | 30 | LPA | 20-28 | Supervised | Routine care |
| **Khoram et al. 2019** | Walking | 4 | 20-30 | MPA | 20 | Unsupervised | Routine care |
| **Nascimento et al. 2011** | Resistance ex. | 1-5 | 40 | LMPA | 16-26 | Supervised + unsupervised | Routine care |
| **O'Connor et al. 2011** | Resistance ex. | 2 | 45 | LMPA | 12 | Supervised | No control |
| **Perales et al. 2016** | Aerobic & resistance ex. | 3 | 55-60 | LMPA | 30 | Supervised | Routine care |
| **Petrov Fieril et al. 2015** | Resistance ex. | 2 | 60 | MVPA | 12 | Supervised | Education on exercises in pregnancy |
| **Ramirez-Velez et al. 2011** | Aerobic & power ex. | 3 | 60 | MVPA | 16 | Supervised | Routine care |
| **Rodríguez-Díaz et al. 2017** | Pilates | 2 | 40-45 | Not specified | 8 | Supervised | Routine care |
| **Seneviratne et al. 2015** | Cycle ergometer | 3-5 | 15-30 | MPA | 16 | Unsupervised | No exercise |
| **Silva-Jose et al. 2021** | Aerobic & resistance ex. + pelvic floor & balance | 3 | 55-60 | MPA | 30 | Virtually supervised | Routine care |
| **Stutzman et al. 2010** | Walking | 3-5 | 0.6 km/day working up to 3km/day | LPA | 16 | Unsupervised | Continued usual PA habits |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vladimirov et al. 2015** | Aerobic – Medical Pole Walking | 7 | 25-30 | MPA | 3 | Supervised | Walking/gymnastics stretching + routine care |
| **Yeo et al. 2000** | Treadmill & cycle ergometer | 3 | 45 | MPA | 10 | Supervised | Continued usual PA habits |
| **Yeo et al. 2008** | Walking | 5 | 40 | MPA | 18-22 | Unsupervised | Stretching exercises |

PA = physical activity; LPA = light physical activity; LMPA = light to moderate physical activity; MPA = moderate physical activity; MVPA = moderate to vigorous physical activity; VPA = vigorous physical activity; ex. = exercise/s; PFMT = pelvic floor muscle training; km = Kilometres

Table 21. Design of the acute studies

| Author | Mode | Duration (min) | Intensity | Control |
|---|---|---|---|---|
| **Amorim et al. 2018** | Treadmill or cycle ergometer | 20 | MPA | No control |
| **Avery et al. 1999** | Resistance exercise | 60 | LMPA | Non-pregnant control |
| **Babbar et al. 2016** | Supervised Yoga | 60 | LPA | Non exercising - PPT presentation |
| **Bgeginski et al. 2015** | Resistance exercise | 40 | 50% 1RM | Non-pregnant control |
| **Bisson et al. 2014** | Treadmill | > 10 | To volitional fatigue | No control |
| **Brun et al. 2011** | Resistance exercises in bed | 30 | LPA | No exercise, listening to music |
| **de Oliveria et al. 2014** | Cycle ergometer | 30 | LMPA | Non exercising |
| **Jeffreys et al. 2006** | Resistance ex. (supine) | 10 | MVPA | No control |
| **Kim et al. 2018** | Resistance ex. in bed | 30 | LPA | Non exercising |
| **Meah et al. 2021** | Cycle ergometer | To 70% HRR | MVPA | Non-pregnant control |
| **Meah et al. 2021** | Resistance ex. | Not specified | MPA | Non-pregnant control |
| **Morrow et al. 1989** | Cycler ergometer | 5 | LMPA | No control |
| **O'Neill et al. 2006** | Cycle ergometer upright vs semi-rec | 12 | MPA | No control |
| **O'Neill et al. 1993** | Treadmill | 26 | LMPA | No control |
| **Petrov Fieril et al. 2016** | Nordic walking or resistance exercise | 30 | LMPA | No control |
| **Pijpers et al. 1984** | Semi-rec cycle ergometer | 20 | LMPA | Non exercising |
| **Pivarnik et al. 1993** | Cycle ergometer | 15 | MVPA | Physically active vs sedentary |
| **Purdy et al. 2019** | Peak cycle ergometer Test | To volitional fatigue | To volitional fatigue | Non-pregnant control |
| **Rafla et al. 1999** | Cycle ergometer | 5 | LMPA | No control |
| **Rafla et al. 2000** | Cycle ergometer | 5 | LMPA | No control |
| **Rauramo et al. 1988** | Cycle ergometer | 5 | MPA | Healthy pregnant women |
| **Rauramo et al. 1988** | Cycle ergometer | 6 | VPA | No control |
| **Sady et al. 1990** | Cycle ergometer | To volitional fatigue | To volitional fatigue | No control |
| **Santos et al. 2016** | Ramp treadmill test | 11.41 ± 4.23 | To volitional fatigue | No control |
| **Sklempe Kokic et al. 2018** | Treadmill | 20 | MVPA | No control |
| **van Doorn et al. 1992** | Max cycle ergometer Test | To volitional fatigue | To volitional fatigue | No control |

| | | | | |
|---|---|---|---|---|
| **Webb et al. 1994** | Submaximal cycle ergometer test | 15 | MVPA | Non exercising |

PA = physical activity; LPA = light physical activity; LMPA = light to moderate physical activity; MPA = moderate physical activity; MVPA = moderate to vigorous physical activity; VPA = vigorous physical activity; ex. = exercise/s; PFMT = pelvic floor muscle training; RM = repetition maximum; Semi-rec = semi-recumbent; HRR = heart rate reserve

### 3.3.4 Meta-analysis

#### *3.3.4.1 Pooled results - uncomplicated pregnancies*

Data were pooled from thirteen studies to assess the effect of a long-term exercise intervention on SBP, and from twelve studies to assess DBP and MAP in uncomplicated pregnancies. There was no significant effect of exercise compared to control on the change in SBP (mean difference [95% CL] -1.54 mmHg [-5, 1.93], p = 0.38, $Tau^2$ = 37.34, $Chi^2$ = 1792.51, df = 12, $I^2$ = 99%), DBP (mean difference [95% CL] -2.25 mmHg [-4.96,0.45], p = 0.1, $Tau^2$ = 20.78, $Chi^2$ = 774.07, df = 11, $I^2$ = 99%) or MAP (mean difference [95% CL] -1.75 mmHg [-5.13-1.63], p = 0.31, $Tau^2$ = 31.75, $Chi^2$ = 1000.16, df = 11, $I^2$ = 99%) when aerobic, resistance and combination exercise studies were pooled.

#### *3.3.4.2 Pooled results – at risk population*

Within the ten at risk studies the pooled data showed a significant effect of exercise on SBP (mean difference [95% CL] -3.91 mmHg, [-6.74, -1.08], p < 0.01, $Tau^2$ = 16.52, $Chi^2$ = 160.29, df = 9, $I^2$ = 94%), DBP (mean difference [95% CL] -2.9 mmHg [-5.11, -0.68], p = 0.01, $Tau^2$ = 10.47, $Chi^2$ = 244.97, df = 9, $I^2$ = 96%) and MAP (mean difference [95% CL] -2.38 mmHg [-4.27, -0.48], p = 0.01, $Tau^2$ = 6.61, $Chi^2$ = 255.06, df = 8, $I^2$ = 97%) compared to the control group.

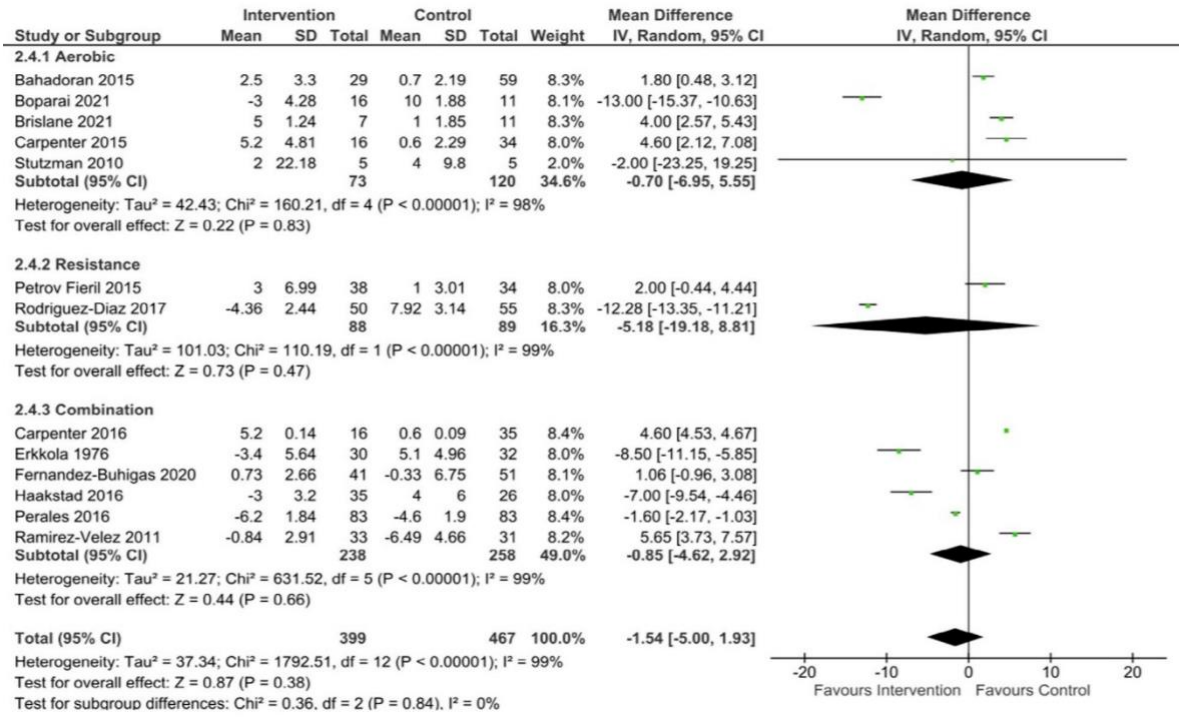



Figure 13. SBP changes following exercise in uncomplicated pregnancies

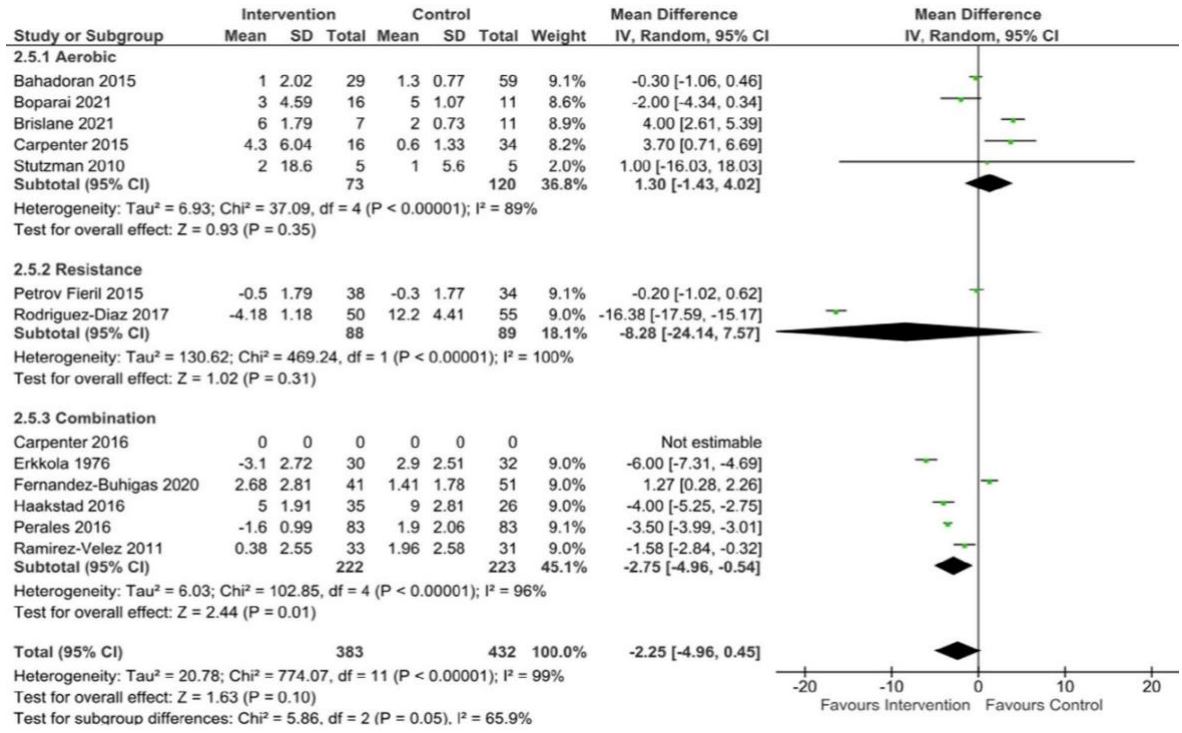



Figure 14. DBP changes following exercise in uncomplicated pregnancies

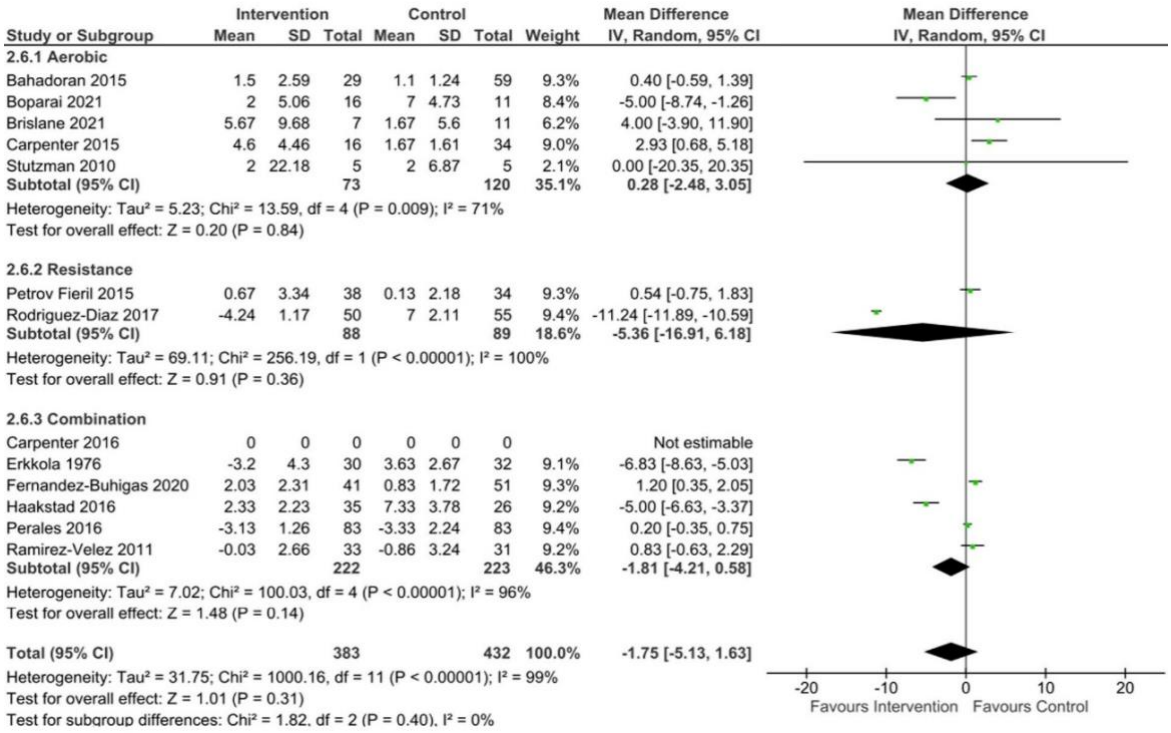



Figure 15. MAP changes following exercise in uncomplicated pregnancies

### *3.3.4.3 Aerobic Exercise Interventions*

#### *Uncomplicated Pregnancies*

Six studies included aerobic exercise interventions within uncomplicated pregnant populations (108, 162, 176, 187, 191, 193), with only one study not meeting the inclusion criteria for the meta-analysis (162). The meta-analysis showed no significant difference in SBP (mean difference [95% CL] = -0.70 mmHg [-6.95, 5.55], p = 0.83, $Tau^2 = 42.43$, $Chi^2 = 160.21$, df = 4, $I^2 = 98\%$) (*Figure 13*), DBP (mean difference [95% CL] = 1.30 mmHg [-1.43, 4.02], p = 0.35, $Tau^2 = 6.93$, $Chi^2 = 37.09$, df = 4, $I^2 = 89\%$ ) (*Figure 14*) and MAP (mean difference [95% CL] = 0.28 mmHg [-2.48, 3.05], p = 0.84, $Tau^2 = 5.23$, $Chi^2 = 13.59$, df = 4, $I^2 = 71\%$) (*Figure 15*) between healthy exercising and control groups following aerobic exercise interventions. The leave-one-out analysis showed a large drop in heterogeneity when one study (176) was excluded from the SBP data (mean difference [95% CL] = 3.26mmHg [1.62, 4.89], p = 0.08, $Tau^2 = 1.35$, $Chi^2 = 6.84$, df = 3, $I^2 = 56\%$) and the MAP data (mean difference [95% CL] = 1.45mmHg [-0.38, 3.29], p = 0.12, $Tau^2 = 1.21$, $Chi^2 = 4.68$, df = 3, $I^2 = 36\%$).

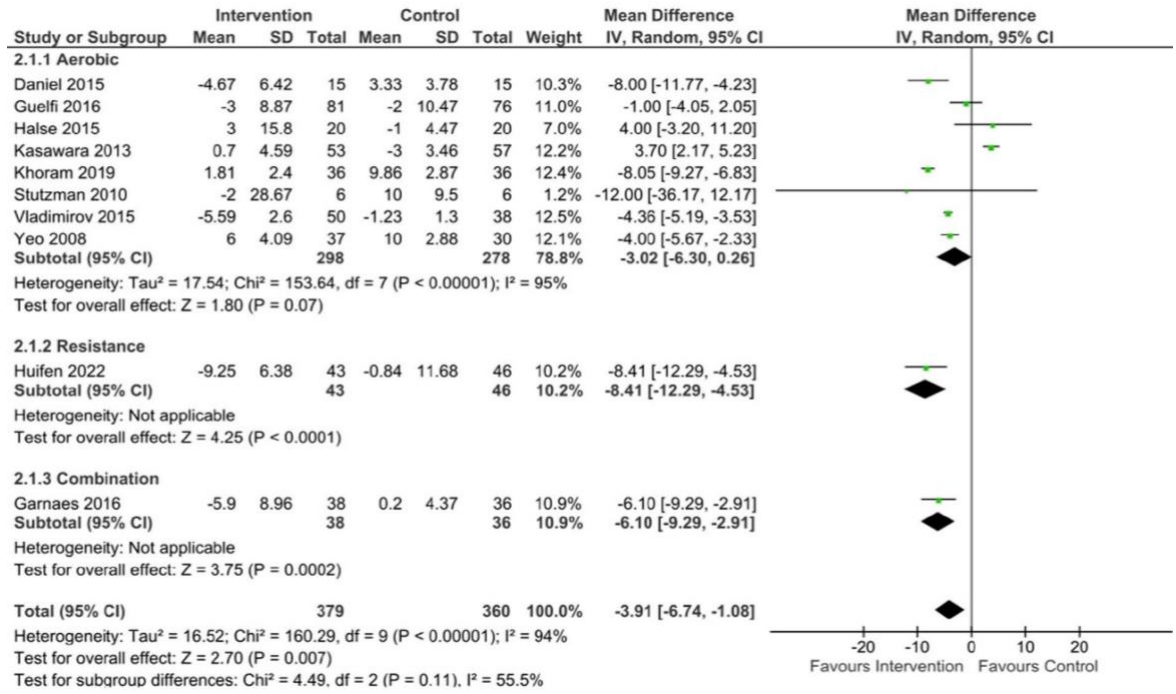



Figure 16. SBP changes following exercise in at risk populations

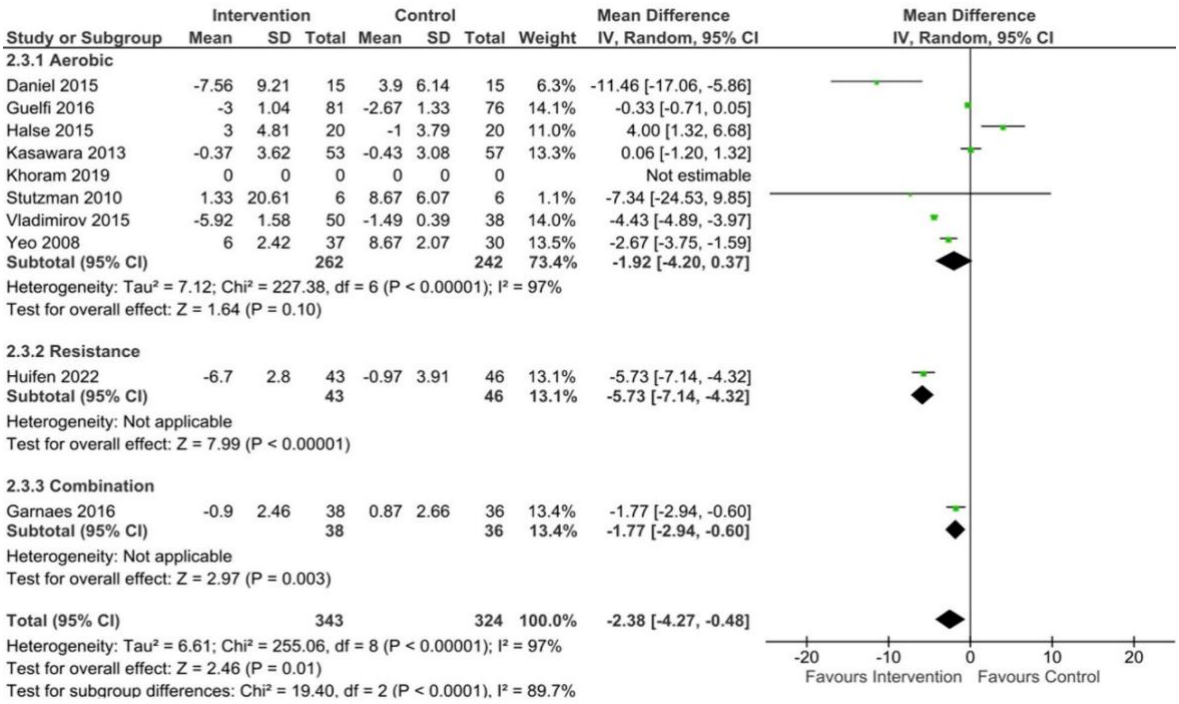



Figure 17. DBP changes following exercise in at risk populations

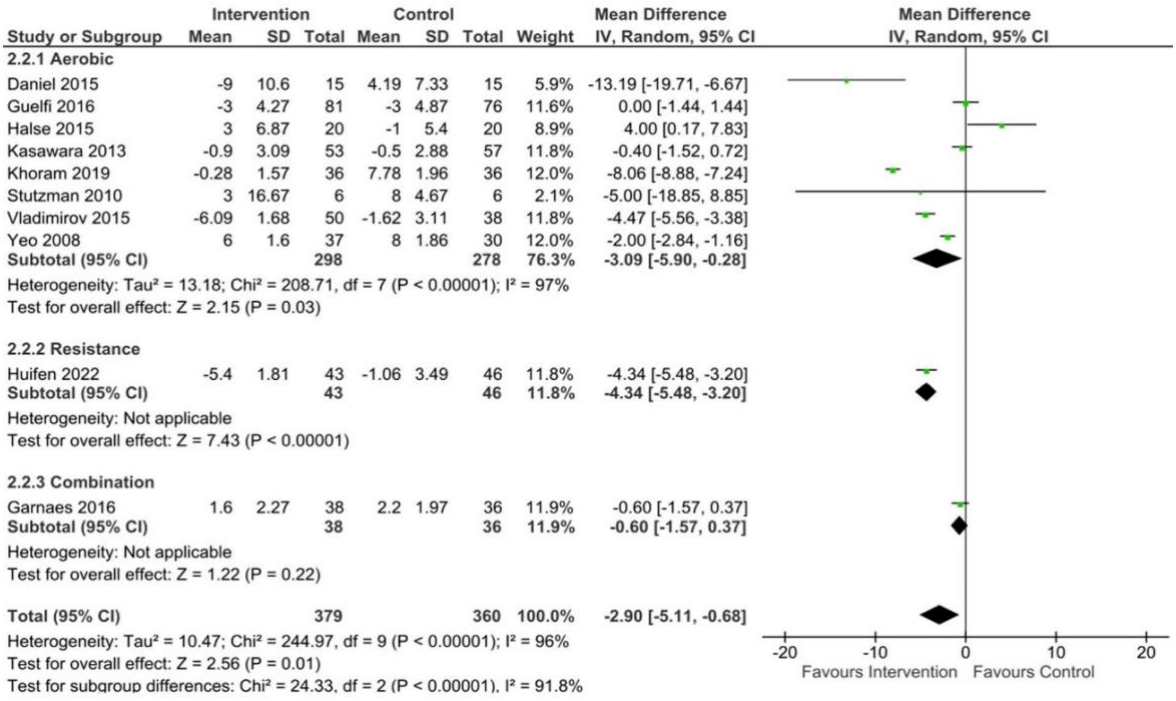



Figure 18. MAP changes following exercise in at risk populations

### *At Risk Populations*

Ten studies included at risk populations performing aerobic exercise interventions, seven of which were included in the statistical analysis (36, 96, 116, 177, 180, 187, 188). The clinical conditions included: overweight/obesity (BMI > 25 kg/m$^2$) (187, 215), GDM or history of GDM (116, 177, 180), anaemia (188) or high risk of GHTN/PE due to chronic or mild HTN, previous GHTN/PE or family history of HTN/PE (36, 96, 164, 167). Following aerobic exercise, a near significant difference was found for SBP (mean difference [95% CL]= -3.02 mmHg [-6.3, 0.26], p = 0.07, Tau2 = 17.54, Chi2 = 153.64, df = 7, I2 = 95%) (*Figure 16*) and MAP (mean difference [95% CL] = -1.92 mmHg [-4.2, 0.37], p = 0.1, Tau2 = 7.12, Chi2 = 227.38, df = 6, I2 = 97%) (*Figure 18*) between exercising and control groups. A statistically significant reduction in DBP (mean difference [95% CL] = -3.09 mmHg [-5.9, -0.28], p = 0.03, Tau2 = 13.18, Chi2 = 208.71, df = 7, I2 = 97%) (*Figure 17*) was found in the at risk population following aerobic exercise compared to control.

The three studies excluded from the analysis did not report baseline and post intervention SBP and DBP therefore the mean change in these measures could not be calculated to be used in the analysis (164, 167, 215). No significant differences in SBP or DBP were discussed by the studies. Long term changes in SBP and DBP were not reported by Khoram

et al. (2019), however acute responses to exercise were discussed. There was a significantly lower incidence of PE and GHTN in the exercising group compared to control ($p < 0.05$) (164). Results from Yeo et al. (2000) showed no significant difference in BP between groups, however both SBP and DBP reduced in the exercising group and increased in the control group with a near significant difference in DBP found with a reduction of 3.5 mmHg in the exercising group and an increase of 1.1 mmHg in the control group ($p = 0.05$) (167). Changes in BP from baseline were not reported by Seneviratne et al. (2015) however, there were no significant differences in mean SBP ($p = 0.25$) or DBP ($p = 0.68$) between exercising and control groups (215).

### 3.3.5 Resistance exercise interventions

***Uncomplicated pregnancies***

Four studies included in the review involved an intervention of supervised low to moderate intensity strength training (163, 166, 184, 185). Two of these did not include a comparator/control group leaving only two studies eligible for inclusion in the analysis (184, 185). No significant differences were seen between groups in the two studies included in the meta-analysis for SBP (mean difference [95% CL] = -5.18 mmHg [-19.18, 8.81], p = 0.47, Tau2 = 101.03, Chi2 = 110.19, df = 1, I2 = 99%) (*Figure 13*), DBP (mean difference [95% CL] = -8.28 mmHg [-24.14, 7.57], p = 0.31, Tau2 = 130.62, Chi2 = 469.24, df = 1, I2 = 100%) (*Figure 14)* or MAP (mean difference [95% CL] = -5.36 mmHg [-16.91, 6.18], p = 0.36, Tau2 = 69.11, Chi2 = 256.19, df = 1, I2 = 100%) (*Figure 15*). The results from the two studies not included in the meta-analysis showed no significant changes in SBP (113.5 ± 8.4 mmHg to 113.9 ± 10 mmHg (166); 108 ± 13.5 mmHg to 113.1 ± 9.12 (163)) or DBP (71.9 ± 6.8 mmHg to 73.3 ± 7.1 mmHg (166); 66.8 ± 10.1 mmHg to 70.6 ± 10.4 mmHg (163)) following the interventions.

***At risk populations***

Two studies included at risk populations performing resistance training (165, 181) however only one of these reported baseline and post intervention SBP and DBP (181), therefore no subgroup analysis could be run, as at least two studies are required (156). One study reported a significant decrease in SBP (Pre: 121.37 ± 15.83 mmHg, Post: 112.12 ± 13.87 mmHg; $p < 0.001$) and DBP (Pre: 75.63 ± 8.96 mmHg, Post: 70.23 ± 7.38 mmHg; $p < 0.001$) in the intervention group compared to control (SBP Pre: 119.8 ± 17.47 mmHg, Post: 118.96 ± 17.38; $p = 0.12$; DBP Pre: 75.65 ± 10.86 mmHg, Post: 74.59 ± 10.94 mmHg; $p = 0.15$) (181).

Arterial BP was reported as a secondary outcome measure in the other RCT with no significant differences found for either SBP or DBP following resistance training (165).

### 3.3.6 Combination interventions

***Uncomplicated pregnancies***

No significant differences were found in SBP (mean difference [95% CL] = -0.85 mmHg [-4.62, 2.92], p = 0.66, Tau2 = 21.27, Chi2 = 631.52, df = 5, I2 = 99%) (*Figure 13*) or MAP (mean difference [95% CL] = -1.81 mmHg [-4.21, 0.58], p = 0.14, Tau2 = 7.02, Chi2 = 100.03, df = 4, I2 = 96%) (*Figure 15)*. A small but statistically significant reduction in DBP was found following an intervention of combined aerobic and resistance exercise compared to control (mean difference [95% CL] = -2.75 mmHg [-4.96, -0.54], p = 0.01, Tau2 = 6.03, Chi2 = 102.85, df = 4, I2 = 96%) (*Figure 14*). Four studies were not included in the analysis as they did not report on the change in BP from baseline (159-161, 186). Three studies did not report baseline BP however found no significant differences between groups for SBP (p > 0.05 (160); p = 0.25 (159); p = 0.49 (161)) or DBP (p > 0.05 (160); p = 0.29 (159); p = 0.74 (161)) post intervention. One study found no differences in SBP or DBP across the three trimesters between intervention and control in a study of 72 women (186).

***At risk populations***

Only one study reported changes in BP following an intervention of combination exercise in an at risk population and found the mean SBP of the exercising group was significantly lower than the control group following intervention, with a mean reduction of 7.7 mmHg (95% CI −13.23, −2.22; p < 0.001) and no significant difference in DBP or MAP between groups (179).

### 3.3.7 Acute aerobic exercise

***Uncomplicated pregnancies***

Eighteen studies were identified that looked at the BP response both during and following an acute bout of aerobic exercise in uncomplicated pregnancies (174, 192, 194, 196-201, 205-213). All studies reported an acute increase in SBP and DBP during aerobic exercise. One study comparing stationary cycling and treadmill walking found similar increases in SBP irrespective of the mode (bike: +8 mmHg p = 0.06, treadmill: +8 mmHg p = 0.02) and DBP (bike: +5 mmHg p = 0.39, treadmill: +6 mmHg p = 0.18) (174). Petrov Fieril et al.

(2016) also reported an increase in SBP and DBP following 15 and 30 minutes of aerobic exercise ($p = 0.01$ and $p = 0.001$ respectively). These two studies, along with de Olivieria et al. (2014) found a post exercise hypotensive response, in which BP dropped below baseline levels from 50 minutes (208) to 14 hours post exercise (174). Two studies that observed BP responses to peak/max cycle tests found lower absolute BP responses in the first and second trimesters, increasing to non-pregnant levels or above in the third trimester (206, 210). One study found a positive correlation between resting SBP and DBP in the second trimester and BP response to submaximal aerobic exercise on the treadmill (211).

***At risk populations***

Four studies measured acute BP response to aerobic exercise in at risk populations. The participants in two of these studies took part in an intervention of exercise during pregnancy however the authors reported acute BP responses to exercise rather than changes from baseline to post intervention (164, 195). Mean SBP rose significantly after five minutes of exercise in one study from 149 mmHg (range 130 ± 170 mmHg) to 171 mmHg (range 150 ± 190 mmHg) in participants with pregnancy induced hypertension (93). Diastolic BP also rose however was not significant in this study (102 mmHg, range 100 ± 110 mmHg to 106 mmHg, range 100 ± 115 mmHg) (93). Another study (164) found a significant difference in mean SBP (exercise: 1.81 ± 2.4 mmHg, control: 9.86 ± 2.87 mmHg $p = 0.03$) and DBP (exercise: -0.28 ± 1.57 mmHg. control: 7.78 ± 1.96 mmHg $p = 0.002$) changes after walking compared with pre-walking. A study comparing responses to aerobic and resistance exercise found no significant change in SBP and DBP from baseline following exercise, with the intervention group recording a significantly higher SBP during aerobic exercise than resistance ($p < 0.01$) (195). No significant differences were found in BP responses following exercise when groups with PE, GDM and Cholestasis were compared (95).

### 3.3.8 Acute resistance exercise

***Uncomplicated pregnancies***

Eight studies measured BP following an acute bout of resistance training during healthy pregnancy (163, 166, 175, 202-204, 209, 214). The participants in two studies (163, 166) took part in resistance interventions described earlier under **Resistance exercise interventions** – ***Uncomplicated populations***, however the authors reported both acute and long-term responses to exercise.

Overall SBP and DBP increased significantly from baseline during exercise and returned to pre-exercise levels within 5 minutes following exercise, with four studies reporting no significant difference between pre and post BP (163, 166, 175, 209). One study comparing pregnant and non-pregnant women found that the SBP, DBP and MAP responses during exercise were all lower ($p = 0.03$, 0.02, 0.01, respectively) within the pregnant group (203). In comparison, another study (202) found no significant differences between SBP and DBP responses between pregnant and non-pregnant groups. One study compared BP responses to 40% 10RM resistance exercises with and without the use of the Valsalva manoeuvre and found a significantly increases MAP when the Valsalva manoeuvre was performed compared to free breathing due to significantly higher systolic ($121 \pm 15$ mmHg vs $116 \pm 12$ mmHg, $p = 0.001$) and diastolic blood pressures ($79 \pm 8$ mmHg vs $77 \pm 8$ mmHg, $p = 0.02$) (204).

***At risk populations***

Three studies found no difference between pre and post SBP or DBP following light (182, 190) and moderate to vigorous (195) resistance exercise in at risk pregnant women.

### 3.3.9 Adherence

Adherence was reported in 21 of the 32 intervention studies, with varied results across the studies with both low (n = 7; 33-62.5%) (36, 96, 146, 165, 179, 180, 215) and high rates of adherence (n = 14; 75-95%) reported (108, 157, 159-161, 167, 176, 177, 180, 183-187). Yeo et al. (2008) found that adherence rates decreased over time, with their participants instructed to exercise five times per week and only completing on average 2.5-4.5 sessions per week (36). One study reported that 28 of the 69 participants in the intervention group completed less than 70% of the exercise sessions and were therefore excluded from the study (178).

## 3.4 Discussion

The aims of this review were to assess the effects of exercise interventions on blood pressure during pregnancy and to understand acute changes in blood pressure during a single bout of exercise in pregnant women. Significant differences in favour of the exercise group were found in SBP, DBP and MAP following exercise interventions in at risk populations. This indicates that pregnant women at a higher risk for cardiovascular conditions may use aerobic or a combination of aerobic and resistance exercise to help prevent an increase in BP often

associated with these conditions. For uncomplicated pregnancies, light to moderate intensity aerobic or resistance exercise had no effect on resting BP throughout pregnancy. Blood pressure showed greater increases with acute aerobic exercise than resistance exercise in uncomplicated and at risk populations, returning to baseline levels post-exercise. A post-exercise hypotensive response in BP may occur following acute aerobic exercise, indicating that acute bouts of aerobic exercise may help lower BP in at risk populations with higher resting BP levels. Compared to usual care, aerobic and/or resistance exercise performed throughout uncomplicated pregnancy had no influence on blood pressure, however higher risk pregnancies may reduce their risk of elevated BP through regular exercise training during pregnancy.

This review found no differences in SBP or MAP in the uncomplicated pregnant population and only a small yet significant decrease in DBP following combined aerobic and resistance exercise intervention. Reassuringly, these participants remained normotensive throughout gestation. In response to vasoactive substances, growth factors and haemodynamic stimuli, the structural components of blood vessel walls are altered through the dynamic process of vascular remodelling during pregnancy (10, 11). The structure and function of arteries are remodelled to accommodate an increased blood volume and cardiac output, and to ensure that the endothelial shear rates remain within healthy limits (10, 12). A curvilinear reduction in blood pressure associated with vascular remodelling and vasodilation has been observed in uncomplicated pregnancies, with a nadir reached between the end of the first and beginning of the second trimester (10, 13). The results from this meta-analysis support previous evidence which indicate that regular exercise during pregnancy does not influence these normal physiological changes that occur during gestation (178). Women with uncomplicated pregnancies can be confident there are no adverse effects of exercise on haemodynamics during gestation. They should be encouraged to continue exercising throughout their pregnancy where possible.

The physiological changes present throughout gestation have been shown to differ between uncomplicated and pathological pregnancies (11, 14). Where normal pregnancy is characterised by a low systemic vascular resistance and an increased cardiac output, the adaptations are often reversed in hypertensive pregnancies (15, 87, 216). Women with insulin resistance or GDM have an increased risk of developing GHTN and PE and these conditions share several risk factors and pathophysiological features including maternal

obesity, excessive gestational weight gain, vascular dysfunction, and inflammation (33, 177, 195). This review found exercising participants diagnosed with clinical conditions showed lower resting BPs following intervention than the non-exercising controls, indicating that regular exercise may help prevent the onset of GHTN or PE in this population (177, 181).

The studies in this review that measured incidence of PE and GHTN identified significantly lower rates of these two conditions in exercising groups compared to non-exercising controls (36, 164, 179). Further, no adverse events were reported by any of the interventions involving at risk pregnancies, even those at high risk for GHTN and PE. This is supported by a systematic review which reported a 39% and 41% reduction in the odds of developing GHTN and a PE respectively when exercise was performed during pregnancy (33). PE and GHTN have long been recognised as absolute and relative contraindications to exercise in international exercise and pregnancy guidelines (91). A review evaluating which clinical conditions may be contraindications to exercise determined that only severe PE should still be considered an absolute contraindication, with mild PE categorised as a relative contraindication, and gestational hypertension (in isolation) no longer considered a contraindication (91). The review highlighted that light to moderate prenatal exercise in women with mild pre-eclampsia caused no adverse changes in BP, UBF and FHR, and can provide a multitude of maternal and foetal benefits (91). It is crucial that pregnant women with these clinical conditions are provided with appropriate guidance based on the most recent evidence to improve maternal and foetal outcomes. More research is needed on the effects of exercise on BP regulation during pregnancy in those at a higher risk of developing gestational hypertensive conditions (211).

Adherence appears to be a limitation in most studies involving overweight or obese pregnant women, with adherence rates between 33-75% reported in exercise interventions (179, 215). Exercise adherence within at risk pregnant populations, particularly women who are overweight or have obesity, is considered a major challenge, therefore finding methods to reduce participant attrition rates is vital (179). It has been suggested that including higher intensity intervals into training may be one method of increasing energy expenditure whilst enhancing enjoyment levels and reducing the time spent exercising (217). Six of the studies included more vigorous intensity exercise (116, 157, 179, 180, 184, 192), with adherence rates varying from 50% (179) to 96% (116). Systematic evidence has found that vigorous intensity exercise appears safe for most uncomplicated pregnancies when completed into the

third trimester (80), however further research is needed within the first and second trimester as well as within higher risk populations.

No significant differences in BP were found following resistance training alone, however only a limited number of studies reported the effects of resistance training during pregnancy. More research is needed on this modality of exercise throughout pregnancy to determine the long-term effects of resistance training on BP, specifically in at risk populations. Similar changes were seen with aerobic and combination exercise in both uncomplicated and at risk populations. It has previously been suggested that aerobic exercise should be supplemented with resistance exercise to aid in the prevention of hypertension in non-pregnant populations (86, 218), however more recent evidence including a systematic review (219) has identified that there is little to no difference in BP between aerobic exercise alone and a combination of aerobic and resistance in non-pregnant populations (218, 219). The findings from this review suggest that within at risk populations aerobic and combination exercise should be prioritised to prevent an increase in BP and reduce the risk of developing gestational hypertensive conditions. Although resistance training may not significantly affect blood pressure changes throughout uncomplicated or at risk pregnancies, it is still recommended as standard exercise prescription due to the benefits to increase/maintain strength and decrease urinary incontinence (220).

As expected, all of the acute studies found significant increases in SBP during exercise, with hypotensive BP responses found following aerobic exercise from 50-60 min (208) to 13-14 hours post exercise (174). Post exercise hypotension (PEH) is commonly seen following acute bouts of aerobic exercise in both normotensive and hypertensive non-pregnant people (203, 208). Findings suggest that BP responses to acute aerobic exercise in pregnant women participating in regular aerobic exercise are significantly lower than non-exercising women. This indicates a training response to regular aerobic exercise with adaptations occurring within the cardiovascular system (87). Previous studies have suggested that some of the physiological mechanisms that reduce BP following chronic exercise may be present in the onset of PEH following acute exercise bouts. Indeed, a systemic adaptation of the arterial wall increasing arterial compliance occurs following an exercise session, thereby decreasing peripheral resistance (87). Characterised by a sustained decrease in BP following a single bout of exercise, PEH has been shown to vary in magnitude and duration, indicating that exercise characteristics may have an influence on levels of PEH (86, 221). It has been

suggested that PEH responses are clinically important as they may help cause an adaptation which results in a lowering of BP (166). A reduction in SBP of as little as 2 mmHg in non-pregnant populations has been shown to reduce the risk of cardiovascular disease by 4-6% (87). The results of this review support previous research indicating that regular bouts of aerobic exercise may help pregnant women reduce their risk of developing gestational hypertensive conditions.

***Limitations***

A limitation in the current review and meta-analysis was the heterogeneity of the research designs. A random effects meta-analysis was used to account for this. The $I^2$ values were high for the uncomplicated and at risk groups when the exercise types were grouped ($I^2$ = 94-99%), and although they dropped slightly when subgroup analysis was performed for exercise type they remained high ($I^2$ = 71-98%) indicating that there may be heterogeneity in the outcomes that are not able to be explained by the studies in this systematic review. The leave-one-out analysis showed slight decreases in heterogeneity when certain studies were removed, however generally remained high (80-99%). This can be expected as the session duration, intensity, frequency, exercise mode and length of intervention varied significantly across the studies, even within the subgroups presented. The mode, length (3-31 weeks), frequency (1-5 sessions/week) and duration (15-60 minutes), varied across interventions, making it hard to distinguish which of these factors may have contributed to changes in BP. A large decrease in heterogeneity was only seen when one study (176) was removed. One notable difference in this study is that BP was measured through finger photoplethysmography with a Finometer (Finometer Pro; Finapres Medical Systems, Amsterdam, the Netherlands), rather than the more common method of brachial auscultation. Research has shown however, that the Finometer is a suitable measure of BP with no significant differences seen between auscultatory measures and Finometer measures when compared (222).

The same issue was faced when comparing the acute studies, as the bouts ranged from 5- to 60- minute bouts and were measured at different time points during pregnancy (12-38 weeks gestation). Most of the control groups were treated with routine prenatal care or continued with their usual PA levels, and as such may have participated in exercise throughout pregnancy of their own accord, potentially influencing results. Furthermore, there were low adherence rates and small sample sizes observed in many of the studies.

**Conclusion**

The findings from this review indicate that moderate to vigorous aerobic exercise during pregnancies complicated with clinical conditions including GDM, overweight and obesity may either reduce, or attenuate an increase in blood pressure that commonly occurs with these conditions. These findings have important implications for pregnant women at risk of developing GHTN and PE. Indeed, particular focus on providing exercise support to clinical pregnancies may have significant impact on future maternal and infant cardiovascular morbidity and mortality.

# Chapter 4. The acute effects of a weekly submaximal aerobic exercise test on arterial stiffness and blood pressure from embryo implantation until birth: a longitudinal case study

## Abstract

### Introduction

Vigorous intensity exercise has been suggested as safe and effective into the third trimester of pregnancy, however research in the first and second trimesters is lacking. Due to the extensive cardiovascular changes that occur during pregnancy, it is important to understand the effects of vigorous intensity exercise on the cardiovascular system. The aim of this study was to compare the acute effects of a submaximal graded exercise test on arterial stiffness and blood pressure (BP) measured each week throughout pregnancy.

### Methods

A healthy pregnant woman was recruited at four weeks of gestation along with a healthy aged matched non-pregnant control, to complete weekly submaximal (ceasing exercise at 85% $HR_{max}$) graded aerobic treadmill testing for approximately 30 weeks. Resting measures were taken after 5 minutes of supine rest. Outcome measures were taken immediately (1-5 minutes) post exercise and again 10-15 minutes post exercise. The primary outcome measures included: arterial stiffness measured by pulse wave velocity (PWV), central and peripheral BP, and mean arterial pressure (MAP).

### Results

The pregnant participant completed 26 exercise sessions over 30 weeks from gestational week 5 to 35. The non-pregnant participant completed 26 sessions over 52 weeks. In the pregnant participant average resting PWV showed a decrease from the first trimester (T1) through the second trimester (T2) ($-0.53 \pm 0.26$ $m.s^{-1}$), with a further decrease into the third trimester (T3) ($-0.94 \pm 0.47$ $m.s^{-1}$). The linear regression analysis found that change in PWV from rest to immediately post exercise was significantly associated with 1) gestational week ($p = 0.010$) and 2) change in MAP ($p = 0.011$). PWV increased slightly immediately following exercise in T1 ($0.42 \pm 0.37$ $m.s^{-1}$), decreasing back towards resting levels by 10 minutes post exercise ($-0.34 \pm 0.16$ $m.s^{-1}$). Conversely, during T2 and T3 PWV decreased immediately following exercise (T2 = $-0.09 \pm 0.52$ $m.s^{-1}$, T3 = $-0.07 \pm 0.20$ $m.s^{-1}$) and increased slightly from immediately post to 10 minutes post exercise (T2 = $0.31 \pm 0.43$ $m.s^{-1}$, T3 = $0.36 \pm 0.44$ $m.s^{-1}$). The time on test for the pregnant participant decreased slightly as gestation progressed (T1: $16.80 \pm 1.01$ min; T2: $16.09 \pm 0.40$ min; T3: $15.55 \pm 0.88$ min).

**Conclusions**

The findings lead us to speculate that the ability of the maternal cardiovascular system to adapt to submaximal exercise may decrease as gestation progresses. Further longitudinal research is needed on the effects of different modes and intensities of exercise on arterial stiffness in larger sample sizes, given the association between increased arterial stiffness in early pregnancy and gestational complications.

## 4.1 Introduction

Pregnancy is a time in which the human body undergoes significant physiological and anatomical adaptations, with some of the most profound modifications occurring within the cardiovascular and haematological systems (1, 3). Many of the cardiovascular changes commence within the first month or two of pregnancy (7, 11, 14). The mechanism of these changes can be elucidated when an additional environmental stress, such as exercise, is applied (223). However, due to a delay in women either 1) finding out they are pregnant, or 2) waiting until later in pregnancy to enroll in exercise research studies, there is limited exercise physiology data on the entirety of gestation.

Arterial stiffness, a measure of arterial wall rigidity, has increasingly been recognised as a non-invasive clinical marker to assess cardiovascular function (64, 98, 224). It is most commonly measured by pulse wave velocity (PWV) (64, 225). In healthy pregnancies, resting PWV and augmentation index (AIx) tend to decrease from early in the first trimester, with central and peripheral arteries reaching maximum compliance late in the second trimester (14, 58, 106, 223, 226) before increasing in stiffness again towards term (14, 58). Functional, rather than structural, adaptations of the vascular system following exercise are most likely responsible for any acute dynamic changes seen in arterial stiffness with a single bout of exercise (98, 100). These changes have been associated with the systemic vasodilation that occurs early in pregnancy to accommodate an increase in cardiac output (CO) and plasma volume (227).

There is limited research on the benefits of regular exercise during pregnancy on arterial stiffness (106, 107) and no studies specifically observe the acute effects of exercise on PWV during pregnancy. Arterial stiffness has been shown to increase immediately post aerobic exercise in non-pregnant populations (98, 100), which indicates the shear stress associated with a bout of exercise is likely driving the association of regular exercise and reduced arterial stiffness (102). However, the acute response in arterial stiffness to aerobic exercise is dependent on the arterial segment being measured, along with the timing of the measurement (98, 100, 101). Measuring the acute effects of exercise during pregnancy may provide a better understanding of the mechanisms through which chronic exercise elicits improvements in pregnancy-induced cardiovascular conditions (98).

The aim of this study was to compare the acute effects of a submaximal graded exercise test on arterial stiffness and BP measured each week throughout pregnancy. It is hypothesised that resting PWV will *decrease* across gestation, due to progressively increasing vasodilation. It is also hypothesised that an *increase* in PWV will occur immediately post exercise due to increased shear stress on the maternal vasculature.

### 4.1.1 Case presentation

A healthy 31-year-old gravida 3, para 2 Caucasian woman was recruited from four weeks of gestation (i.e. shortly after embryo implantation) to perform weekly submaximal aerobic exercise testing sessions. The testing sessions were conducted from gestational week 5 until gestational week 35. An aged matched non-pregnant healthy control was recruited and performed the same testing sessions weekly or fortnightly over 52 weeks. Prior to the first sessions the women completed an informed consent, and the pregnant participant completed the PARmed-X for Pregnancy (Appendix 4) (125). Both participants were considered healthy with no previously diagnosed hypertensive conditions.

## 4.2 Methods

### 4.2.1 Testing protocol

The participants reported to the clinic in a fed state following 24 hours of no strenuous exercise. Upon arrival at the clinic participants were weighed, and then asked to rest in a semi-recumbent position for 5 minutes prior to resting haemodynamic measures being collected. The participants then completed a graded submaximal exercise test on the treadmill according to the Cornell Protocol, which has previously been used in pregnant populations (135, 136). The test was terminated once 85% of the participant's age predicted heart rate maximum ($PHR_{max}$) was reached to ensure the test remained sub-maximal, and within the vigorous intensity threshold (<90%MHR). The participants were then required to lay down in the semi-recumbent position (15 degrees incline) immediately post exercise for 10-15 minutes while the post exercise measures were recorded. The timing of measures was shown previously in 2.6 Outcome Measures - *Figure 7*. The below methods provide a summary of outcome measures previously detailed in Chapter 2.

### 4.2.2 Arterial stiffness

Arterial stiffness was measured using the semi-automatic SphygmoCor Xcel system which uses high fidelity applanation tonometry to measure carotid-femoral PWV (cf-PWV). Central BP were also assessed using the SphygmoCor Xcel.

### 4.2.3 Blood pressure

Resting central and peripheral BP was measured following 5 minutes of rest in the supine position using the SphygmoCor Xcel automatic device. BP was measured using this device immediately following exercise (1-2 minutes) and again 10-12 minutes post exercise. Brachial BP was measured manually during exercise at the end of every 2-minute stage using a standing aneroid sphygmomanometer and a stethoscope.

### 4.2.4 Maternal and foetal heart rate

Resting heart rate (HR) measurements were recorded following 5 minutes of semi-recumbent rest. HR was constantly monitored throughout the exercise sessions and for 10-15 minutes following exercise. HR was measured using photoplethysmography with a chest strap connected via Bluetooth to a phone application and recorded every minute during exercise, at 1-3 minutes post and again 10 minutes post exercise. Heart rate recovery (HRR) was observed by recording post exercise HR 1-3 minutes following exercise sessions and subtracting these measures from the peak heart rate. FHR was measured through ultrasound using a foetal doppler at rest, post exercise (within 1-2 minutes) and again 10 minutes post exercise from 13 weeks of gestation onwards.

### 4.2.5 Steps

The participants recorded their daily step count over the study period with their own smartwatch (pregnant participant - Google WearOS, non-pregnant participant – FitBit Versa).

### 4.2.6 Nutrition

Participants were required to report all food and drink intake over the 24-hours prior to each session. The MyFitnessPal smartphone application was used to track diet which provided a breakdown of calories, sodium, carbohydrates, fat and protein over the 24-hour period.

### 4.2.7 Statistical analysis

Statistical analyses were performed using IBM SPSS (version 29). A linear regression analysis was conducted to examine the relationship between the change in PWV in response to the submaximal test, and factors including gestational week, pre-pregnancy body mass index (BMI), and time on test. A *P* value of $< 0.05$ was considered statistically significant.

## 4.3 Results

The pregnant participant completed 26 exercise sessions over 30 weeks from gestational week 5 to 35. Only four sessions were missed, three due to illness (GW 16, 17 and 23) and one due to COVID-19 lockdown restrictions (GW 29). The non-pregnant participant completed 26 sessions over 52 weeks. The first 8 sessions for the non-pregnant participant were completed weekly, however due to logistical reasons the subsequent sessions were conducted fortnightly. In order to compare the same period of time for the non-pregnant and pregnant participants, 30 weeks' worth of data from the non-pregnant participant has been analysed, totalling 15 sessions. Participant demographics can be seen in *Table 22.*

Table 22. Participant demographics at baseline

| | **Pregnant** | **Non-pregnant** |
|---|---|---|
| **Age (years)** | 31 | 31 |
| **Gestational week** | 5 | N/A |
| **Height (cm)** | 176 | 165 |
| **Weight (kg)** | 80 | 62 |
| **BMI (kg/m$^2$)** | 25.8 | 22.2 |
| **Gravidity** | 3 | 2 |
| **Parity** | 2 | 2 |

Table 23. Trimester average of haemodynamic responses to submaximal graded exercise test in Study 2

| | Resting | Immediately post | 10 min post |
|---|---|---|---|
| **Pulse wave velocity ($m.s^{-1}$)** | | | |
| ***T1*** | 6.96 ± 0.2 | 7.38 ± 0.5 | 7.04 ± 0.5 |
| ***T2*** | 6.43 ± 0.2 | 6.40 ± 0.7 | 6.71 ± 0.5 |
| ***T3*** | 5.49 ± 0.9 | 5.42 ± 0.8 | 5.78 ± 0.7 |
| ***NP*** | 5.68 ± 0.5 | 5.81 ± 0.4 | 5.60 ± 0.3 |
| **Peripheral systolic BP (mmHg)** | | | |
| ***T1*** | 118 ± 4.8 | 155 ± 5.8 | 123 ± 2.6 |
| ***T2*** | 111 ± 8.2 | 147 ± 5.6 | 114 ± 2.2 |
| ***T3*** | 116 ± 11.0 | 149 ± 3.7 | 118 ± 5.7 |
| ***NP*** | 108 ± 7.1 | 116 ± 12.1 | 105 ± 4.2 |
| **Peripheral diastolic BP (mmHg)** | | | |
| ***T1*** | 69 ± 3.8 | 78 ± 6.6 | 70 ± 3.8 |
| ***T2*** | 62 ± 4.3 | 72 ± 6.1 | 64 ± 3.1 |
| ***T3*** | 65 ± 5.0 | 72 ± 7.5 | 69 ± 4.7 |
| ***NP*** | 65 ± 4.1 | 69 ± 3.2 | 65 ± 3.0 |
| **Peripheral mean arterial pressure (mmHg)** | | | |
| ***T1*** | 82 ± 3.7 | 98 ± 8.2 | 85 ± 3.5 |
| ***T2*** | 76 ± 4.5 | 92 ± 5.0 | 79 ± 2.9 |
| ***T3*** | 79 ± 6.2 | 93 ± 6.4 | 85 ± 3.2 |
| ***NP*** | 79 ± 4.3 | 84 ± 4.7 | 78 ± 4.0 |
| **Maternal heart rate (bpm)** | | | |
| ***T1*** | 68 ± 6 | 102 ± 12 | 81 ± 7 |
| ***T2*** | 76 ± 5 | 107 ± 9 | 81 ± 6 |
| ***T3*** | 76 ± 13 | 114 ± 11 | 90 ± 9 |
| ***NP*** | 73 ± 10 | 83 ± 5.2 | 74 ± 8.5 |
| **Central systolic BP (mmHg)** | | | |
| ***T1*** | 100 ± 5.1 | 125 ± 4.6 | 103 ± 2.8 |
| ***T2*** | 94 ± 3.1 | 119 ± 4.8 | 95 ± 2.1 |
| ***T3*** | 97 ± 7.7 | 120 ± 3.5 | 101 ± 4.2 |
| ***NP*** | 96 ± 5.5 | 100 ± 8.4 | 93 ± 4.2 |
| **Central diastolic BP (mmHg)** | | | |
| ***T1*** | 69 ± 3.8 | 80 ± 8.0 | 71 ± 4.0 |
| ***T2*** | 63 ± 4.8 | 74 ± 6.3 | 69 ± 2.9 |
| ***T3*** | 67 ± 6.3 | 75 ± 8.7 | 76 ± 3.9 |
| ***NP*** | 67 ± 4.5 | 71 ± 2.8 | 65 ± 3.0 |

T1 = trimester 1 (0-12 weeks gestation); T2 = trimester 2 (13-26 weeks gestation); T3 = trimester 3 (27-40 weeks gestation); NP = non-pregnant; BP = blood pressure; N/A = not applicable; bpm = beats per minute; mmHg = millimetres of mercury; $m.s^{-1}$ = meters per second.

### 4.3.1 Arterial stiffness

In the pregnant participant average resting PWV showed a decrease from the first trimester (T1) through the second trimester (T2) (-0.53 ± 0.26 $m.s^{-1}$) , with a further decrease into the third trimester (T3) (-0.94 ± 0.47 $m.s^{-1}$) (*Table 23; Figure 19*). There was variation week to week in resting PWV as seen in *Figure 199*, particularly from 28-31 weeks of gestation. This may be due to the participant's diet in week 30, with a higher sodium intake reported in the 24 hours prior to the test in week 30 (2721 mg) than in weeks 28 (1074 mg) and 31 (981 mg). The linear regression analysis found that change in PWV from rest to immediately post exercise was significantly associated with 1) gestational week (p = 0.010) (*Figure 21*) and 2) change in MAP (p = 0.011). PWV increased slightly immediately following exercise in T1 (0.42 ± 0.37 $m.s^{-1}$), decreasing back towards resting levels by 10 minutes post exercise (-0.34 ± 0.16 $m.s^{-1}$). Conversely, during trimester 2 (T2) and T3 PWV decreased immediately following exercise (T2 = -0.09 ± 0.52 $m.s^{-1}$, T3 = -0.07 ± 0.20 $m.s^{-1}$) and increased slightly from immediately post to 10 minutes post exercise (T2 = 0.31 ± 0. 43 $m.s^{-1}$, T3 = 0.36 ± 0.44 $m.s^{-1}$). The non-pregnant participant consistently showed an increase in PWV immediately following exercise (0.21 $m.s^{-1}$), decreasing towards baseline levels by 10 minutes post exercise (-0.19 $m.s^{-1}$) (Figure 20).

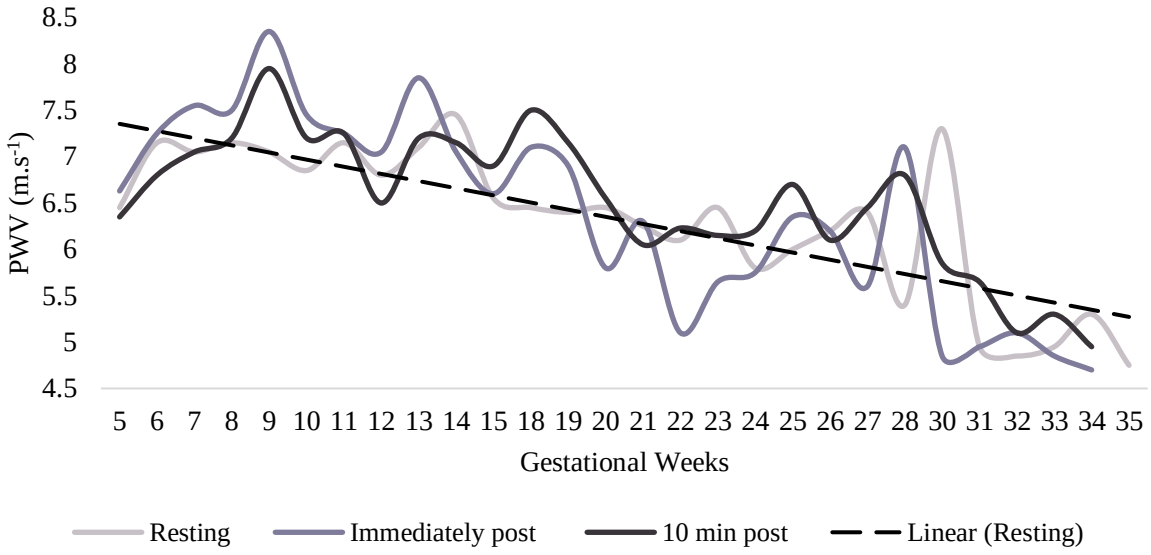



Figure 19. PWV in the pregnant participant

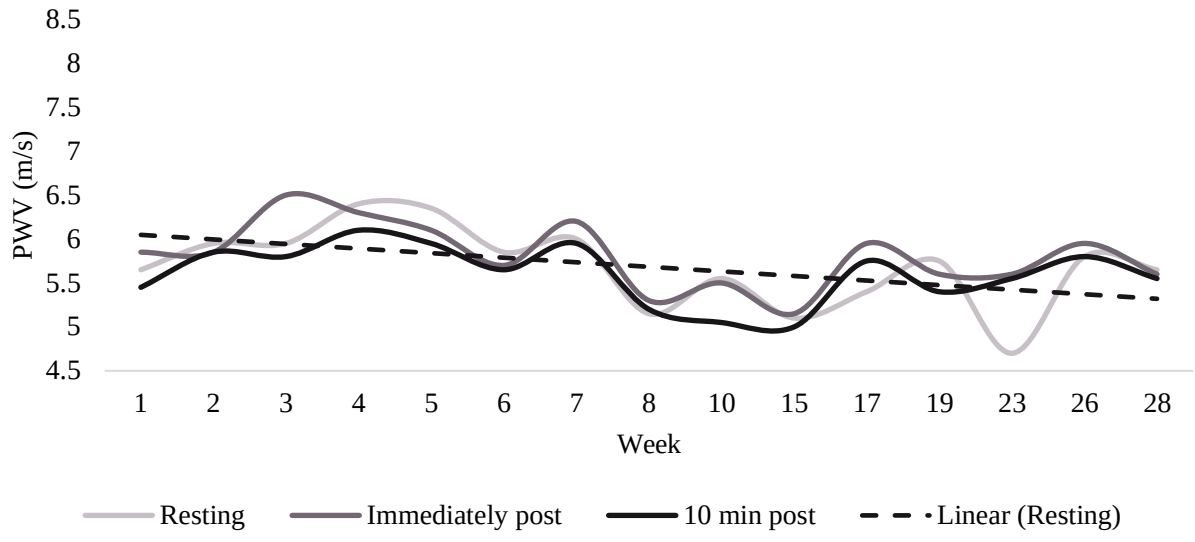



Figure 20. PWV in the non-pregnant participant

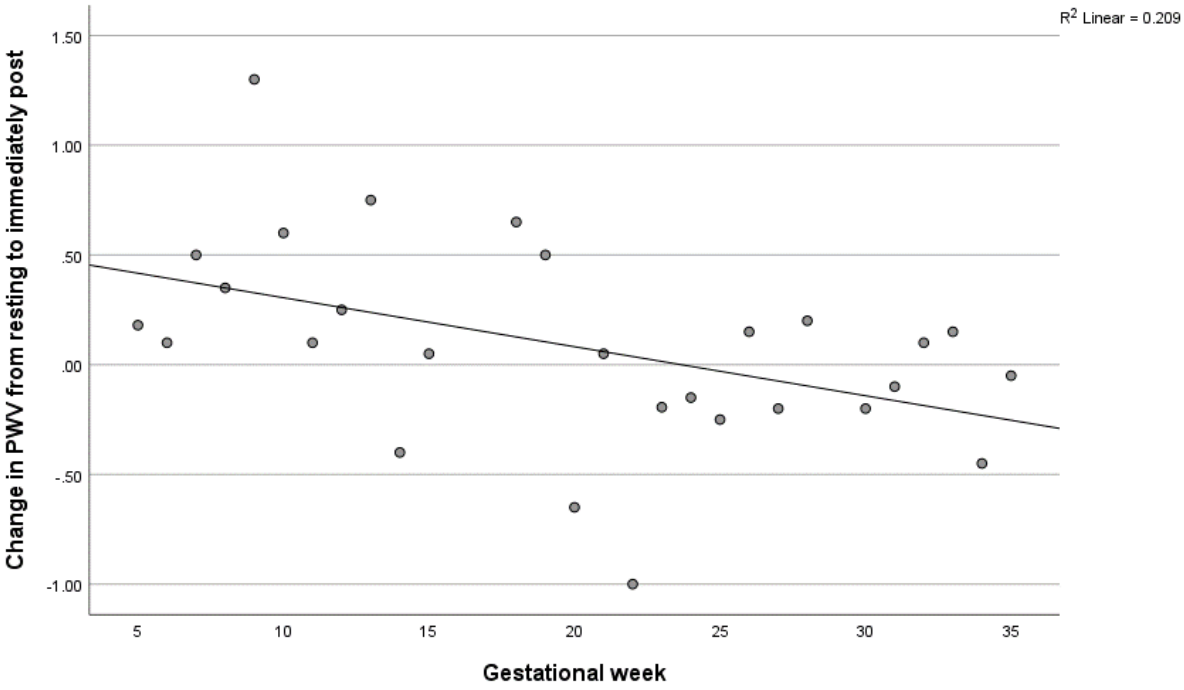



Figure 21. Acute change in PWV across gestational weeks

### 4.3.2 Blood pressure

In the pregnant participant, resting PSBP decreased from T1 to T2 (-7 ± 3.6 mmHg) increasing again into T3 (+5 ± 2.7 mmHg) (*Table 23*). A similar increase in PSBP was seen immediately post exercise across all three trimesters (T1 = +37 ± 7.8 mmHg, T2 = +35 ± 6.1 mmHg, T3 = +33 ± 9.6 mmHg), dropping back towards baseline from immediately post to 10 minutes following exercise (T1 = -34 ± 6.9 mmHg, T2 = -34 ± 5.0 mmHg, T3 = -32 ± 7.0 mmHg) (*Figure 22*). Resting PDBP decreased from T1 to T2 (-6 ± 3.2 mmHg), increasing into T3 (+3 ± 1.3 mmHg). PDBP increased immediately following exercise in T1 (+9.9 ± 7.5 mmHg), T2 (+8.9 ± 5.8 mmHg) and T3 (+7.1 ± 7.9 mmHg) (*Figure 24*). A decrease was seen across the trimesters in PDBP 10 minutes post exercise from immediately post (T1 = -8.6 ± 3.6 mmHg; T2 = -6.6 ± 4.4 mmHg; T3 = -2.9 ± 6.3 mmHg). The acute change in SBP and DBP from resting to immediately post exercise decreased as gestation increased (*Figure 26* and *27*). As expected, the non-pregnant participant had an increase in BP from rest to immediately post-exercise, which dropped to below resting levels 10 minutes post exercise (*Figure 23* and *Figure 255*.).

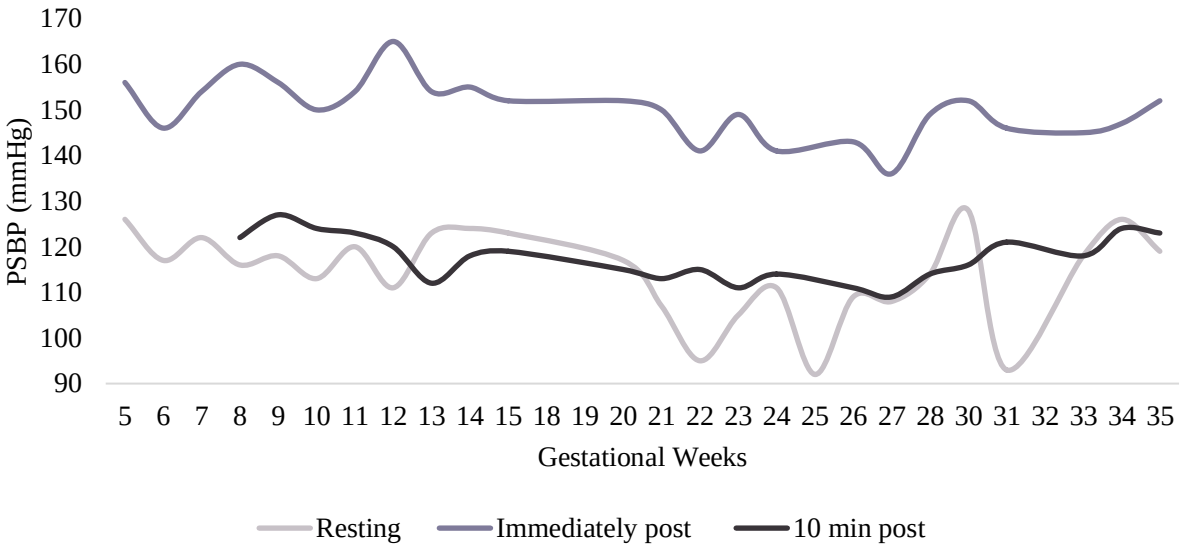



Figure 22. PSBP in the pregnant participant

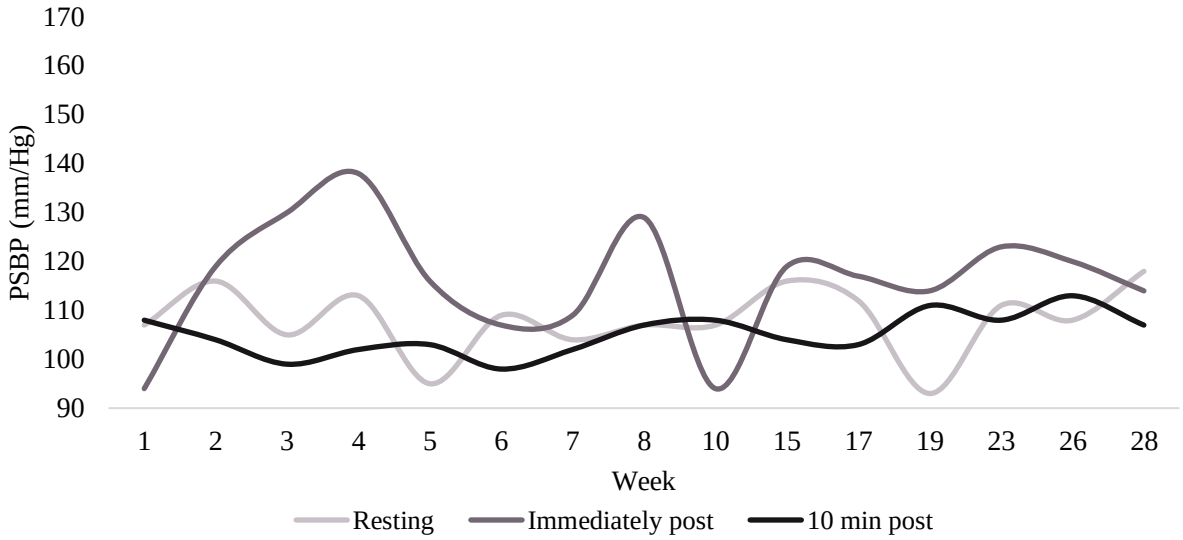



Figure 24. PSBP in the non-pregnant participant

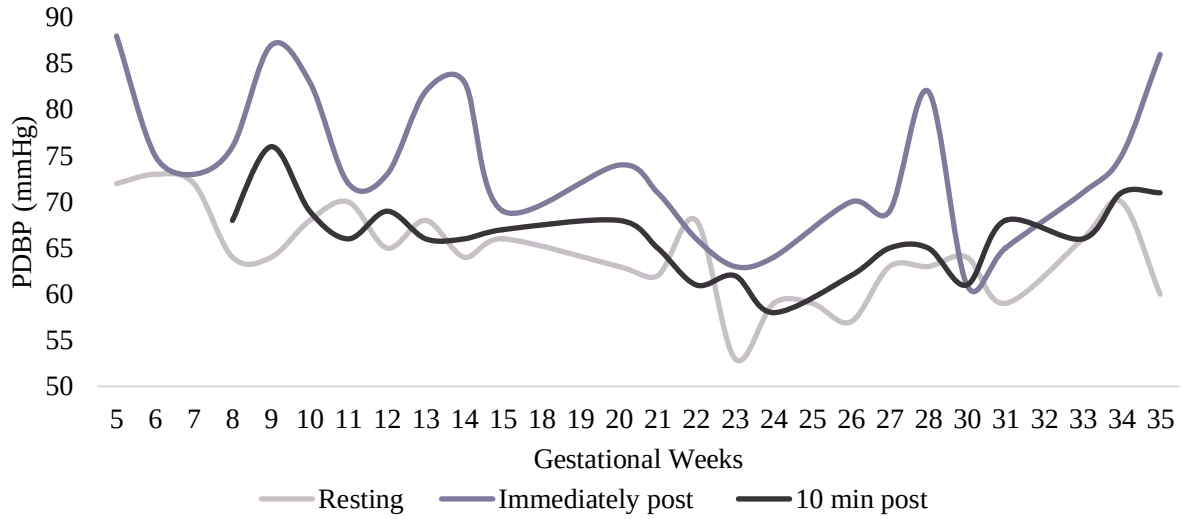



Figure 23. PDBP in the pregnant participant

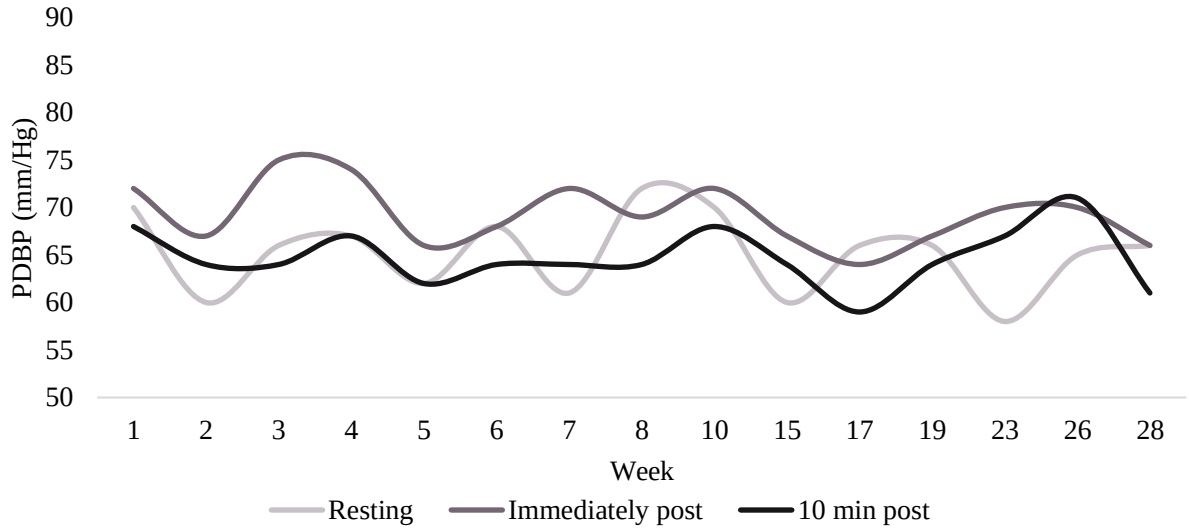



Figure 25. PDBP in the non-pregnant participant

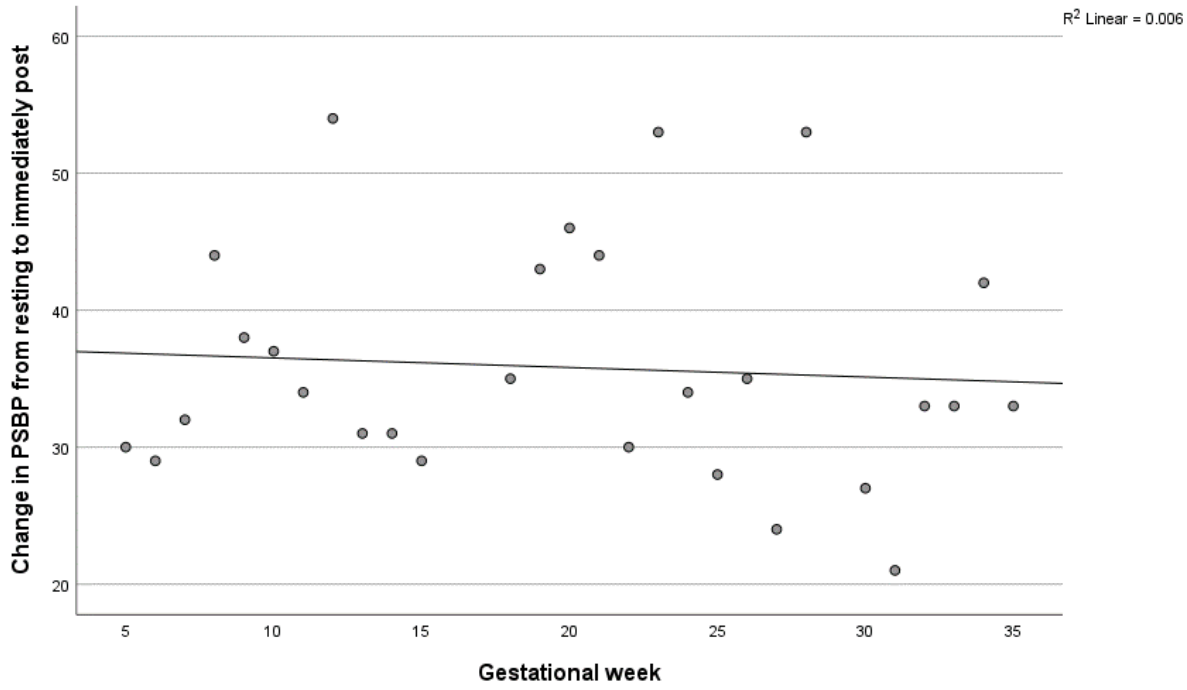



Figure 26. Acute change in PSBP across gestational weeks following a submaximal exercise test

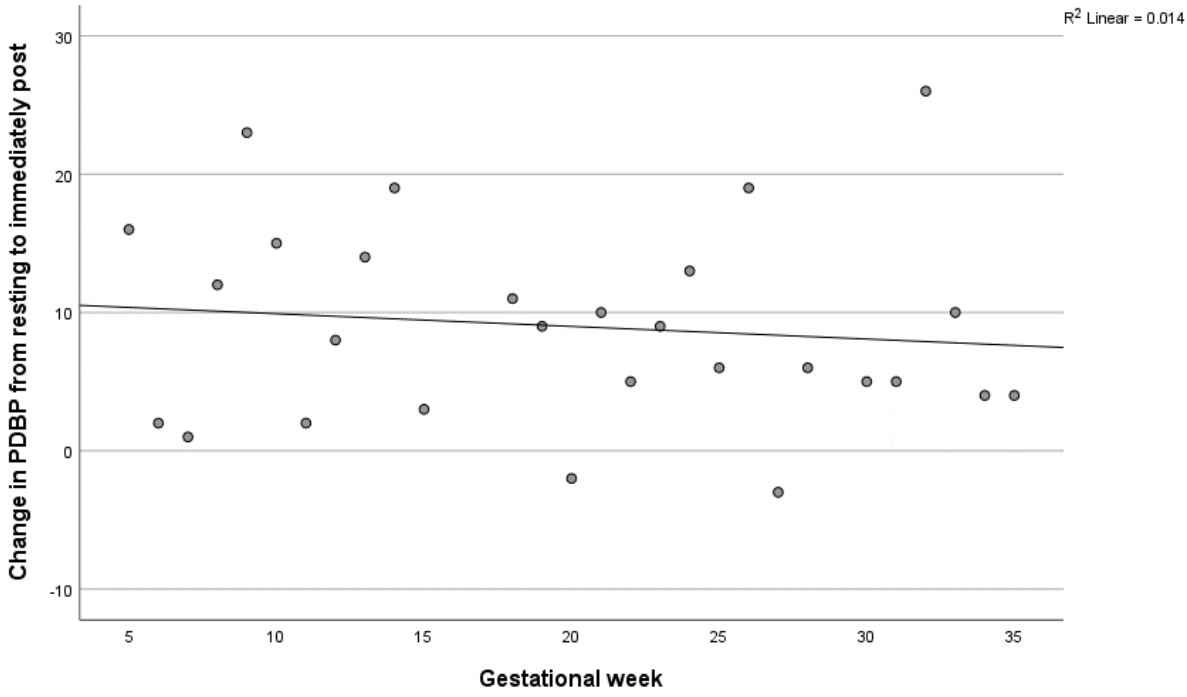



Figure 27. Acute change in PDBP across gestational weeks following a submaximal exercise test

### 4.3.3 Peripheral mean arterial pressure

Resting MAP decreased from T1 to T2 (-5 ± 2.7 mmHg), increasing into T3 (+3 ± 1.3 mmHg). MAP increased immediately following exercise in T1 (+17 ± 7.4 mmHg), T2 (+14.6 ± 5.7 mmHg) and T3 (+14.1 ± 6.6 mmHg) (*Figure 28*). From immediately post to 10 minutes post exercise MAP had decreased towards resting levels in each trimester (T1 = -12 ± 5.9 mmHg; T2 = -11.1 ± 3.0 mmHg; T3 = -8.1 ± 6.1 mmHg). The acute change in MAP from resting to immediately post exercise decreased as gestation progressed (*Figure 30*).

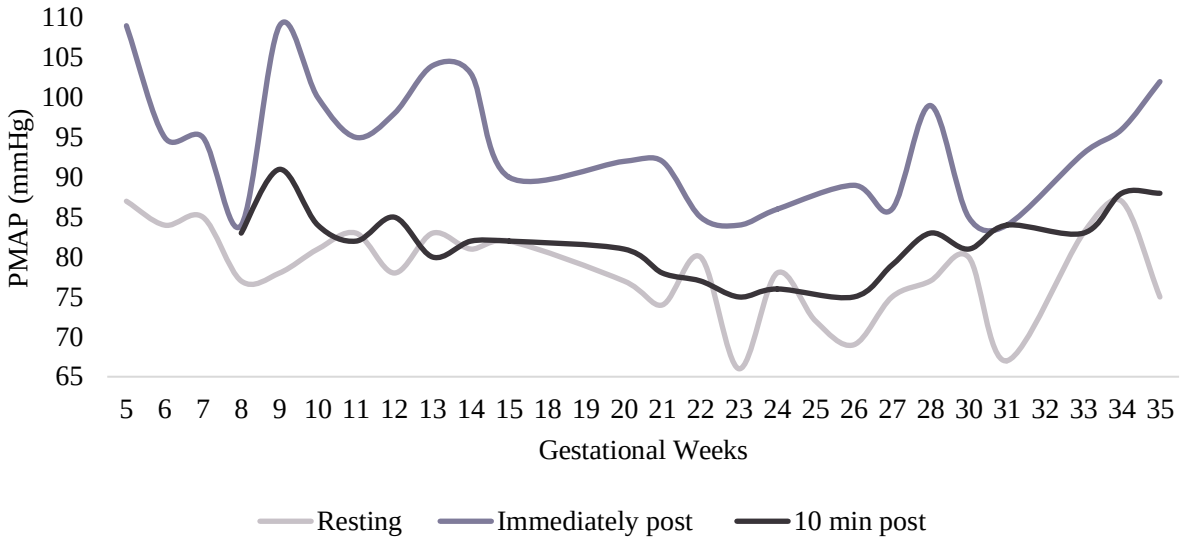



Figure 28. PMAP in the pregnant participant

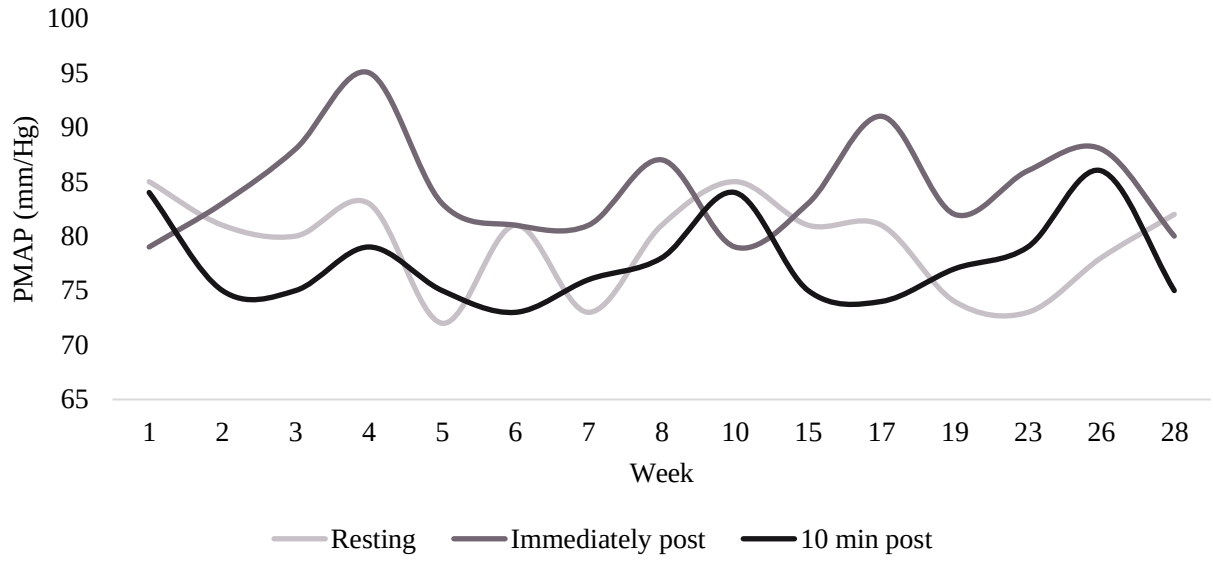



Figure 29. PMAP in the non-pregnant participant

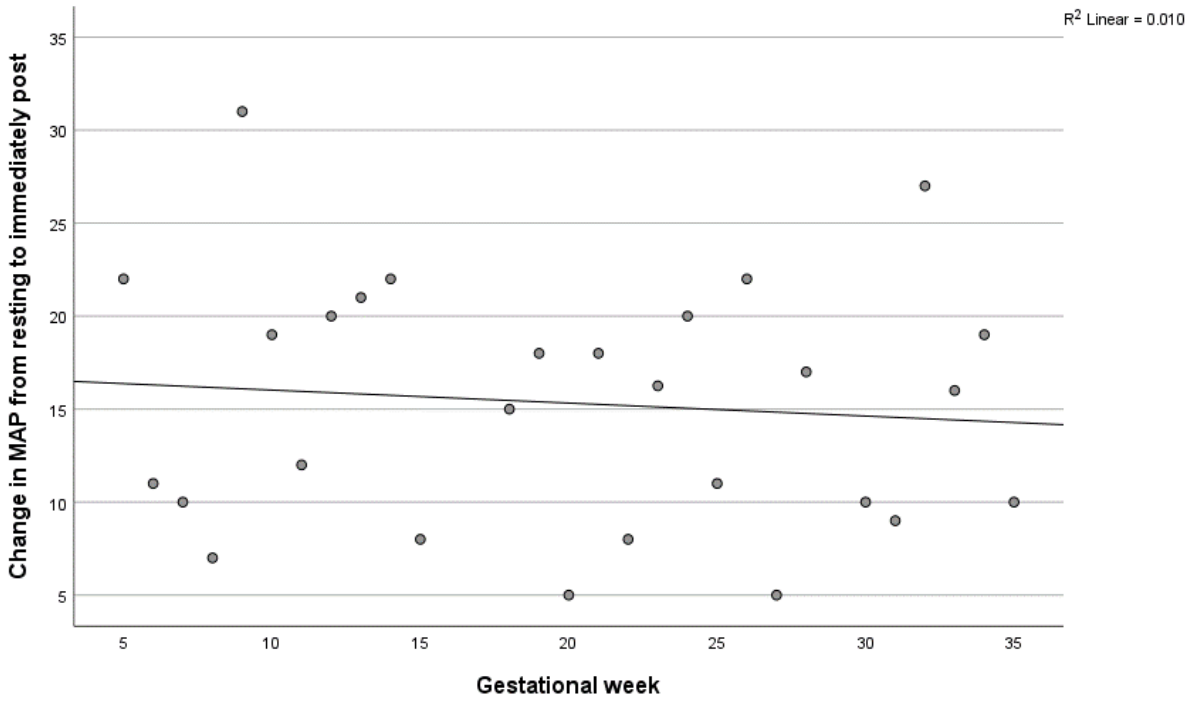
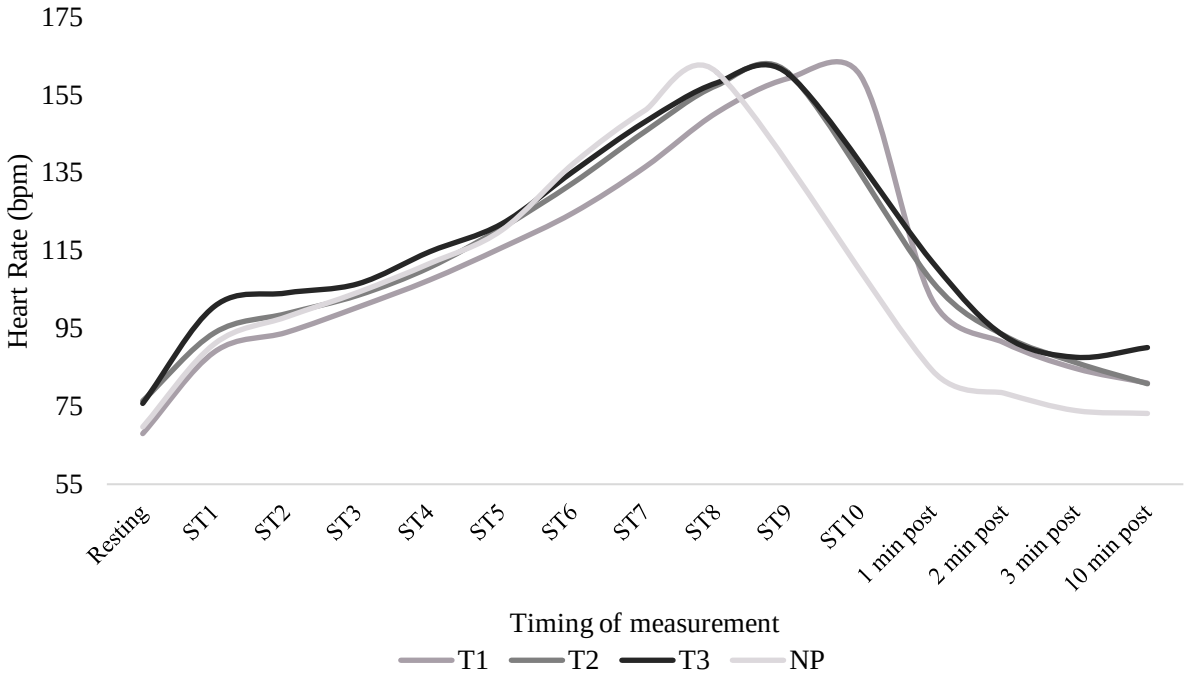



Figure 30. Acute change in PMAP across gestational weeks following a submaximal exercise test

### 4.3.4 Heart rate and heart rate recovery

Both participants reached at least 85% $PHR_{max}$ in all sessions. *Figure 31* shows the HR response to exercise across the weeks. Resting HR increased from T1 to T2 (8 ± 4.15 bpm), with no change seen in T3 (0 ± 0.33 bpm). HRR decreased from T1 to T3 with the most significant decrease 1 minute post exercise (-11 ± 5.5 bpm) (*Table 24*). Similar decreases in HR were seen from 1 minute to 10 minutes post exercise in each trimester (T1: -21.6 ± 5.2 bpm; T2: -26.1 ± 11.5 bpm; T3: -23.5 ± 12.8 bpm).

The non-pregnant participant showed a quicker HRR than the pregnant participant. At 10 minutes post exercise the non-pregnant participant's average HR decreased close to resting levels.




ST1-10 = stage 1-10; bpm = beats per minute; T1 = trimester 1; T2 = trimester 2; T3 = trimester 3; NP = non-pregnant; 1-10 min post = 1-10 minutes post exercise

Figure 31. HR response to the submaximal exercise test in each trimester and the non-pregnant participant

Table 24. Heart rate recovery from peak HR following the Cornell test in each trimester and the non-pregnant participant

| | **T1** | **T2** | **T3** | **NP** |
|---|---|---|---|---|
| **HRR1** | -58 ± 12 | -54 ± 9 | -47 ± 11 | -78 ± 5 |
| **HRR2** | -69 ± 10 | -68 ± 3 | -66 ± 6 | -83 ± 7 |
| **HRR3** | -76 ± 8 | -75 ± 3 | -73 ± 5 | -88 ± 6 |
| **HRR10** | -81 ± 7 | -81 ± 6 | -90 ± 9 | -73 ± 10 |

HRR1 = heart rate recovery at 1 min post exercise; HRR2 = heart rate recovery at 2 min post exercise; HRR3 = heart rate recovery at 3 minutes post exercise; HR10 = heart rate recovery at 10 minutes post exercise

### 4.3.5 RPE

*Figure 32* shows the average RPE response to the Cornell test. The pregnant participant reached stage 9 of the test in T1, however only reached stage 8 in T2 and T3 before her HR reached 85% $HR_{max}$. On average, the participant reached stage 9 ± 0.7 in T1, stage 9 ± 0.4 in T2 and stage 8 ± 0.5 in stage 3 before hitting 85% $HR_{max}$. Whilst the workload intensities remained the same throughout pregnancy, the pregnant participant reported a higher RPE in T2 and T3 compared to T1 (*Figure 32*). The time on test for the pregnant participant decreased slightly as gestation progressed (T1: 16.80 ± 1.01 min; T2: 16.09 ± 0.40 min; T3: 15.55 ± 0.88 min) as shown in *Figure 33*.

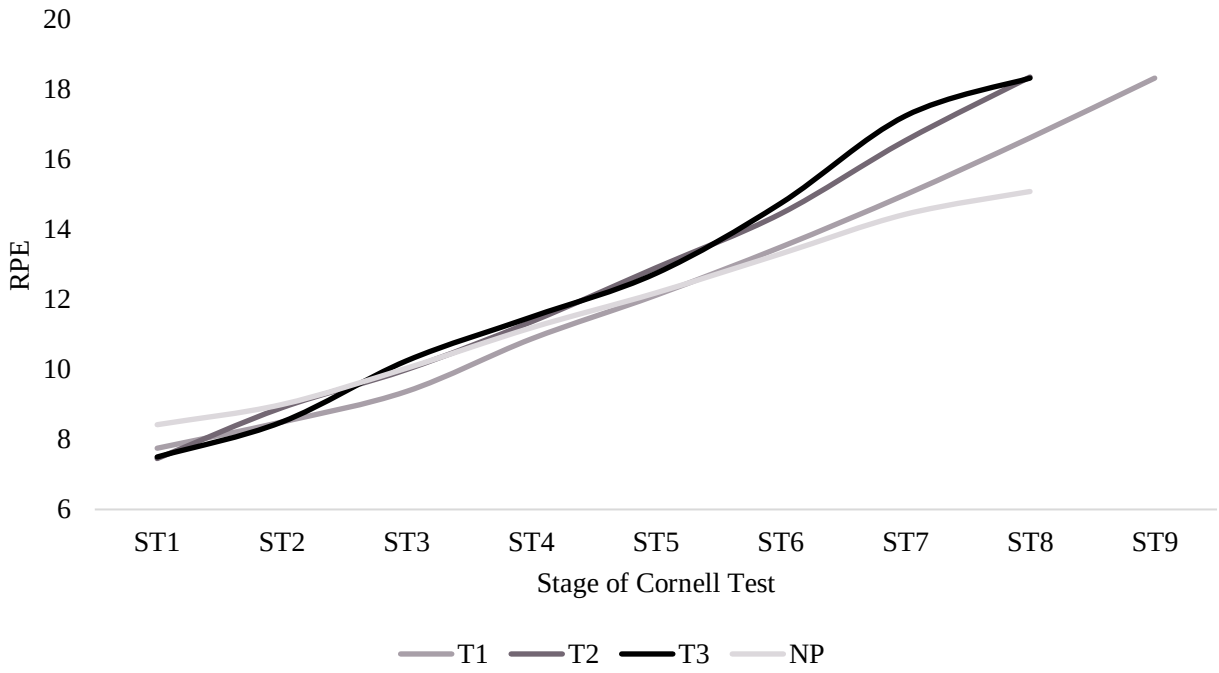



Figure 32. RPE response to the Cornell test in each trimester and the non-pregnant participant

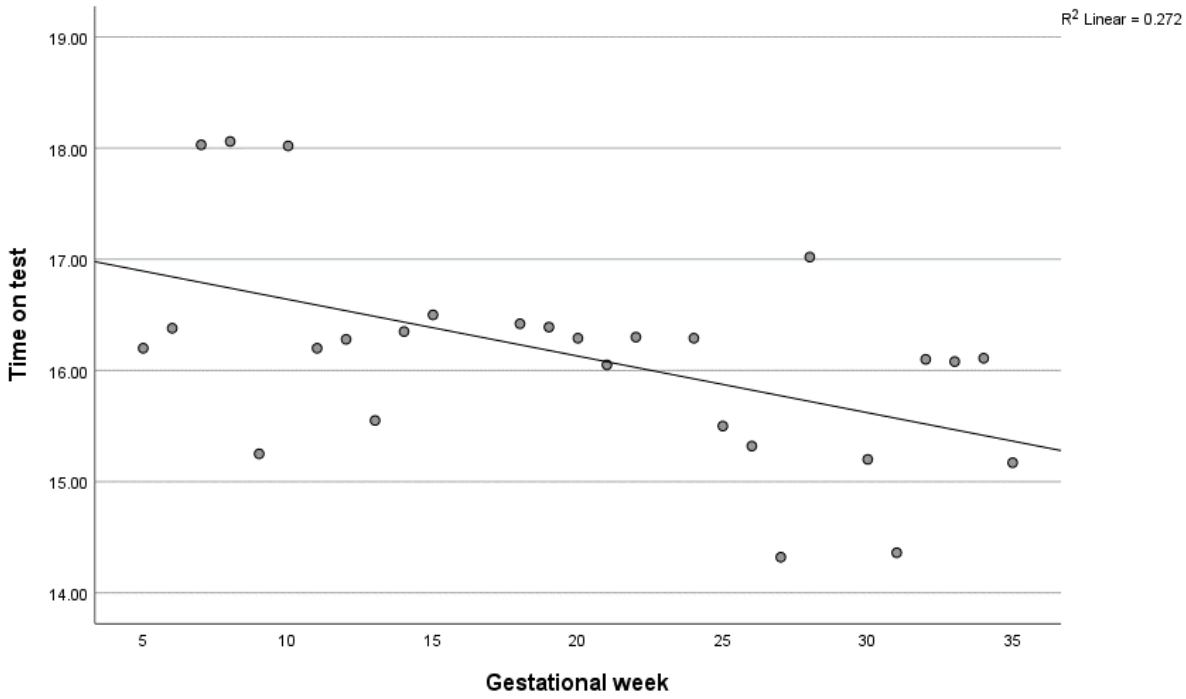



Figure 33. Time on test across gestation

### 4.3.6 Other measures assessing overall health

#### *4.3.6.1 Steps*

The average weekly number of steps decreased gradually during gestation (*Figure 34*). The non-pregnant participant's average weekly steps ranged from 8189 to 13955, averaging 10700 ± 1406 per week and showing no real trend over the 30 weeks (Figure 35).

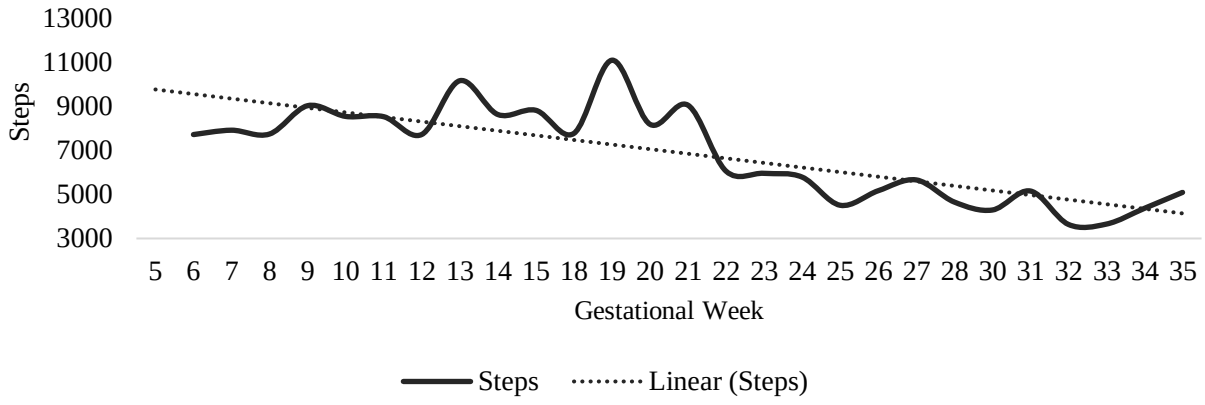



Figure 34. Pregnant participant's average daily steps across gestation

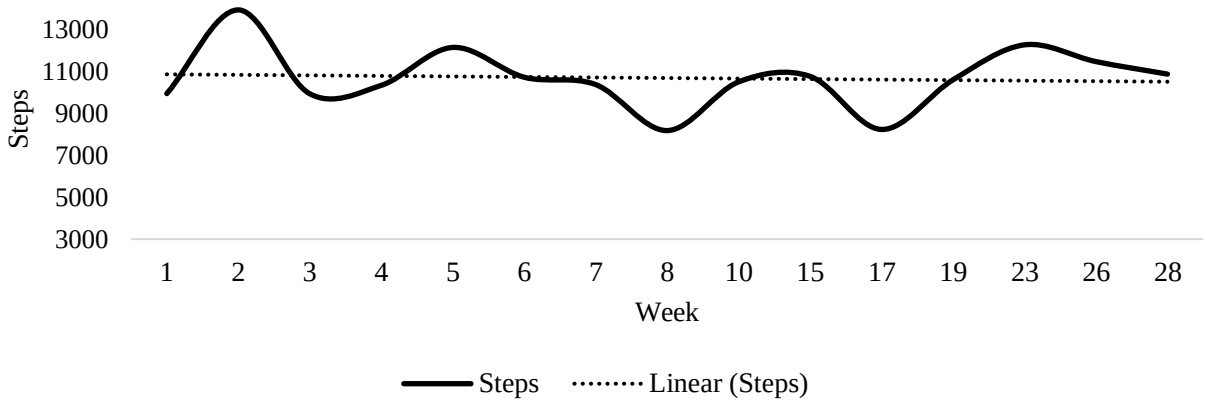



Figure 35. Non-pregnant participant's average daily steps

#### *4.3.6.2 Nutrition*

The dietary behaviours for the 24 hours prior to testing can be seen in *Table 25*. Both participant's diets varied week to week resulting in differences in each of the nutritional variables. The average 24-hour calories decreased from T1 to T2 (-279 ± 139 kcal) but increased again in T3 (+218 ± 109 kcal). 24-hour sodium levels were similar in T1 and T2 (-11 ± 6 mg), decreasing further in T3 (-146 ± 73 mg).

Table 25. Other health measures

| | **T1** | **T2** | **T3** | **NP** |
|---|---|---|---|---|
| **Steps (n)** | 8159 ± 525 | 7588 ± 2076 | 4560 ± 719 | 10700 ± 1406 |
| **Weight gain (kg)** | 1.4 | 3.1 | 5.6 | N/A |
| **Day prior to test** | | | | |
| ***Calories (kcal)*** | 2289 ± 354 | 2010 ± 442 | 2228 ± 327 | 1747 ± 148 |
| ***Sodium (mg)*** | 1647 ± 938 | 1636 ± 633 | 1490 ± 622 | 2288 ± 206 |
| ***Carbohydrates (g)*** | 227 ± 47 | 238 ± 49 | 256 ± 57 | 262 ± 38 |
| ***Fat (g)*** | 113 ± 34 | 76 ± 20 | 83 ± 23 | 64 ± 9 |
| ***Protein (g)*** | 86 ± 19 | 68 ± 28 | 77 ± 21 | 63 ± 12 |
| **AM of test** | | | | |
| ***Calories (kcal)*** | 545 ± 168 | 388 ± 167 | 409 ± 251 | 649 ± 598 |
| ***Sodium (mg)*** | 549 ± 513 | 248 ± 304 | 381 ± 395 | 649 ± 623 |

T1 = Trimester 1; T2 = Trimester 2; T3 = Trimester 3; NP = non-pregnant; kcal = calories; mg = milligrams; g = grams

#### *4.3.6.3 Weight*

*Figure 36.* shows the pregnant participant's weight across gestation. The pregnant participant gained 10.1 kilograms across gestation, with the largest increase in weight seen in T3 (5.6 kg) (*Table 25*).

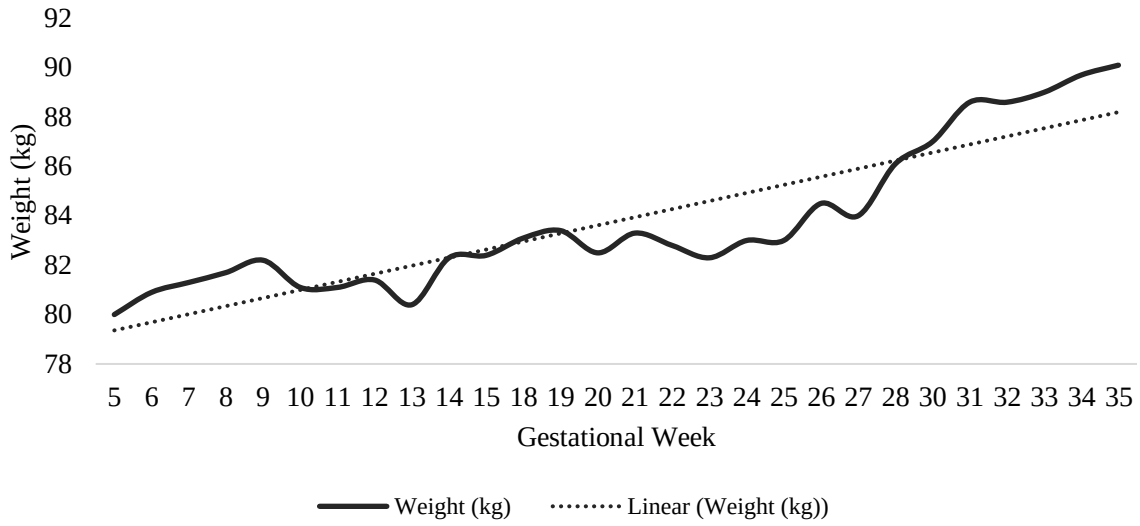



Figure 36. Pregnant participant's weight across gestation

## 4.4 Discussion

The aim of this study was to track the acute effects of a weekly submaximal graded exercise test on arterial stiffness and BP throughout pregnancy. The findings showed a gradual decrease in resting arterial stiffness throughout pregnancy, with an increase in PWV immediately following exercise seen in the first trimester only. Measures of BP also followed similar trends post exercise across pregnancy, increasing immediately post exercise and decreasing towards baseline levels 10 minutes following. HRR 1 minute post exercise appeared to be slower as gestation progressed, however by 2-3 minutes post exercise HRR responses were similar in all trimesters. Whilst the workloads remained consistent across gestation, the time on test for the pregnant participant decreased as gestation progressed and the acute exercise induced changes in PWV and BP decreased. The results of this study suggest that the ability of the body to respond to a stressful environment (i.e. submaximal exercise) may decrease as pregnancy progresses, however further research with larger sample sizes is required to corroborate this hypothesis.

Gestational week had a significant effect on the PWV response to exercise, with an acute increase in PWV seen immediately post exercise in T1, whilst a decrease was seen in T2 and T3. We hypothesised that PWV would increase immediately following submaximal exercise as seen in T1, however did not hypothesise that this response would decrease as gestation progressed. There is longitudinal data suggesting that maternal carotid distensibility and compliance decreases throughout gestation (10), which may play a role in the ability for the maternal body to adapt to "stress" or acute submaximal exercise. Vasodilation of the maternal vasculature begins from gestational week 5 and continues throughout pregnancy due to increased oestrogen biosynthesis (228, 229). This vasodilation results in a significant increase in blood flow to the uterus (20-50 fold) in the late stages of gestation (228). The results of our study report a change in PWV and BP from rest to immediately post exercise decreased from T1-T3 which aligns with this baseline increase in vasodilation. The maternal vessels at baseline in T2 and T3 are already more stressed (vasodilated), therefore they have a reduced capacity to respond to external stressors (exercise). Physiological changes with exercise are dependent on the efficacy of the intervention, but also on the amplitude for improvement (230). This indicates that a stimulus of vigorous intensity exercise may not elicit the same benefits to the cardiovascular system in the later stages of pregnancy, as it does in the first trimester. Further research on the acute responses to vigorous exercise across gestation is needed in a larger sample size, in order to assess whether the effect of exercising at higher intensities in T2 and T3 has an ameliorated cardiovascular superiority to moderate intensity exercise. This may have important implications for optimising exercise prescription and adherence in pregnancy.

The decrease in resting PWV from T1 through to T2 seen in the pregnant participant aligns with previous evidence (14, 58, 106, 108, 226). However, a slight increase in resting PWV into T3 is often reported (14, 58, 106, 108, 226) which was not seen in the current study. Increases in blood volume, nitric oxide (NO), relaxin and progesterone have previously been suggested as an explanation for the decrease in PWV in early pregnancy, however the mechanisms are not well understood (106). The processes driving the increase in PWV from mid-pregnancy to delivery are equally unknown, with an increase in cardiac output and circulatory volume, or an inhibition of NO suggested as potential mechanisms (58). PWV has also been associated with total peripheral resistance, which declines from gestational week five, and reaches a nadir between 20-32 weeks, before gradually increasing until full term (58, 227). The results seen in our study are consistent with those of one other study

comparing resting arterial function in pregnant and non-pregnant women (227). They observed 471 pregnant women throughout gestation and saw a decrease in resting PWV in the second and third trimesters, with an increase in PWV post-partum (227).

It has been suggested that continuing regular exercise throughout pregnancy may reduce or prevent the increase in PWV seen from T2-T3 due to the augmentation of peripheral vascular compliance and dilation (227, 231). One study investigating this however, found that an exercise intervention of thrice weekly, moderate intensity (50-70% HR reserve) aerobic exercise sessions in T2 and T3 had no effect on PWV in 59 pregnant women (exercising n = 31, control n = 28) (231). However, there is some evidence to show that regular exercise in pregnancy may reduce or prevent the increase in PWV often seen in mid-late pregnancy (106, 227, 231). In the current study the pregnant participant completed at least one bout of moderate-vigorous intensity exercise each week throughout gestation and completed at least 4560 ± 719 steps per day. She also reported completing at least x 30-minute walk, and 1 x 45 minute reformer Pilates session most weeks throughout pregnancy, suggesting reasonable levels of PA across a week. While average daily steps decreased as gestation progressed, we did not assess weekly activity volume or exercise intensity, which reportedly has an influence on peripheral and central PWV (106). One observational study of 39 women (21 non-pregnant, 18 pregnant) found a strong association between meeting the MVPA guidelines (150 min/week) and lower measures of both central and peripheral PWV (106). The association between gestational age and central PWV measures was reduced in pregnant participants who met the guidelines throughout gestation (106). This highlights that volume of exercise during pregnancy, may have an influence on resting PWV, and as such may explain the divergence in patterns from previous literature.

It is important to note however, that normal limits for PWV throughout pregnancy have not yet been established, with values for non-pregnant females often used as a surrogate measure (227). Based on the normal limits for PWV used in non-pregnant populations of $10 m.s^{-1}$, both the pregnant and non-pregnant participants resting values remained normal throughout the study (228). When women with normotensive, hypertensive and pre-eclamptic pregnancies were compared it was found that total arterial compliance and all measures of arterial stiffness were increased in the women with PE (cfPWV + $1.04 m.s^{-1}$) both during and after gestation (54). As such, PWV measurements have been identified as a promising predictive tool for gestational hypertensive conditions (232), however the lack of reference

values for PWV in pregnant populations limits the applicability of this measure within clinical practice (228). Further research on measures of arterial stiffness from pre-conception through to post-partum in larger groups is warranted, in order to establish pregnancy specific normal ranges and cut off values which may aid in the risk stratification of pregnant women (228).

In line with previous longitudinal studies, a curvilinear decrease in resting BP was seen in the pregnant participant, reaching a nadir in the second trimester before increasing back to pre-pregnancy values in the third trimester (231, 233). The BP responses immediately and 10 minutes post exercise followed this same trend of increasing with exercise, before decreasing by 10 minutes post exercise, which is consistent with literature in pregnant populations (13, 58, 234, 235). Physical activity (236) and sodium intake (237, 238) are factors known to influence BP in pregnancy. These responses in BP did not appear to differ with a change in daily step count, which decreased as gestation progressed, or with sodium intake 24 hours prior to exercise which fluctuated throughout pregnancy. As such, the expected changes in BP that occurred throughout pregnancy may be independent of the potential influence of PA and sodium intake.

In the current study resting HR increased as expected in the pregnant participant throughout gestation. During pregnancy, resting HR is known to increase progressively with gestation due to an increased demand of blood supply for the growing foetus (233). Despite this increase in resting HR, maximal exercising HR has been found to remain the same or decrease slightly, which research suggests may be due to a lower sympathoexcitatory response to exercise (233, 239). Due to limited evidence around the safety of maximal exercise in pregnancy, the pregnant participant was instructed to terminate exercise at 85% $HR_{max}$. What we can observe up until this point though, is that the workload associated with the 85%$HR_{max}$ (160 bpm) only decreased slightly throughout pregnancy (time on test decreased from 16.80 min in T1 to 15.55 min in T3) which may indicate resilience in tolerating these higher intensities of exercise, with only minor increases in RPE with increasing gestation. While a predicted $VO_{2max}$ is able to be used as an index of vagal reactivation, a predictor of mortality and a potential marker of cardiovascular fitness within some populations (240, 241), it was not calculated in this study due to the confounding influence of changing resting HR. However, HRR, which has also been shown as a reflection of decreased vagal activity and a powerful predictor of overall mortality independent of

workload (242) was calculated. In the current study, HRR at 1 minute post exercise appeared to reduce as gestation progressed (~10 bpm), which may indicate a decrease in cardiovascular fitness throughout pregnancy.

**Strengths and limitations**

The strengths of this study lie in the longitudinal design which allows for the comprehensive assessment of resting cardiovascular changes across gestation in a single participant. By tracking this participant over time, we gain valuable insights into the dynamic nature of pregnancy related alterations in arterial stiffness, and the acute responses to an exercise stress test with progressing gestation which provides novel and mechanistic information not previously reported. However, the case study design is one of the limitations of this study as the results are not indicative of the general pregnant population, therefore no strong conclusions can be drawn. It does however provide useful information in the generation of hypotheses within this novel area of research. Further, it demonstrates the safety and feasibility of a pregnant participant engaging in regular submaximal aerobic exercise throughout gestation. Evidence has indicated that the timing of post-exercise arterial stiffness measurements is critical to ensure accuracy of data. The logistical limitations of the current project only allowed us to reasonably observe the cardiovascular response 10-15 minutes post-exercise. Being able to monitor participants post exercise for 24 hours would provide further insight into the acute cardiovascular responses to submaximal exercise, given research indicates that there may be lasting effects on BP and arterial stiffness 24 hours post exercise.

Whilst 24-hour diet was recorded prior to each exercise session, it was not controlled which resulted in an inconsistent sodium intake across the weeks for both participants. It is well known that high sodium levels are associated with an increase in resting BP in non-pregnant populations (243), however the effects during pregnancy are not yet understood. It was not feasible within this study to provide a standardised meal, however collecting more information on the timing and contents of the participants' most recent meals would have strengthened the study. Additionally, after the first 8 sessions, it was not logistically possible for the control subject to attend weekly therefore fortnightly sessions were conducted. Due to Covid-19 restrictions that were put in place throughout the study, some weeks were missed for both the pregnant and non-pregnant participant. Ideally both the control subject

and pregnant participant would have attended weekly sessions over 30 weeks with no interruption, however this was impossible during this period of time.

**Conclusions**

The findings from this study lead us to speculate that the ability of the maternal cardiovascular system to adapt to submaximal exercise may decrease as gestation progresses. It is important to observe the effects of exercise in each trimester of pregnancy to identify if there are more adaptive stages in pregnancy that may optimise vascular function. Further longitudinal research is needed on the effects of different modes and intensities of exercise on arterial stiffness in larger sample sizes, given the association between increased arterial stiffness in early pregnancy and gestational complications.

# Chapter 5. The effects of a submaximal graded exercise test on mean arterial pressure in pregnancy: A cross-sectional analysis

## Abstract

### Introduction

Pregnancy is often described as a 9-month stress test for the mother, resulting in progressive adaptations of the cardiovascular system from early gestation through to delivery. Research indicates that an increase in heart rate (HR), blood pressure (BP) and mean arterial pressure (MAP) and a decrease in vascular resistance are a natural response to acute aerobic exercise bouts. However, the majority of research conducted on the acute cardiovascular response to exercise has utilised light-moderate intensity, with limited studies observing acute BP or MAP responses following vigorous-high intensity exercise. The aim of this study is to observe the effects of a submaximal graded exercise (vigorous intensity) test during pregnancy on measures of vascular function including MAP and arterial stiffness.

### Methods

A total of 34 pregnant women completed a submaximal graded exercise test following the Cornell protocol. Resting measures included HR, BP, MAP, PWV and foetal heart rate (FHR). During exercise, HR and RPE were taken every minute. Exercising BP was taken at the end of each 2-minute stage. All outcome measures were taken immediately following exercise, and then again 10-15 minutes post exercise in the semi-recumbent position. A linear regression analysis was conducted to examine the relationship between the change in MAP following the exercise test, and gestational week, age, pre-pregnancy body mass index (BMI), time on test and percentage of age predicted maximum heart rate (%$HR_{max}$).

### Results

Thirty-four women (32.5 ± 3.6 years, GW = 19.4 ± 7.1 weeks) completed the exercise test, 23 of which successfully reached 85% of their age predicted heart rate maximum ($PHR_{max}$) (range: 74-86% $HR_{max}$). On average it took until the fifth-sixth stage of the test for the participants to reach 70% $HR_{max}$, with participants reaching 85% $HR_{max}$ by the sixth (n = 7), seventh (n = 13), eighth (n = 8) and ninth stages (n = 6). A significant association between the change in MAP from resting to immediately post exercise, time on test ($\beta = 0.416$, $p = 0.01$) and %$HR_{max}$ ($\beta = 0.448$, $p < 0.01$) was found ($R^2 = 0.335$, $p = 0.006$). There was a significant association between the change in MAP immediately post exercise to 10 minutes post exercise and %$HR_{max}$ ($\beta = -0.459$, $p = 0.10$). There were varied responses in central PWV immediately and 10 minutes post exercise. There were no adverse responses in FHR

to exercise (range 135-160 bpm). Average FHR did not appear to change in response to exercise.

**Conclusion**

Based on the findings from this study, it is suggested that the maternal body is able to adapt to stressful stimuli, with the cardiovascular system recovering quickly (within 10 minutes) following vigorous intensity exercise. Further research in pregnancy is warranted on the acute effects of vigorous exercise on arterial stiffness given the varied responses seen in this study Further research is needed on the feasibility and efficacy of vigorous intensity exercise during pregnancy. The acute cardiovascular effects to this intensity of exercise should be measured longitudinally to observe whether maternal and foetal responses to exercise do indeed change across gestation.

## 5.1 Introduction

Pregnancy is often described as a 9-month stress test for the mother, resulting in progressive adaptations of the cardiovascular system from early gestation through to delivery (223). Notable cardiovascular changes include an increase in HR, stroke volume (SV) and cardiac output (CO) (223, 244, 245). The structure and function of arteries are altered through remodelling to accommodate the increased blood volume and subsequent cardiac output, and to ensure that BP remains within normal values throughout pregnancy (10, 12, 13). While it is well documented that the cardiovascular system undergoes these significant adaptations longitudinally across gestation, it remains unclear whether these gestational changes influence acute responses to vigorous-intensity exercise. The inclusion of vigorous intensity exercise in recent physical activity guidelines for pregnancy (68) highlights the need to better understand the acute cardiovascular responses associated with this level of exertion. The systematic review in Chapter 3. The effects of aerobic and resistance exercise on blood pressure in uncomplicated and at risk pregnancies: A systematic review and meta-analysis identified that the majority of research conducted on the acute cardiovascular response to exercise has utilised light-moderate intensity, with limited studies observing acute BP or MAP responses following vigorous-high intensity exercise available (72, 194, 204, 208). This knowledge gap is critical, as better understanding these interactions can provide further insight into the safety and efficacy of higher intensity exercise during pregnancy.

Research indicates that an increase in HR, BP, MAP, SV and a decrease in vascular resistance are a natural response to acute aerobic exercise bouts (223). Adaptation to graded exercise involves a coordinated response of central and peripheral factors that work together to elevate MAP and direct blood flow to the working muscles (246). The regulation of MAP during exercise is therefore of considerable physiological and clinical importance (246). It has been proposed that the vasodilation occurring during pregnancy may attenuate changes in diastolic blood pressure (DBP) during exercise (249), thereby influencing changes in MAP. Additionally, as the degree of resting vascular resistance decreases throughout pregnancy, it seems reasonable to suggest that the ability of exercise to support these acute vascular responses will vary across gestation.

Regular aerobic exercise in pregnancy has been shown to have a positive effect on endothelial function. This is due in part to the upregulation of vasoactive substances such as nitric oxide (NO) to accommodate increased blood flow to the working muscles (157, 247). Given these changes are similar to the haemodynamic alterations that are already occurring naturally in pregnancy at rest, the ability of the maternal cardiovascular system to adapt to the additional biological stress incurred by acute bouts of exercise may be an important indicator of health (207). Indeed, the acute cardiovascular stress that occurs with exercise may unmask subclinical cardiovascular conditions that may otherwise have gone unnoticed at rest (244, 245). As such, performing a graded exercise stress test during pregnancy may highlight impaired endothelial response to increased stress. Impaired endothelial function is a known risk factor for future cardiovascular conditions such as gestational hypertension (GHTN) and pre-eclampsia (PE), so identifying this as early as possible is important for optimising health outcomes through early treatment.

The aim of this study is to observe the effects of a submaximal graded exercise (vigorous intensity) test during pregnancy on measures of vascular function including MAP and arterial stiffness. It is hypothesised that there will be an immediate increase in BP and PWV following an acute bout of submaximal exercise during pregnancy.

## 5.2 Methods

### 5.2.1 Ethical approval

This study protocol was approved by the Australian Catholic University Human Research Ethics Committee (ACU HREC), ethics register number: 2020-103H. All participants provided written informed consent prior to participation in the study.

### 5.2.2 Study participants

A total of 34 pregnant women completed a submaximal graded exercise test at the Exercise Lifestyle Clinic at the Australian Catholic University (ACU), Brisbane, Australia. Participants were recruited via social media advertisements, flyers placed around the ACU campus, as well as through Pear Exercise Physiology clinic (Brisbane, Australia). Participants were aged between 18-40 years and were non-smokers. This study is a baseline sub-analysis of three longitudinal studies. As such, the gestational age at the time of baseline testing varies from 5 weeks through to 33-weeks gestation. Gestational age was calculated

based on a 40- week due date. Normotensive women with a history of Type 1 diabetes or gestational diabetes (GDM), GHTN and PE in previous pregnancies were accepted into the study.

### 5.2.3 Study protocol

Prior to enrolment participants were asked to complete a pregnancy specific pre-exercise screening form (124). Once enrolled in the study participants were then asked to complete a short questionnaire to obtain data on pre-pregnancy weight, age, gestational age, parity, education, marital status and current level of PA (self-reported estimated daily steps). Medical clearance was also obtained for each participant by their GP, OBGYN or midwife via the PARmed-X for pregnancy (2015), which is a screening tool provided by the Canadian Society for Exercise Physiology (Appendix 4). All participants reported for testing in a fed state following 24 hours of no strenuous activity.

### 5.2.4 Submaximal exercise test

All participants completed the submaximal graded exercise test following the Cornell protocol, which has previously been used with pregnant populations (135, 136). The speed and grade of the treadmill were adjusted every two minutes, with participants walking until either a rating of perceived exertion (RPE) of 18 (Borg 6-20 scale) or 85% of their $PHR_{max}$ was reached, or if the participant asked to terminate the test. $PHR_{max}$ was calculated by the formula 220 - age (248). Upon completion of the test participants were asked to lay in a semi-recumbent position for 10 minutes to allow for post exercise measures to be taken.

### 5.2.5 Outcome measures

Upon arrival at the clinic participants were asked to lay in a semi-recumbent position (~15 degree incline) for 5 minutes prior to collection of the resting measures. Resting measures included HR, peripheral BP, pulse wave analysis (PWA), pulse wave velocity (PWV) and FHR for those ≥ 12 weeks of gestation (FHR). During exercise, HR and RPE were taken every minute. Exercising BP was taken manually at the end of each 2-minute stage using a standing aneroid sphygmomanometer and a stethoscope. All outcome measures were taken immediately following exercise once the participants had laid back down on the plinth, and then again 10-15 minutes post exercise in the semi-recumbent position.

PWA, PWV and peripheral BP were assessed using the semi-automatic device and software SphygmoCor Xcel. Exercising brachial BP was measured manually using a standing aneroid sphygmomanometer and a stethoscope. Arterial stiffness was measured using carotid-femoral PWV (cfPWV). This was measured through applanation tonometry at the carotid artery and cuff based detection of the pulse at the femoral artery with the semi-automatic device and software SphygmoCor Xcel. PWA was performed with the same device, with an arm cuff capturing a peripheral waveform. Central BP and MAP were then estimated from this waveform.

HR was measured using photoplethysmography with a chest strap connected via Bluetooth to a phone application (Wahoo TICKR). Heart rate recovery (HRR) was observed by recording post exercise heart rate every minute for 3 minutes following exercise. FHR was measured using a basic 2Mhz foetal doppler (Edan Sonotrax) at rest and again immediately post and 10 min post-exercise in the semi-recumbent position. FHR was considered normal between 110-160 bpm.

### 5.2.6 Statistical analysis

A linear regression analysis was conducted to examine the relationship between the change in MAP following the exercise test, and gestational week, age, pre-pregnancy body mass index (BMI), time on test and percentage of maximum heart rate (%$HR_{max}$). A *P* value of < 0.05 was considered significant. Statistical analyses were performed using IBM SPSS version 29. The power analysis found the achieved sample size of 34 provided insufficient statistical power to detect observed effects in post exercise central PWV (G*Power 3.1.9.6, Düsseldorf) (249). As such we have observed the trends in PWV, however have not reported on any statistical significance.

## 5.3 Results

A total of 34 women (32.5 ± 3.6 years, GW = 19.4 ± 7.1 weeks, pre-pregnancy BMI = 24.7 ± 3.3 kg/$m^2$) were enrolled in the study. The baseline demographics for the participants can be seen in *Table 26*.

### 5.3.1 Exercise intensity

Of the 34 participants, 23 successfully reached 85% of their $PHR_{max}$ before the test was terminated. Seven of the participants asked to terminate the test prior to reaching 85% $PHR_{max}$ due to fatigue. All seven of these participants reported an RPE of 18/20 prior to termination. Four participants reached a stage in the test in which they were unable to maintain the speed without running prior to their HR reaching 85% of their $PHR_{max}$ and so requested to stop. The range of $\%HR_{max}$ achieved for all participants was 74-86%, therefore all tests were considered to be of vigorous intensity (6- < 9 METs, 70 < 90% $HR_{max}$, RPE 14-16) (115). All participants were included in the analysis, as predicted HR is not a true maximum HR, and the test used in this case was a peak test rather than a maximal test. On average it took until the fifth-sixth stage of the test for the participants to reach 70% $PHR_{max}$, with participants reaching 85% $PHR_{max}$ by the sixth (n = 7), seventh (n = 13), eighth (n = 8) and ninth stages (n = 6). Participants spent 2-8 minutes exercising at a vigorous intensity. *Table 27* shows the average intensity reached and the peak cardiovascular outcomes measured during the Cornell test.

Table 26. Participant characteristics at baseline

| **Total n = 34** | | | |
|---|---|---|---|
| **Age (years)** | 32.5 ± 3.6 | **Education** | |
| **Gestational week** | 19.4 ± 7.1 | *Graduate diploma/ Graduate certificate* | 5 |
| **Height (cm)** | 167.8 ± 5.9 | *Advanced Diploma* | 4 |
| **Pre-pregnancy weight (kg)** | 69.8 ± 11.5 | *Bachelor* | 13 |
| **Pre-pregnancy BMI ($kg/m^2$)** | 24.7 ± 3.3 | *Masters* | 8 |
| **Ethnicity** | | *PhD* | 2 |
| *Caucasian* | 31 | *M.D* | 2 |
| *Asian* | 2 | **Employment status** | |
| *Hispanic* | 1 | *Part-time* | 5 |
| **Parity** | | *Full-time* | 27 |
| *0* | 21 | *Self-employed* | 2 |
| *1* | 10 | **Average reported daily steps** | |
| *2* | 3 | *<5k* | 5 |
| **Gravidity** | | *5-10k* | 27 |
| *1* | 18 | *10-15k* | 2 |
| *2* | 8 | **History of HTN** | 0 |
| *3* | 6 | **Family History of HTN** | 10 |

| | | | | |
|---|---|---|---|---|
| | *4* | 1 | **Diagnosed conditions in current pregnancy** | 0 |
| | *6* | 1 | **Diagnosed conditions in any previous pregnancies** | |
| **Singleton** | 31 | | *GDM* | 3 |
| **Twins** | 3 | | *GHTN* | 1 |

kg = kilograms; BMI = body mass index; kg/m$^2$ = kilograms per meter squared; cm = centimetres; M.D = Doctor of Medicine; k = thousand; HTN = hypertension; GDM = gestational diabetes mellitus; GHTN = gestational hypertension

Table 27. Exercise intensity achieved during the Cornell test

| | ***Mean ± SD*** | ***Range*** |
|---|---|---|
| **PHR (bpm)** | 157 ± 6.3 | 135-166 |
| **%HR$_{max}$ (%)** | 83.77 ± 3.01 | 74-86 |
| **Peak METs** | 10.82 ± 1.67 | 8.6-13.6 |
| **Peak RPE** | 16.59 ± 1.46 | 14-19 |
| **Peak SBP (mmHg)** | 144 ± 13.18 | 128-190 |
| **Peak DBP (mmHg)** | 59 ± 6.25 | 44-78 |
| **Peak MAP (mmHg)** | 70.24 ± 12.03 | 41-112 |

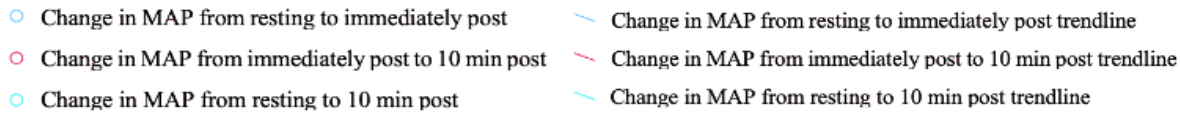
PHR = peak heart rate; bpm = beats per minute; %HR$_{max}$ = % of heart rate maximum; peak METs = peak metabolic equivalents; peak RPE = peak rating of perceived exertion; peak SBP = peak systolic blood pressure; peak DBP = peak diastolic blood pressure; peak MAP = peak mean arterial pressure

### 5.3.2 Mean arterial pressure

A significant association between the change in MAP from *resting* to *immediately post exercise*, %HR$_{max}$ ($\beta = 0.448$, $p < 0.01$, 95%CI [0.39-2.22]) (*Figure 37*) and time on test ($\beta = 0.416$, $p = 0.01$) (*Figure 38*) was found ($R^2 = 0.335$, $p = 0.006$). The association between gestational week and change in MAP from resting to immediately post exercise was non-significant ($\beta = 0.264$, $p = 0.09$). These findings suggest that participants who spent more time on the test, and who reached a higher percentage of their age PHR$_{max}$ had a greater acute response in MAP. It seems that gestational week may positively influence the strength of this association, although it is not statistically significantly.

There was a significant association between the change in MAP *immediately post exercise* to *10 minutes post exercise* and %HR$_{max}$ ($\beta = -0.459$, $p = 0.10$), with time on test ($\beta = -0.325$, $p = 0.06$) approaching statistical significance, and no significant association with gestational week ($\beta = -0.221$, $p = 0.19$). There were no significant associations found between the change in MAP from *resting* to *10 minutes post exercise*, time on test ($\beta = 0.34$, $p = 0.86$), %HR$_{max}$ ($\beta = -0.014$, $p = 0.94$) and gestational week ($\beta = 0.144$, $p = 0.46$). These findings indicate that BP returns to baseline levels by 10 minutes post exercise despite vast

differences in the time spent exercising (10.47-17.01 minutes) and the intensity of exercise (74-86% $HR_{max}$).



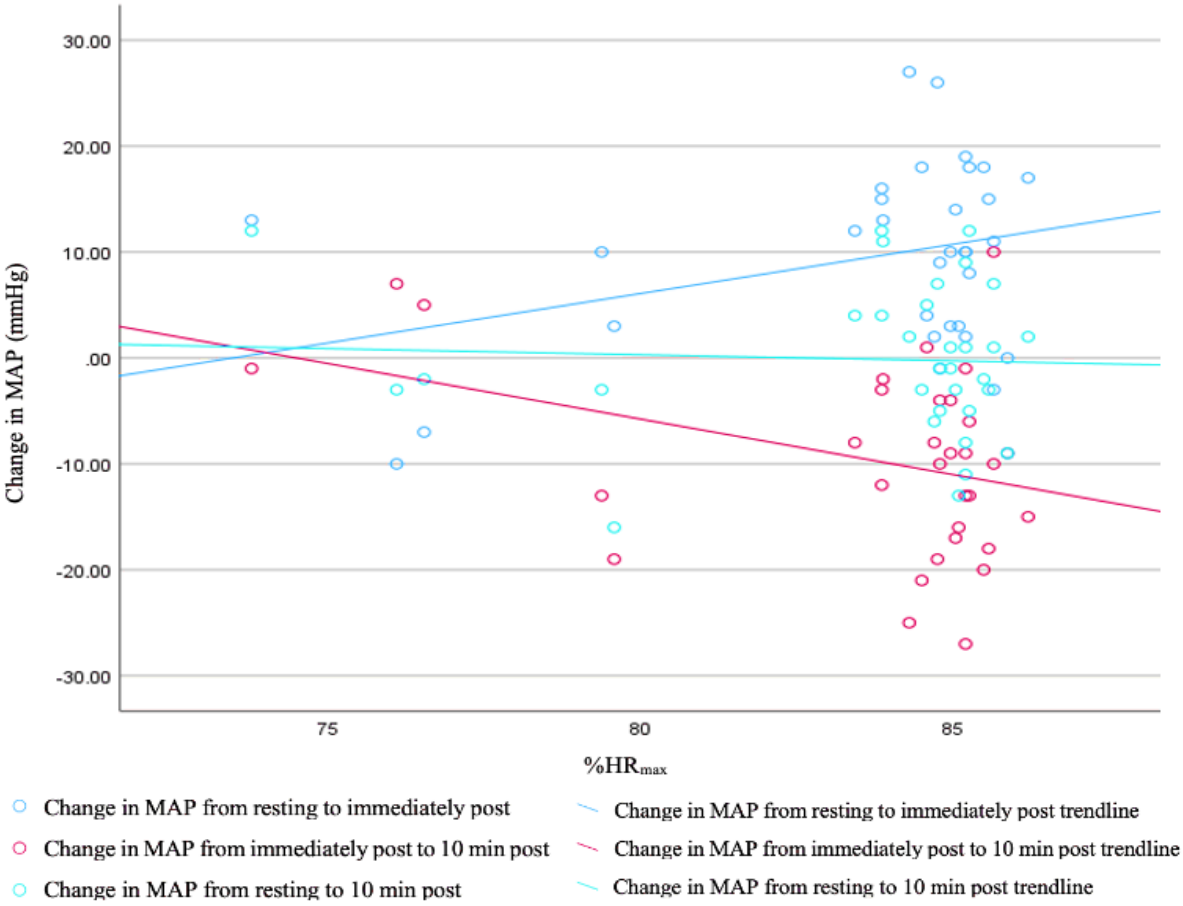



Figure 37. Association between the change in MAP between each time point and the $\%HR_{max}$ reached

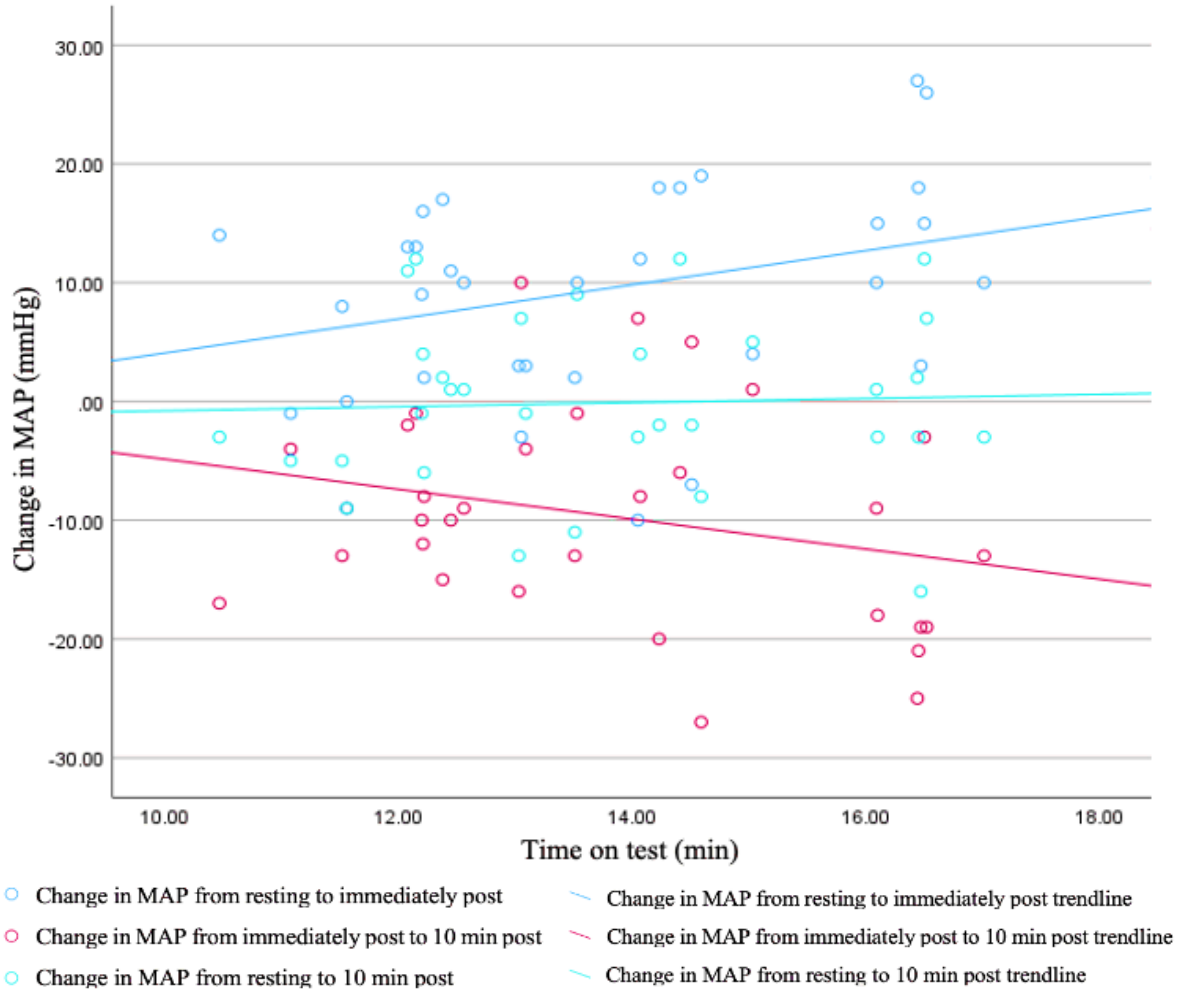



Figure 38. Association between the change in MAP between each time point and the time spent on the test

Table 28. Haemodynamic responses to the Cornell test

| | Resting | Immediately post | 10 min post |
|---|---|---|---|
| **HR (bpm)** | 75 ± 9.2 | 100 ± 15.6 | 86 ± 8.9 |
| **PWV (m.s$^{-1}$)** | 5.39 ± 0.67 | 5.59 ± 0.82 | 5.60 ± 0.80 |
| **ASBP (mmHg)** | 103 ± 8 | 115 ± 10.6 | 99 ± 7.6 |
| **ADBP (mmHg)** | 71 ± 7.2 | 77 ± 8.6 | 72 ± 6.6 |
| **PSBP (mmHg)** | 117 ± 9.6 | 133 ± 14.1 | 112 ± 9.1 |
| **PDBP (mmHg)** | 69 ± 7.3 | 75 ± 8.3 | 70 ± 6.4 |
| **AMAP (mmHg)** | 85 ± 7.5 | 95 ± 9.5 | 84 ± 7 |
| **FHR (bpm)** | 148 ± 6.7 | 148 ± 6.8 | 147 ± 7.3 |

HR = heart rate; bpm = beats per minute; PWV = pulse wave velocity; m.s$^{-1}$ = metres per second; ASBP = aortic systolic blood pressure; ADBP = aortic diastolic blood pressure; PSBP = peripheral systolic blood pressure; PDBP = peripheral diastolic blood pressure; AMAP = aortic mean arterial pressure; mmHg = millimetres of mercury; FHR = foetal heart rate

### 5.3.3 Haemodynamic responses

Average PWV increased slightly immediately following exercise, with this increase sustained 10 minutes post exercise (*Table 28*). The PWV response varied across participants (range = -0.65-2.35 $m.s^{1}$) and was not associated with GW (*Figure 39*). Average central/aortic (ASBP and ADBP) and peripheral BP (PSBP and PDBP) increased from resting to immediately post exercise, then decreased towards or below baseline levels by 10 minutes post exercise.

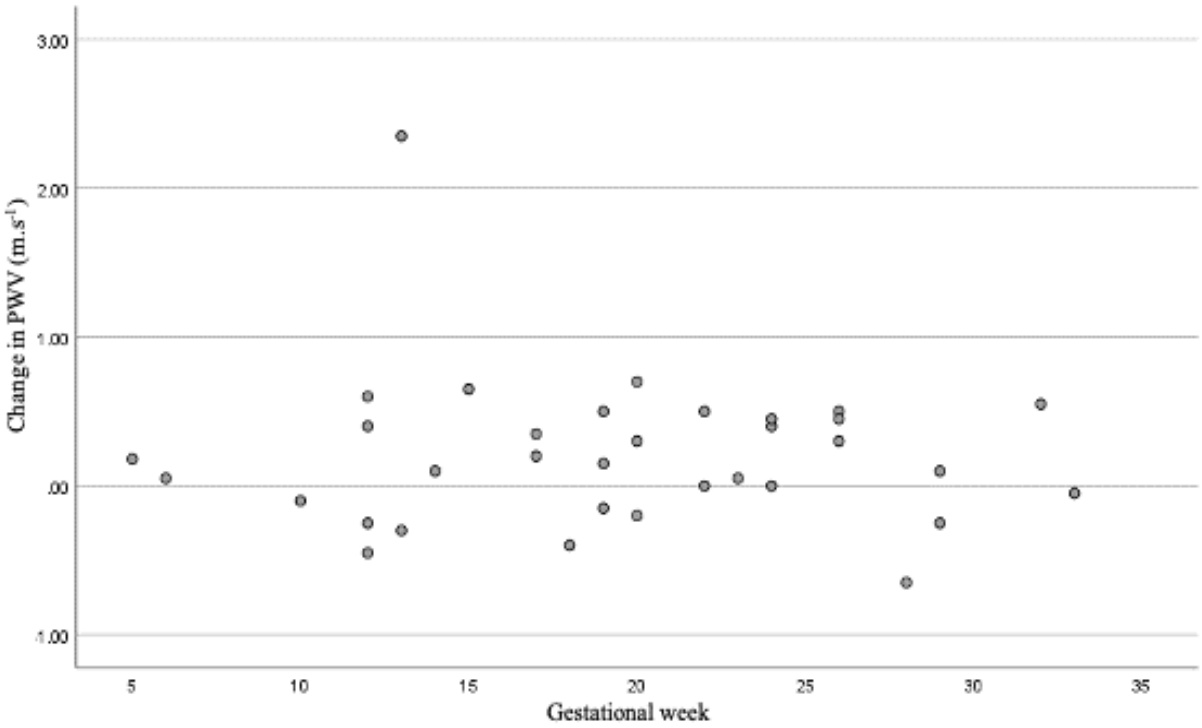



Figure 39. Association between acute change in PWV and gestational week

### 5.3.4 Foetal heart rate

There were no adverse responses in FHR to exercise (range 135-160bpm). Average FHR did not appear to change in response to exercise.

## 5.4 Discussion

The aim of this study was to observe the effects of a submaximal graded exercise test during pregnancy on measures of vascular function including MAP. The results show that participants who were able to achieve a higher $\%HR_{max}$ and a longer time on test saw greater increases in MAP from resting to immediately post exercise, and decreases from immediately post exercise to 10 minutes post exercise. These findings indicate that the intensity of exercise may play an important role in eliciting acute vascular adaptations, and

therefore the potential optimisation of vasculature health during pregnancy with repeated exercise bouts. In addition, the results from this study showed that maternal MAP recovered quickly (within 10 minutes) back to baseline levels. This highlights that even at higher intensities of exercise the maternal body is able to recover quickly post exercise. Our study demonstrated varied central PWV responses following exercise. On average, PWV increased post-exercise, however, some participants exhibited a decrease in PWV. These findings may suggest a potential disconnect between maternal cardiovascular adaptations and arterial stiffness. The underlying mechanisms driving these differential responses remain unclear and warrant further investigation.

The findings from the current study demonstrate that an acute bout of vigorous intensity exercise may provide enough stimulus to elicit cardiovascular adaptations that may be beneficial when performed repeatedly throughout pregnancy. It appears that gestational week may influence the strength of this association, although this finding was not statistically significant therefore further research is warranted to investigate this relationship. Adapting to graded exercise involves a complex response in central and peripheral factors that work together to increase MAP and increase/direct blood flow to the working muscles (246). The regulation of MAP during exercise therefore holds significant physiological and clinical importance (246). It has been suggested that the vasodilation that occurs in pregnancy may mitigate changes in DBP with exercise (250), thereby effecting the change in MAP. Peripheral vasodilation allows for a progressive decrease in total peripheral resistance (TPR), despite an increase in cardiac output as gestation advances (10). An increase in shear stress in pregnancy has been associated with maternal arterial diameter (10, 251). The largest increases in vessel diameter have been seen in the third trimester (10, 252) with even small changes resulting in increased aortic compliance (10). Therefore, it is reasonable to speculate that the acute response in MAP and BP to exercise will change across gestation, given the capacity of the vessels to respond to exercise is likely altered with this decrease in TPR and increase in arterial compliance. There is currently a lack of evidence on the acute cardiovascular responses to vigorous exercise across pregnancy, therefore longitudinal research on this is warranted.

There is a lack of evidence available on the acute responses in central and peripheral PWV following exercise in pregnancy, with no normative ranges available. One systematic review published investigating acute responses in non-pregnant populations found that central PWV

increases immediately after exercise (0-14 minutes), then decreases within 30 minutes post-exercise (100). Conversely, peripheral PWV decreases immediately post exercise (0-14 minutes), increasing towards baseline levels 30 minutes post (100). Whilst on average the central PWV in our study increased immediately and 10 minutes post-exercise, in 12 participants we saw either no change or a decrease in PWV immediately post-exercise. PWV and BP are considered to be closely related, with some suggesting that the acute changes in PWV with exercise may be mediated by the acute effects on BP (100). There appears to be a disconnect between the PWV responses in our study and the cardiovascular responses immediately and 10 minutes post exercise, with increases in all measures of BP and HR seen immediately post exercise, decreasing towards baseline by 10 minutes post. In non-pregnant populations the relationship between BP and PWV does appear to be stronger in the peripheries, potentially due to the elasticity of large arteries which decreases gradually towards the periphery (100). The mechanisms through which these changes occur are not fully understood, however it has been suggested that the differing responses between central and peripheral PWV may be a consequence of the elastin/collagen ratio which decreases towards the periphery, and endothelium-derived hyperpolarising factor (100). Further investigation is warranted into any predictors of acute change in central PWV following bouts of exercise in pregnant women, however a larger sample size would be required to ensure the study is adequately powered.

Cardiopulmonary exercise testing during pregnancy is a valuable tool in identifying potential underlying cardiopulmonary conditions and establishing exercise tolerance (72). As exercise mirrors a state of systemic metabolic stress, it has the potential to unveil abnormal functions that might otherwise have gone unnoticed during resting measures alone (245). Abnormal responses in recovery post submaximal exercise may also indicate cardiovascular dysfunction (244, 253). Normative values for healthy responses to cardiopulmonary exercise testing in pregnancy have not been established, with further large-scale, longitudinal intervention studies needed to identify what constitutes an abnormal or adverse response (244). As such, we cannot comment on whether the central PWV responses in this study are considered ‘normal’. Future studies should look into the predictive abilities of the chronotropic response to exercise testing in pregnancy in identifying potential CV dysfunction.

***Strengths and limitations***

This study contributes valuable insights into the haemodynamic responses to submaximal exercise throughout gestation (135). However, the majority of participants enrolled in the second trimester, precluding a comprehensive analysis across the entirety of gestation. The wide range of gestational weeks included in the study allowed us to see whether there were any associations between the GW and changes in cardiovascular measures. This study was however underpowered, making it difficult to draw any meaningful conclusions on the acute responses in PWV to a submaximal exercise test in pregnancy. As such, further research with a larger sample size is warranted. The analysis was confined to measurements taken in the 10 minutes post-exercise, limiting the observation window for physiological responses. This may overlook important changes that occur beyond the immediate to 10-minute post-exercise period. The PA assessment was also only assessed through self-report of daily average steps. A more comprehensive analysis of PA would have provided important information regarding the participant cohort. It seems reasonable to assume that women interested in enrolling in these longitudinal exercise studies in pregnancy are highly motivated to exercise and are therefore not likely representative of the general pregnant population.

***Conclusions***

Based on the findings from this study, it is suggested that the maternal body is able to adapt to stressful stimuli, with the cardiovascular system recovering quickly (within 10 minutes) following vigorous intensity exercise. Further research in pregnancy is warranted on the acute effects of vigorous exercise on arterial stiffness given the varied responses seen in this study. Additionally, further research examining the feasibility and efficacy of vigorous intensity exercise during pregnancy is warranted, given the little evidence available. The acute cardiovascular effects to this intensity of exercise should be measured longitudinally to observe whether maternal and foetal responses to exercise do indeed change across gestation.

# Chapter 6. Feasibility and efficacy of completing vigorous intensity interval training, resistance training and reformer Pilates during pregnancy: a pilot observational study

## Abstract

### Introduction

It is well established that regular exercise throughout pregnancy provides significant benefits to both maternal and foetal health outcomes. Despite the known benefits, it has been shown that weekly physical activity intensity and frequency decrease as pregnancy progresses, along with an increase in sedentary behaviour. One of the main barriers reported is lack of knowledge around what modes of exercise are appropriate in pregnancy. There is currently no research comparing the acute effects of aerobic, resistance or Pilates exercise during pregnancy, with very limited research on the effects of any exercise on measures of arterial stiffness throughout pregnancy. The aim of this study was to investigate the feasibility of performing three different popular exercise modalities (vigorous intensity interval training (VIIT), resistance (RT) and reformer Pilates (PIL)) and observe the acute cardiovascular effects of each type of exercise during the second and third trimesters of pregnancy.

### Methods

Eleven pregnant women were recruited in the second and third trimesters of pregnancy to participate. Participants were: 18-40 years, non-smokers, gestational weeks (GW) 13-32 with no absolute contraindications to exercise. Baseline submaximal graded exercise testing (Cornell protocol) was performed upon enrolment. Participants then performed three bouts of exercise (VIIT, RT, PIL) across three weeks in that trimester. Those who enrolled in trimester two (T2) also performed the three bouts in the third trimester (T3). The primary outcome measure was the feasibility of each modality of exercise. Secondary outcome measures included pulse wave velocity (PWV), blood pressure (BP), mean arterial pressure (MAP) and foetal heart rate (FHR). Resting measures were taken after 5 min of semi-recumbent rest and again immediately (1-5 minutes) and 10-15 minutes post exercise. Heart rate (HR), BP and RPE were monitored throughout exercise. Participants completed post-delivery questionnaires to determine maternal and foetal birth outcomes, and enjoyment/motivation related to each type of exercise.

### Results

Eleven women (age 32 ± 3 years, BMI 24 ± 3.4 kg.m$^2$, GW 22 ± 5) were recruited in T2 and T3. The desired intensities for each stage of the VIIT protocol were maintained in T2 and T3 based on RPE and $\%HR_{max}$. Average RPE for the vigorous intensity bouts was higher in T3 than T2, despite $\%HR_{max}$ remaining consistent across trimesters. The VIIT sessions were

ranked the least enjoyable out of the 3 modalities (6/10 ± 2, range 3-9/10), with only one out of eleven participants listing VIIT as their first preference for exercise modality. There were no adverse responses in FHR with any modality.

**Conclusions**

VIIT, RT and PIL appear to be feasible in both T2 and T3 of uncomplicated pregnancy. However, VIIT appears to be the least enjoyable mode of exercise, compared to resistance training and Pilates. Acute maternal and foetal cardiovascular responses to VIIT, RT and PIL appear similar in T2 and T3 of pregnancy. The reduced motivation for vigorous intensity aerobic exercise provides important insights for optimising physical activity adherence when prescribing a balanced exercise program. Additional research on the longitudinal effects of these exercise modalities is warranted to determine whether the cardiovascular response to exercise changes across gestation.

## 6.1 Introduction

It is well established that regular exercise throughout pregnancy provides significant benefits to both maternal and foetal health outcomes (72, 73). Despite these known benefits, data have shown that only 30% of pregnant women meet the minimum recommended amount of moderate to vigorous physical activity (MVPA) (73). Most current international guidelines, including from Australia, recommend that women with healthy pregnancies perform at least 150 minutes of MVPA each week, through a combination of aerobic and resistance exercises (73, 77). The main barriers reported for exercise during pregnancy include fatigue, lack of time, pregnancy discomforts as well as lack of knowledge and concerns around the perceived safety of certain types and intensities of exercise for the baby and mother (118, 119). Identifying safe and effective modalities of exercise for pregnant women which may increase their adherence to PA guidelines is of paramount importance.

One of the main fears surrounding exercise in pregnancy, is the reduction of blood flow to the foetus with increasing exercise intensities. Vigorous to high intensity exercise has historically been advised against during pregnancy due to these concerns (74). However, high intensity interval training (HIIT) ($\geq$ 85% $HR_{max}$) (115) has become increasingly popular over the past decade (254, 255), with a growing body of research indicating that exercising up to 90% of $HR_{max}$ appears safe for the mother and foetus in most healthy pregnancies (80). HIIT shows greater improvements in cardiorespiratory fitness ($VO_{2peak}$), when isocalorically matched to moderate intensity continuous training (MICT) (55-70% $HR_{max}$ (115)) in young to middle aged adults (256), with both modes producing similar improvements in body composition in overweight and obese non-pregnant populations (257), yet requires 40% less time commitment (72). The restrictions surrounding higher intensities of exercise, have been removed from many international guidelines, with countries including Australia (73), Brazil (258) and Spain (259) now including vigorous intensity physical activity/exercise within their recommendations (77).

As such, we are currently in a phase of exercise and pregnancy research marked by growing interest in exploring the feasibility, safety and effectiveness of higher-intensity exercise during pregnancy, with a few recent studies examining the acute maternal and foetal responses to HIIT (72, 78, 112, 113). A systematic review of 12 studies found that the HIIT protocols used in pregnant populations varied substantially in terms of frequency, intensity

(60% $VO_{2max}$ – self-reported maximum), type and duration, resulting in different exercise stimuli in the groups studied (113). The authors highlighted that despite this, HIIT programs were considered safe, and were well tolerated by pregnant participants regardless of the session structure (113). It should be noted that whilst some studies report HIIT, the intensities sometimes prescribed actually fall within vigorous intensity (6-9 METs, 70-90% $HR_{max}$, rating of perceived exertion (RPE) 14-16) rather than high intensity (≥ 9 METs, ≥ 90% $HR_{max}$, RPE ≥17) based on Australian exercise intensity guidelines (115).

One study comparing cardiovascular responses (HR, BP, MAP) between MICT (30 min at 64-76% $HR_{max}$) and HIIT (10 x 1 min at ≥ 90% $HR_{max}$) during pregnancy found that maternal and foetal responses were similar in both sessions, with no indicators of foetal distress present (increases in mean uterine blood flow (UBF) indices or bradycardia (FHR < 110 bpm)) (260). Conversely, a study of pregnant Olympic-level athletes showed cases of transient foetal bradycardia and high umbilical artery pulsatility index in certain participants when exercising >90%$HR_{max}$ for 5 minute bouts (78). Despite the growing body of research in this area, the safe upper limit of exercise intensity and volume in pregnancy is still not known. As such, vigorous (i.e. < 90% $HR_{max}$), rather than high intensity (≥ 90% $HR_{max}$) exercise is still suggested in pregnancy (73). Moreover, whether women will willingly incorporate vigorous intensity interval training (VIIT) into a balanced training program, and if there is any additional benefit of this type of training, is not known.

Most of the available research on the acute effects of exercise in pregnancy has focused on one type or intensity of exercise. Given the varied benefits derived from a balanced exercise program which incorporates both aerobic and resistance exercise, it is important to understand the acute physiological effects, safety, perceived enjoyment, and motivation of different modes of exercise in each trimester of pregnancy. Resistance training during pregnancy helps build or maintain muscular strength and functional capacity, with some evidence to suggest that resistance training during pregnancy has been shown to strengthen the benefits conferred by aerobic training when used in combination (120). Given the pregnancy discomforts that many women report, some may find resistance training more comfortable than aerobic training. Pilates (PIL) exercise is a form of lower intensity resistance exercise amongst women, particularly in pregnancy, however the acute maternal and foetal responses to this type of exercise are not well understood. Given the popularity of Pilates throughout pregnancy, and the light intensity nature, this type of exercise may

counter some of the perceived barriers surrounding fear of maternal/foetal harm. Despite the popularity of Pilates, there is little evidence on the acute cardiovascular responses to Pilates during pregnancy.

The aim of this study was to investigate the feasibility of performing three different common exercise modalities (VIIT, RT, and PIL) and observe the acute cardiovascular effects of each type of exercise during the second and third trimesters of pregnancy. It is hypothesised that these three types of exercise will be safe for the mother and foetus in the second and third trimesters. Further it is hypothesised that vigorous intensity exercise will show greater acute cardiovascular benefit than moderate intensity exercise.

## 6.2 Methods

### 6.2.1 Study participants

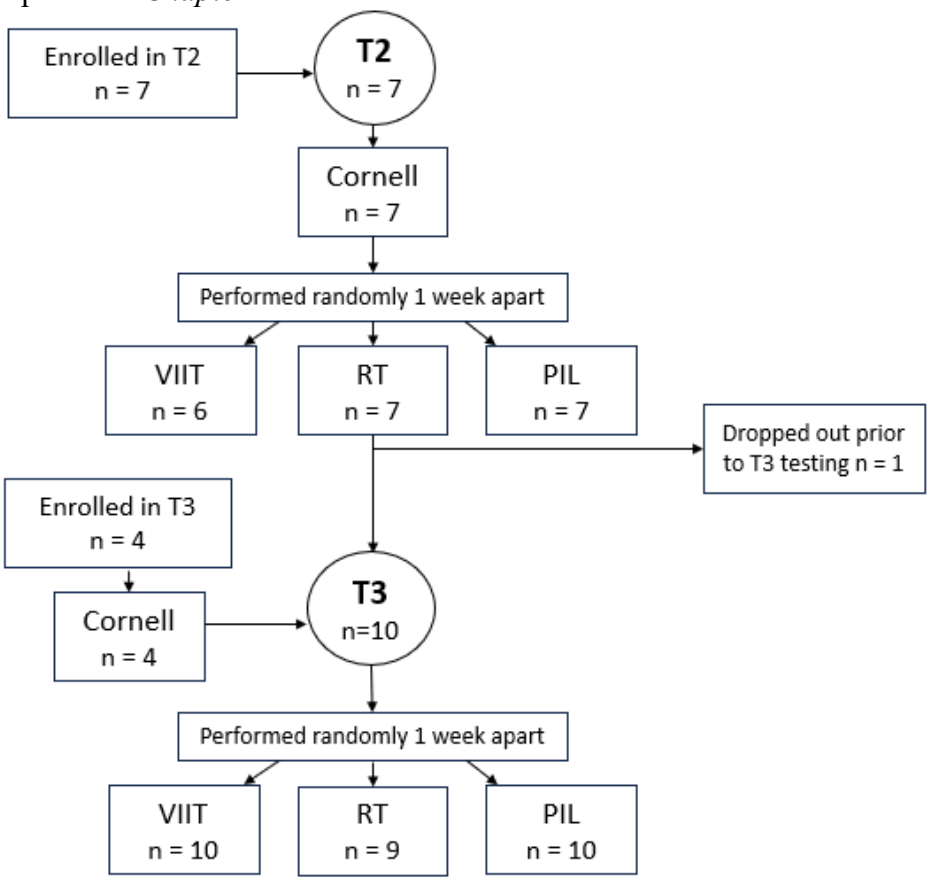
A convenience sample of eleven pregnant women were recruited in the second and third trimesters of pregnancy to participate in this randomised crossover trial. Seven participants enrolled in trimester 2 (T2) and 4 enrolled in trimester 3 (T3). Participants were aged between 18-40 years, were non-smokers and had no absolute contra-indications to exercise upon enrolment (e.g., incompetent cervix, placenta previa, evidence of intra-uterine growth restriction (IUGR)). Women with Type 1 diabetes (T1DM), gestational diabetes (GDM), gestational hypertension (GHTN) or pre-eclampsia (PE) diagnosed in this, or previous pregnancies were accepted into the study albeit with medical clearance (124, 125). Participants were also required to complete an online questionnaire QualtricsXM (Qualtrics, Provo, UT) which collected demographic data. This study protocol was approved by the Australian Catholic University Human Research Ethics Committee (ACU HREC), ethics register number: 2020-103H. All participants provided written informed consent prior to participation in the study. Further detail on the inclusion/exclusion criteria and recruitment process are provided in *Chapter 2.*

### 6.2.2 Study design

Participants performed baseline testing (the results of which are included in the sub-study in *Chapter 5*) in the trimester that they enrolled and then performed three bouts of exercise across three weeks in that trimester. Those who enrolled in T2 (n = 7) also performed the three bouts in T3 (*Figure 40*). Table *29* shows which sessions were completed by each of

the participants across both trimesters. Pre-exercise resting cardiovascular measures were obtained following 5 minutes of rest in the semi-recumbent position (pulse wave velocity (PWV), pulse wave analysis (PWA), BP, HR and FHR). During the VIIT sessions HR and RPE were recorded every minute, with BP recorded in the last minute of each stage. In the RT and PIL sessions HR and RPE were recorded every 5 minutes, so as to not impede the flow of the session. All outcome measures were taken again immediately post exercise and following 10 minutes of rest in the semi-recumbent position.

Exercise sessions and outcome measures are briefly outlined below, with further details reported in *Chapter 2*.




T2 = trimester 2; T3 = trimester 3; VIIT = vigorous intensity interval training; RT = resistance training; PIL = reformer Pilates; Cornell = Cornell submaximal treadmill protocol

Figure 40. Flowchart of participant enrolment

Table 29. Sessions completed by each participant

| | T2 | | | | T3 | | | |
|---|---|---|---|---|---|---|---|---|
| **Participant** | **Cornell** | **VIIT** | **RT** | **PIL** | **Cornell** | **VIIT** | **RT** | **PIL** |
| **1** | C | C | C | C | N | C | N | C |
| **2** | C | C | C | C | N | C | C | C |
| **3** | C | N | C | C | N | C | C | C |
| **4** | C | C | C | C | N | C | C | C |
| **5** | C | C | C | C | N | C | C | C |
| **6** | C | C | C | C | N | C | C | C |
| **7** | C | C | C | C | N | N | N | N |
| **8** | N | N | N | N | C | C | C | C |
| **9** | N | N | N | N | C | C | C | C |
| **10** | N | N | N | N | C | C | C | C |
| **11** | N | N | N | N | C | C | C | C |

T2 = trimester 2; T3 = trimester 3; VIIT = vigorous intensity interval training; RT = resistance training; PIL = reformer Pilates; Cornell = Cornell submaximal treadmill protocol; C = completed; N = not completed

***Visit 1: Cardiorespiratory Fitness Test***

After enrolment a submaximal graded exercise test was performed on the treadmill following the Cornell protocol, which has previously been used in pregnant populations (135, 136). The test was terminated once either 85% of the participant's age predicted heart rate maximum ($PHR_{max}$) or an RPE of 18 was reached, or if they asked to stop prior to this. Participants were asked to avoid caffeine, alcohol and exercise for 12 hours prior to each session. The data collected from these sessions has been used in the sub-analysis reported in Chapter 5. The effects of a submaximal graded exercise test on mean arterial pressure in pregnancy: A cross-sectional analysis

***Visits 2-4 and 5-7:***

A single bout of three different modes of exercise were then performed in each trimester across the subsequent three to four weeks. The order of the exercise sessions was randomised using a computer-generated random number selection tool. The three modes of exercise were VIIT on the treadmill, moderate intensity RT, and light to moderate intensity PIL.

### 6.2.3 Vigorous intensity interval training

The vigorous intensity interval sessions consisted of a light 5-minute warm up on a treadmill (8-11 RPE, 45-60% $HR_{max}$). The participants then performed four x four-minute intervals of vigorous intensity walking (RPE 14-16, 70-85% $HR_{max}$) interspersed with four x three-minute intervals of moderate intensity walking (RPE 11-13, ~65% $HR_{max}$) (total time = 33 minutes). The intensity was varied by increasing/decreasing the speed and gradient of the treadmill to ensure the participants HR remained within the target HR.

### 6.2.4 Resistance training

The RT sessions included a light 5-minute warm up involving dynamic stretches of each major muscle group. The sessions then consisted of 30-35 minutes of resistance training using bodyweight exercises, free weights, resistance bands and machine-based exercises. Two supersets of three exercises were performed, with one exercise targeting the upper body, lower body and trunk in each superset. Each superset was performed three to four times, with 8-10 repetitions performed for each exercise. The load was maintained at a moderate intensity (RPE 11-13, 55-70% $HR_{max}$). Five minutes of light static stretching was performed at the end of each session.

### 6.2.5 Reformer Pilates

The PIL sessions included a light 5-minute warm up involving dynamic stretches of each major muscle group. The sessions then consisted of 30-35 minutes of light to moderate (RPE 8-13, 40-70% $HR_{max}$) exercises targeting each major muscle group performed on the reformer. Exercises performed in the supine position were avoided as a precaution, as supine rest has been associated with symptomatic hypotension in up to 10% of pregnant women due to vena caval compression (140) The sessions concluded with five-minutes of light static stretching.

### 6.2.6 Feasibility

The intensity of each session was determined based on $PHR_{max}$ (220 - age) and RPE (129). A combination of $\%PHR_{max}$ and RPE were used to determine exercise intensity, as there remains no decisive recommendations on the most appropriate metrics to use during pregnancy given changes in resting HR across gestation. The session was considered feasible if participants were able to achieve the target intensity (both $\%HR_{max}$ and RPE) for each

mode of exercise. A post-delivery questionnaire was delivered which included ratings of enjoyment and motivation for each type of exercise. In the questionnaire participants were asked: “On a scale of 0-10 how much did you enjoy the VIIT/RT/PIL sessions?” and “On a scale of 0-10 how motivated were you to complete the VIIT/RT/PIL sessions?” Where 0 = not at all and 10 = extremely motivated. Participants were also asked to rank the three modes of exercise in order of first, second and third preference.

In addition to exercise intensity, the timing of each session was considered when determining the feasibility of each exercise mode. The time spent exercising, as well as the time it took to finish taking each set of outcome measures was assessed.

### 6.2.7 Maternal and foetal exercise-induced cardiovascular changes

Arterial stiffness was measured using the semi-automatic SphygmoCor Xcel system which uses high fidelity applanation tonometry to measure carotid-femoral PWV (cfPWV). Two measures were taken at each time point with an average of the two measures used in the analysis. When the two measures were greater than 0.5 $m.s^{-1}$ apart, a third measure was taken, with the median value recorded. PWA was performed using the same automatic device (SphygmoCor Xcel) with augmentation index (AIx), augmentation index 75 (AIx75), augmentation pressure (AP), pulse pressure (PP) and central/aortic blood pressure (ASBP/ADBP) calculated from the brachial artery following 5 minutes of semi-recumbent rest.

Resting and post exercise BP were measured using the SphygmoCor Xcel device with a brachial cuff. Exercising BP was measured at the end of every stage of the Cornell exercise test in the initial session, and in the last minute of every stage of the VIIT sessions manually using the auscultation method.

HR was measured continuously using photoplethysmography with a chest strap connected via Bluetooth to a phone application. Heart rate recovery (HRR) was calculated following the graded exercise test by recording post exercise HR 1-3 minutes following exercise and subtracting these measures from the peak heart rate (PHR) achieved. FHR was measured at rest and again immediately and 10 minutes post exercise in the semi-recumbent position using a foetal doppler.

### 6.2.8 Maternal and foetal birth/delivery outcomes

The post-delivery questionnaire included questions on maternal birth outcomes (type of delivery, duration of labour, gestational age at delivery, complications, medical inventions used, time spent in hospital following delivery) and foetal birth outcomes (sex of baby, birth weight, birth length, head circumference, APGAR scores).

The protocols for each exercise session along with the timing of outcome measures are demonstrated in **2.6 Outcome Measures** - *Figure 8.*

### 6.2.9 Statistical analysis

Due to the small sample size, no formal statistical analyses were performed. Rather, data are descripted, and presented as mean ± standard deviation, and any difference between trimesters are estimated using Hedges g effect sizes along with 95% confidence intervals where appropriate.

## 6.3 Results

### 6.3.1 Participants

A total of 11 women (age 32 ± 3 years, pre-pregnancy body mass index (BMI) 24 ± 3.4 $kg/m^2$) were enrolled in the study (mean GW 22 ± 5). Participant demographics can be viewed in *Table 30*.

Table 30. Participant characteristics at baseline

| **Total n = 11** | | | |
|---|---|---|---|
| **Age (years)** | 32 ± 3 | **Education** | |
| **Gestational week** | 22 ± 5 | *Graduate diploma/ Graduate certificate* | 4 |
| **Height (cm)** | 167 ± 5 | *Advanced Diploma* | 3 |
| **Pre-pregnancy weight (kg)** | 67 ± 10 | *Bachelor* | 3 |
| **Pre-pregnancy BMI (kg/m$^2$)** | 24 ± 3.4 | *M.D* | 1 |
| **Ethnicity** | | **Employment status** | |
| *Caucasian* | 9 | *Part-time* | 2 |
| *Caucasian/Hispanic* | 1 | *Full-time* | 9 |
| *Caucasian/Maltese* | 1 | **Average reported daily steps** | |
| **Born in Australia** | | *<5k* | 1 |
| *Yes* | 10 | *5-10k* | 9 |
| *No* | 1 | *10-15k* | 1 |
| **Parity (number of previous live births)** | | **Enjoys exercise** | |
| *0* | 8 | *Yes* | 8 |
| *1* | 3 | *Sometimes* | 3 |
| **Gravidity (number of pregnancies)** | | *No* | 0 |
| *1* | 8 | **Diagnosed conditions in current pregnancy** | 0 |
| *2* | 1 | **Diagnosed conditions in any previous pregnancies** | |
| *3* | 2 | *GDM* | 2 |
| **Singleton** | 10 | **History of HTN** | 0 |
| **Twins** | 1 | **Family history of HTN** | 3 |

HTN = hypertension; BMI = body mass index; kg = kilograms; cm = centimetres; GDM = gestational diabetes

### 6.3.2 Feasibility

#### *6.3.2.1 Exercise intensity*

***Cornell test***

All participants reached 85% $PHR_{max}$ during the submaximal exercise test except two participants (79% and 83% $PHR_{max}$). Both participants asked to terminate the test due to fatigue and a reported RPE of 18-19. The data from the baseline testing was included in the sub study and has been analysed in further detail in *Chapter 5*.

***VIIT***

The $\%HR_{max}$ response to the VIIT sessions is shown in *Figure 41* and the RPE response to VIIT sessions is shown in *Figure 42*. The mean RPE and $\%HR_{max}$ responses to each stage in the VIIT sessions are provided above each box plot. The desired intensities for each stage of the VIIT protocol were maintained in T2 and T3 based on RPE and $\%HR_{max}$. MHR did not appear to recover as well between intervals in T3 compared to T2, given the workload for the 'moderate' intervals remained consistent (*Figure 41*). Large effect sizes were reported for the response in maternal HR 10 minutes post exercise following VIIT (T2: 84 ± 9.8 bpm, T3: 92 ± 5.3 bpm, g = 1.11, 95%CI [-0.03-2.12]) and RT (T2: 80 ± 9.8 bpm, T3: 89 ± 9.3 bpm, g = 0.95, 95%CI [-0.87-1.06]). Average RPE for the vigorous intensity bouts were higher in T3 than T2, despite $\%HR_{max}$ remaining fairly consistent across trimesters. The $\%HR_{max}$ during the recovery periods tended to be higher in T3 than T2, despite no change in RPE.

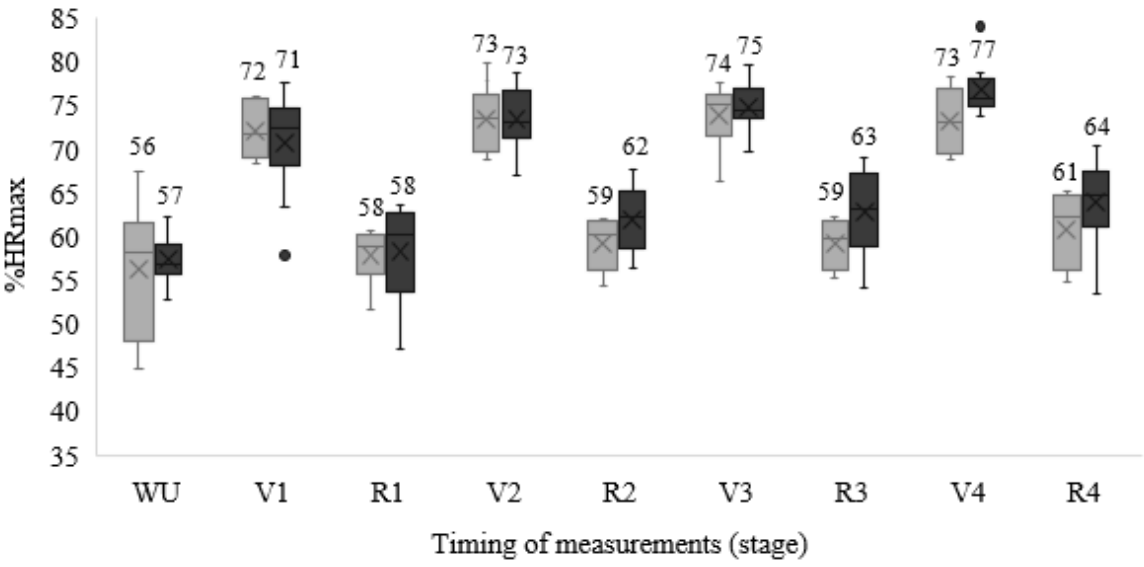



Figure 41. $\%HR_{max}$ response to the VIIT sessions in T2 and T3. Mean values are presented above each box plot

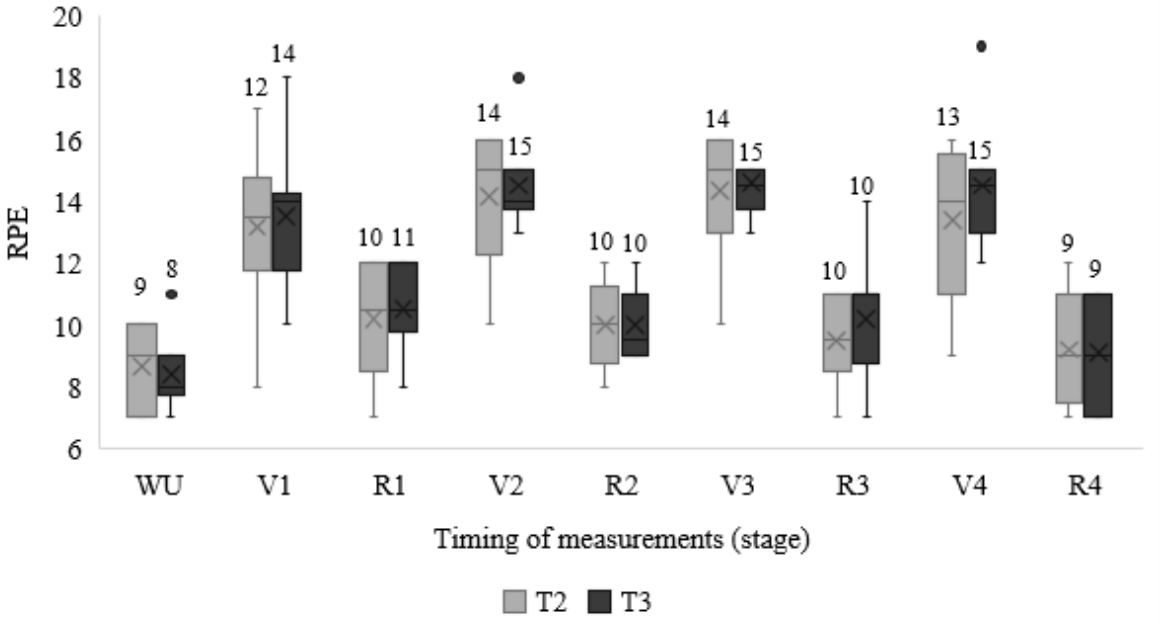



Figure 42. RPE response to the VIIT sessions. Mean values are presented above each box plot

***RT***

The %$HR_{max}$ reached in the RT sessions is shown in *Figure 43* whilst the RPE for the RT sessions is shown in *Figure 44*. The mean RPE and %$HR_{max}$ for each session are provided above each box plot. The desired intensity for the RT sessions were maintained in T2 and T3 based on RPE and %$HR_{max}$. Similar responses in RPE and %$HR_{max}$ were seen in T2 and T3.

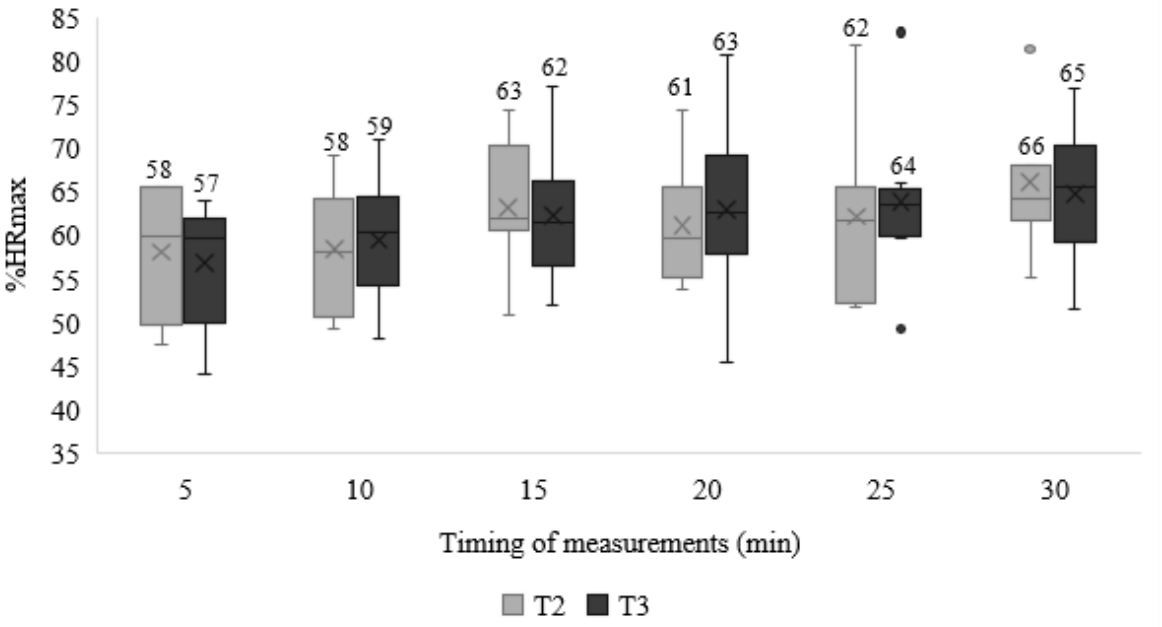



Figure 43. %$HR_{max}$ responses to the RT sessions. Mean values are presented above each box plot.

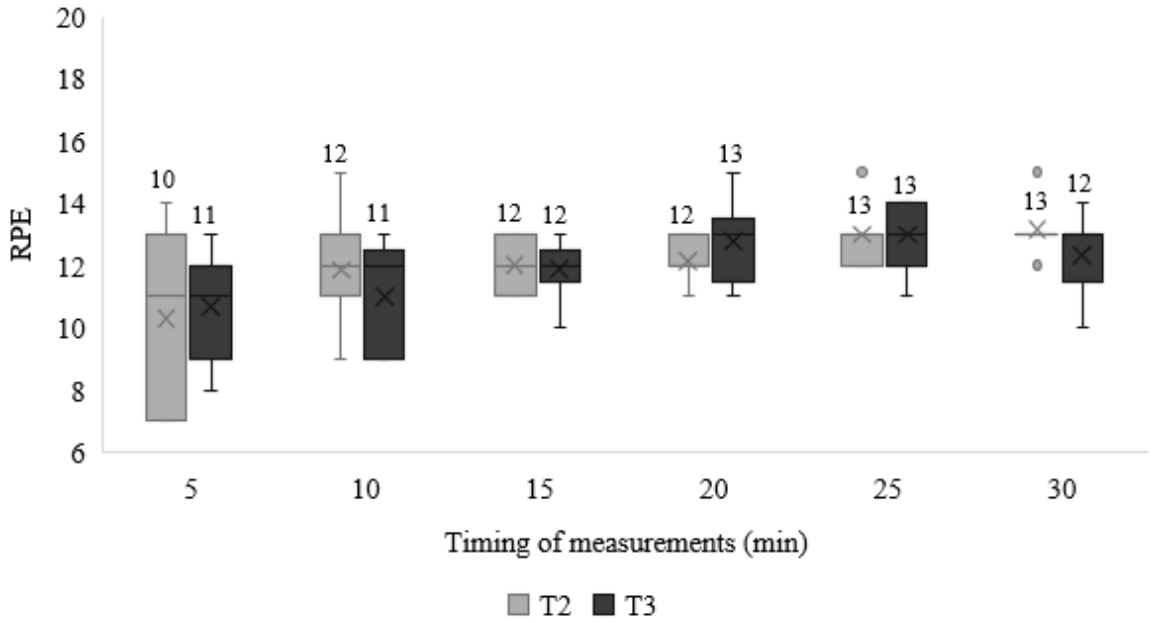



Figure 44. RPE response to RT sessions in T2 and T3. Mean values are presented above each box plot.

***PIL***

The %$HR_{max}$ achieved throughout the PIL sessions is shown in *Figure 45* and the RPE responses to PIL sessions are shown in *Figure 46*. RPE was rated slightly higher in T3 compared to T2 during the PIL sessions. The %$HR_{max}$ reached throughout the PIL sessions was also slightly higher in T3 compared to T2.

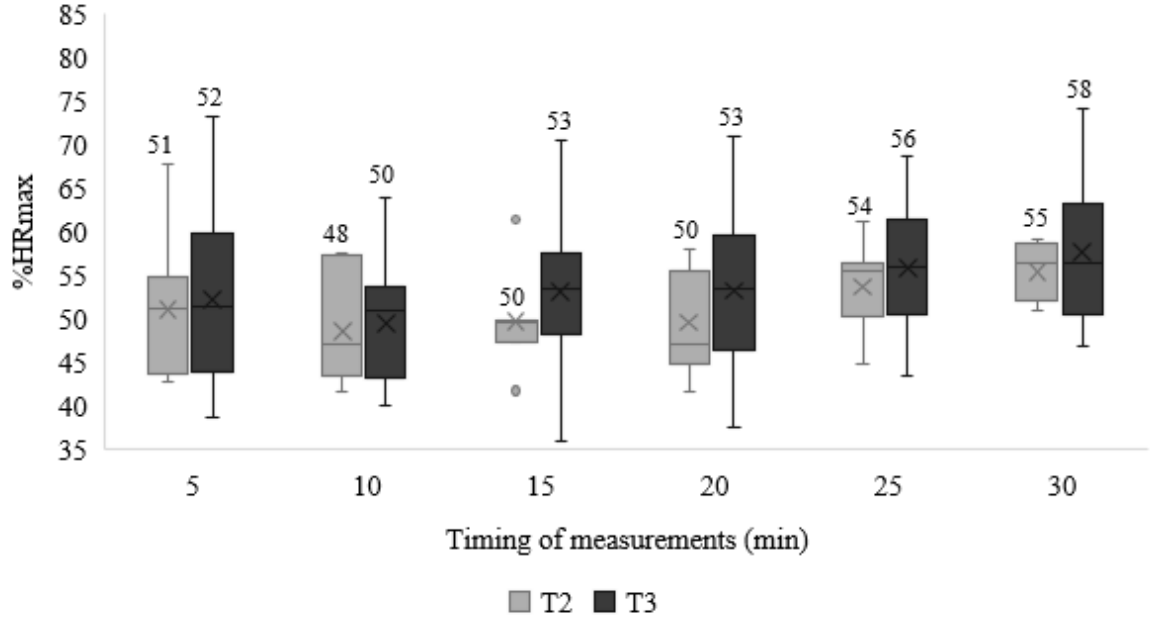



Figure 45. %$HR_{max}$ response to PIL sessions in T2 and T3. Mean values are presented above each box plot.

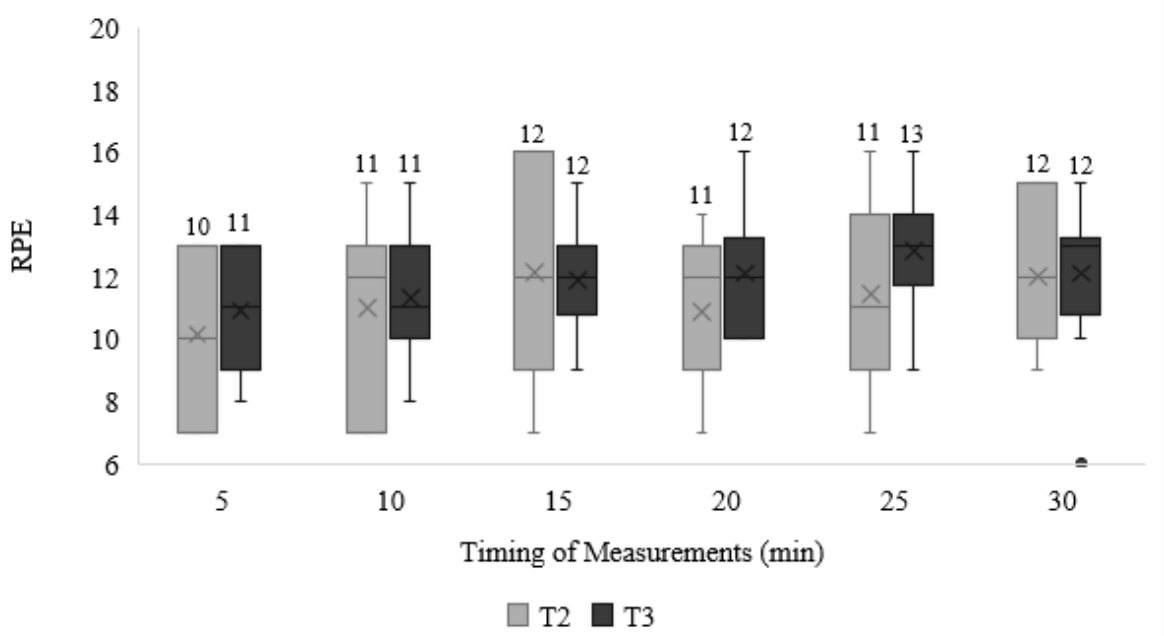



Figure 46. RPE response to PIL sessions in T2 and T3. Mean values are presented above each box plot.

#### *6.3.2.2 Timing of session*

The timing of post-exercise measures differed slightly across exercise modes, as the time taken from the cessation of exercise to when the first post-exercise measure (PWA) was taken varied from within 30 seconds (VIIT) to 1-2 minutes (RT, PIL). This was due to the proximity of the treadmill, reformer and RT area to where the SphygmoCor Xcel device was set up. On top of this, PWV measurements could not be taken until the PWA measurement had finished (approximately 1-2 minutes). This meant that the first PWV measurement occurred 2-3 minutes after the participant had ceased exercise. At times the PWV reading was more difficult to obtain, as the device is automatically triggered once the carotid tonometer detected a regular pulse wave with a valid signal quality. This can be potentially challenging due to increased adiposity around the carotid artery, along with involuntary movements from the participant that effect the signal quality (e.g. swallowing/coughing etc.). FHR was measured whilst the PWA measurement was automatically being taken by the SphygmoCor Xcel device.

In total, each session ran for between 55-60 minutes (5 minute rest, ~5 minutes to take resting measures, 30-35 minutes of exercise, ~1-2 minutes to set up for post exercise testing, 10-15 minutes for 2 x post exercise measurements).

#### *6.3.2.3 Completion of protocol*

One participant dropped out of the study before completing the third trimester sessions due to Covid-19 restrictions. One participant was unable to complete the VIIT session in T2 as she was ill for a week, and by the time she had recovered she was in T3 (27 weeks gestation). One further participant was unable to complete the RT session in T3, as she gave birth the week that this session was to be completed (36 weeks gestation).

#### *6.3.2.4 Enjoyment/motivation*

The results can be seen in *Table 31* and *32***.** The VIIT sessions were ranked the least enjoyable out of the three exercise modalities (6/10 ± 2, range 3-9), with only one out of eleven participants listing VIIT as their first preference for exercise modality. RTand PIL measured similarly in terms of enjoyment and motivation (Enjoyment: RT 8/10 ± 2, range 4-10; PIL 8/10 ± 2, range 2-10; Motivation: RT 7/10 ± 3, range 1-10, PIL 8/10 ± 2, range 2-10).

Table 31. Reported enjoyment and motivation levels for each type of exercise

| **n = 11** | **Type** | **Mean ± SD** | **Range** |
|---|---|---|---|
| **Enjoyment /10** | *VIIT* | 6 ± 2 | 3-9 |
| | *RT* | 8 ± 2 | 4-10 |
| | *PIL* | 8 ± 2 | 2-10 |
| **Motivation /10** | *VIIT* | 7 ± 2 | 3-9 |
| | *RT* | 7 ± 3 | 1-10 |
| | *PIL* | 8 ± 2 | 2-10 |

VIIT = vigorous intensity interval training; RT = resistance training; PIL = Pilates

Table 32. Exercise preferences

| | **1st Preference** | **2nd Preference** | **3rd Preference** |
|---|---|---|---|
| **VIIT** | 1 | 4 | 6 |
| **RT** | 5 | 4 | 2 |
| **PIL** | 5 | 3 | 3 |

VIIT = vigorous intensity interval training; RT = resistance training; PIL = Pilates

### 6.3.3 Maternal and foetal birth outcomes

Maternal and foetal birth outcomes can be viewed in *Table 33* and *34*. All babies were born healthy (birthweight: 2500-4500 grams, 5 min APGAR score: ≥7), with only one baby born late preterm (36 weeks) with the average gestational age at delivery being 39 ± 1.5 weeks (range 36-42 weeks). The average labour lasted 8.2 ± 4.6 hours (range 3-18), and the participants spent on average 3.5 ± 2 days (range 7 hours – 7 days) in hospital following delivery. Following participation in the study one participant was diagnosed with PE (GW 33) and one participant was diagnosed with GDM (GW 32), with both participants having been diagnosed with GDM in previous pregnancies.

Table 33. Self-reported maternal delivery outcomes

| **n = 11** | **Mean ± SD** |
|---|---|
| **Type of delivery** | |
| *Vaginal* | 6 |
| *Planned Caesarean* | 3 |
| *Emergency Caesarean* | 2 |
| **Labour duration (hours)** | 8.2 ± 4.6 |
| **GW at delivery** | 39 ± 1.5 |
| **Complications** | |
| *Perineal tears* | 3 |
| *Foetal distress* | 3 |
| *Excessive bleeding* | 3 |
| *Labour that did not progress* | 2 |
| *Umbilical cord problems* | 1 |
| *Placenta previa* | 1 |
| *Preterm Labour* | 1 |
| *Breech* | 0 |
| *Clitoral tears* | 0 |
| *Shoulder dystocia* | 0 |
| **Interventions used** | |
| *Induction* | 6 |
| *Epidural* | 5 |
| *Forceps* | 2 |
| *Episiotomy* | 1 |
| *Vacuum* | 0 |
| **Time spent in hospital following delivery (days)** | 3.5 ± 1.9 |

| | | |
|---|---|---|
| **Diagnosed conditions during pregnancy** | | |
| | *PE* | 1 |
| | *GDM* | 1 |

GW = gestational week; PE = pre-eclampsia; GDM = gestational diabetes mellitus

Table 34. Foetal/birth outcomes

| | **n = 12** | **Mean ± SD** | **Range** |
|---|---|---|---|
| **Sex** | | | |
| | *Female* | 9 | |
| | *Male* | 3 | |
| **Weight (kg)** | | 3.23 ± 0.34 | 2.71-3.78 |
| **Length (cm)** | | 50.96 ± 2.60 | 44-54 |
| **Head Circumference** | | 33.5 ± 1.53 | 30-35 |
| **APGAR 1 min** | | 8 ± 1 | 7-9 |
| **APGAR 5 min** | | 8 ± 1 | 8-9 |

kg = kilograms; cm = centimetres; APGAR 1 & 5 min = Appearance, Pulse, Grimace, Activity, Respiration score at 1 minute and 5 minutes.

### 6.3.4 Maternal and foetal exercise-induced cardiovascular changes

#### *6.3.4.1 Pulse wave velocity*

PWV responses to each type of exercise can be seen in *Figures 47, 48* and *49*. There was a trend for resting PWV to be lower in T2 compared to T3 (T2 = 4.94 ± 0.62 $m \cdot s^{-1}$, T3 = 5.4 ± 0.51 $m \cdot s^{-1}$, g = 0.82, 95%CI [0.31-1.33]. There was no difference in the PWV response to each type of exercise across the trimesters (immediately post: VIIT: g = -0.37, 95%CI [-1.36-0.67]; RT: g = 0.12, 95%CI [-0.88-1.10]; PIL: g = 0.04, 95%CI [-0.93-1.01]; 10 min post: VIIT: g = 0.08, 95%CI [-0.94-1.08]; RT: g = 0.21, 95%CI [-0.80-1.18]; PIL: g = 0.44, 95%CI [-0.56-1.40]). The range in effect sizes following exercise during each trimester (-0.37-0.44), along with confidence intervals crossing zero indicates a large amount of inter-individual variability in the PWV responses. There was a trend for PWV to increase slightly one minute following each type of exercise in each trimester, before returning towards baseline levels by 10 minutes post exercise.

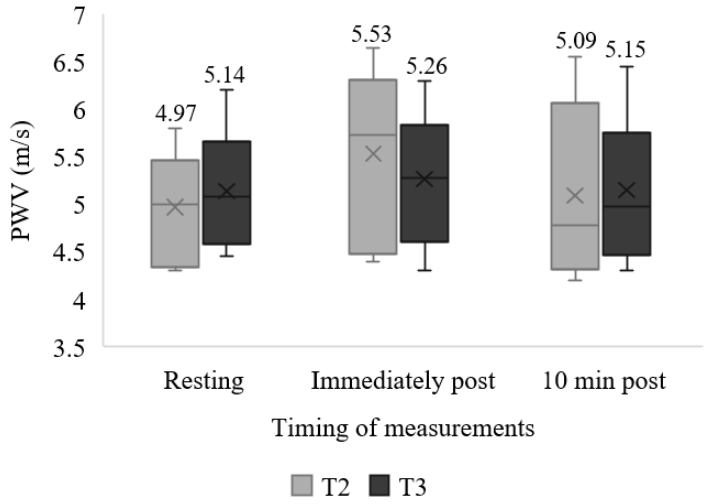



Figure 47. PWV response to VIIT sessions in T2 and T3.

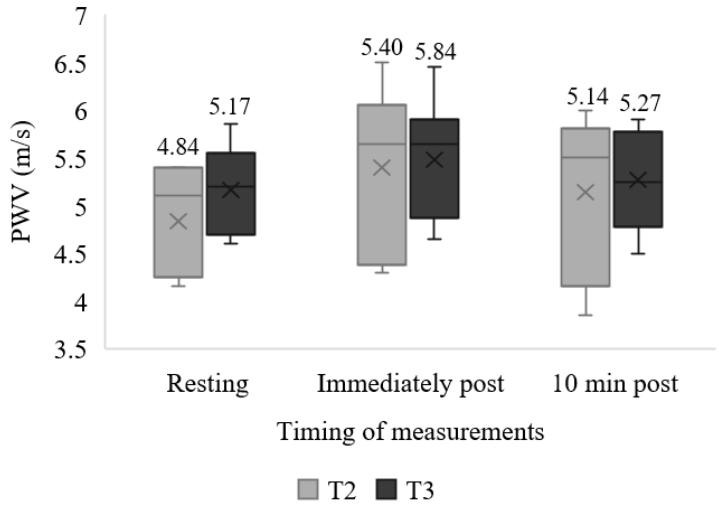



Figure 48. PWV response to RT sessions in T2 and T3.

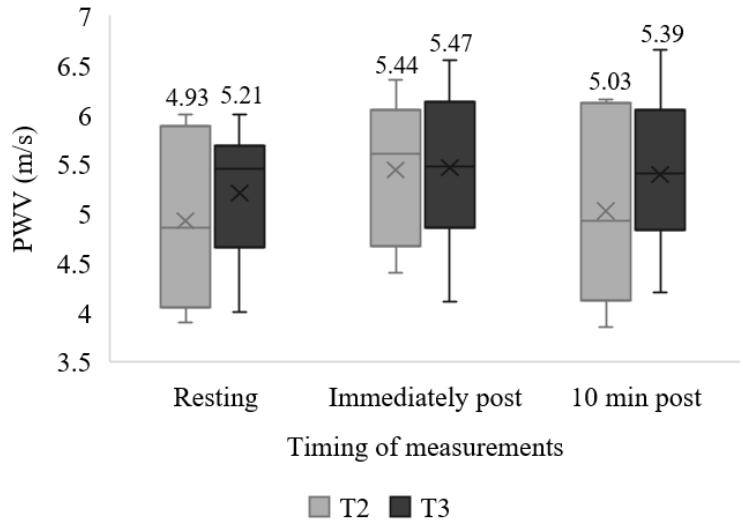



Figure 49. PWV response to PIL sessions in T2 and T3.

#### *6.3.4.2 Blood pressure*

SBP responses to each type of exercise can be seen in *Figures 50, 51* and *52*, with DBP responses shown in *Figures 53, 54* and *55*. There was a trend for resting SBP to be higher in T3 than T2 (T2 = 112 ± 7 mmHg, T3 = 116 ± 11 mmHg, g = 0.41, 95%CI [-0.08-0.91]). Systolic BP was higher in T3 than T2 immediately following Pilates exercise (T2: 110 ± 5.8 mmHg, T3: 121 ± 11.7 mmHg, g = 1.13, 95%CI [0.04-2.1]), and 10 minutes following resistance training (T2: 105 ± 10.1 mmHg, T3: 115 ± 5.0 mmHg, g = 1.44, 95%CI [0.27-2.46]). There was a trend for resting DBP to be higher in T3 than T2 (T2 = 64 ± 7 mmHg, T3 = 69 ± 9mmHg, g = 0.60, 95%CI [0.10-1.10]). Diastolic BP 10 minutes following VIIT was higher in T3 than T2, however the confidence interval crosses zero, indicating large variation in responses (T2: 63 ± 5.9 mmHg, T3: 72 ± 8.9 mmHg, g = 1.13, 95%CI [-0.01-2.15]). There were no differences in all other measures of DBP between trimesters.

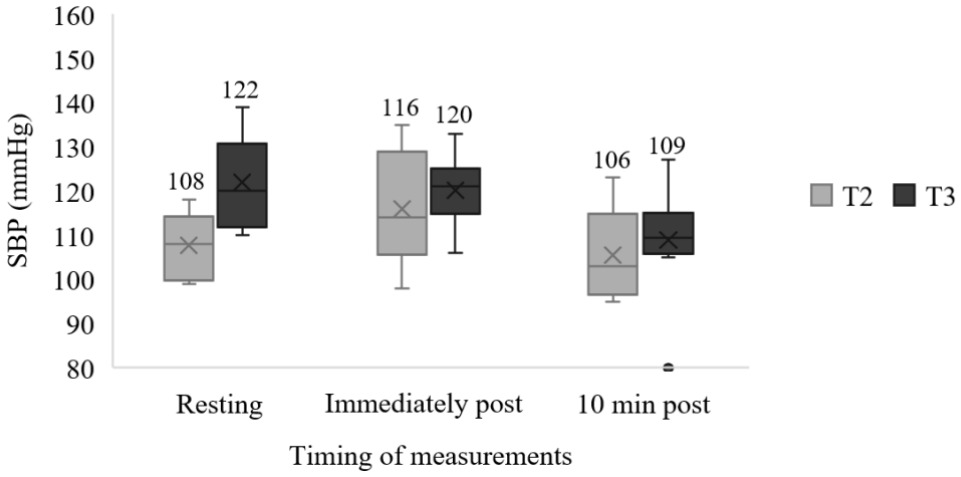



Figure 50. SBP response to VIIT sessions in T2 and T3

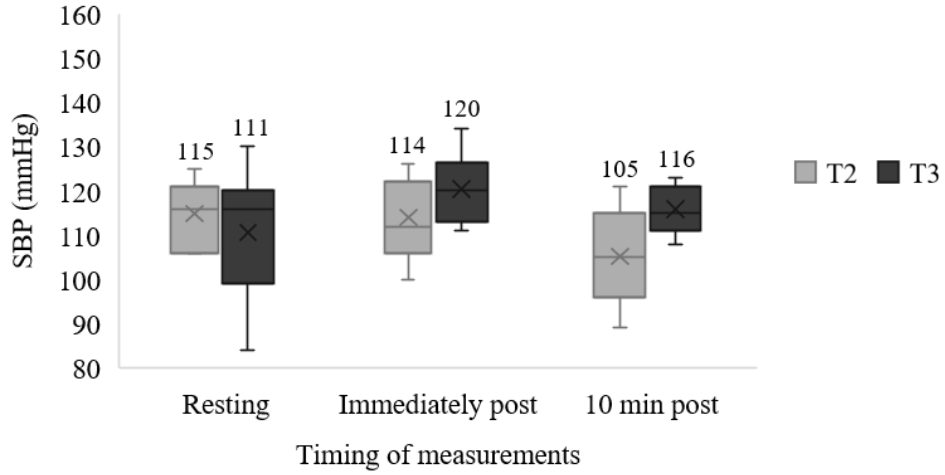



Figure 51. SBP response to RT sessions in T2 and T3

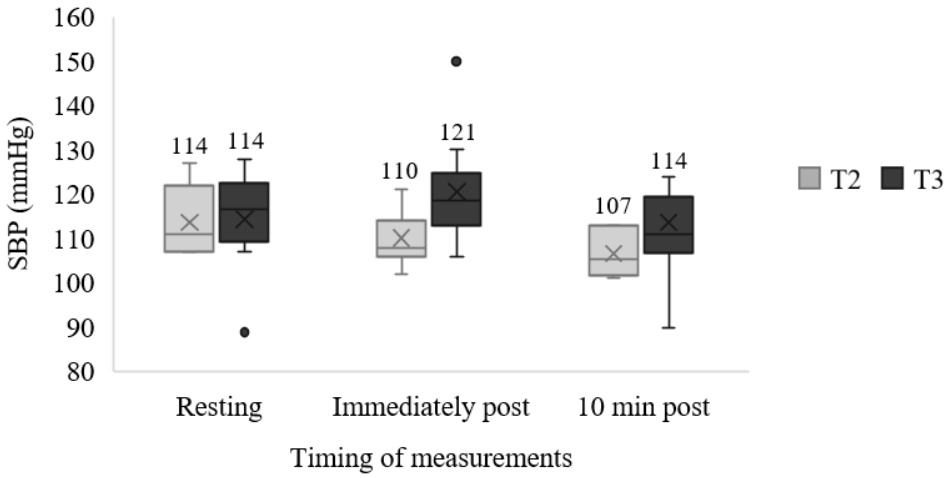



Figure 52. SBP response to PIL sessions in T2 and T3

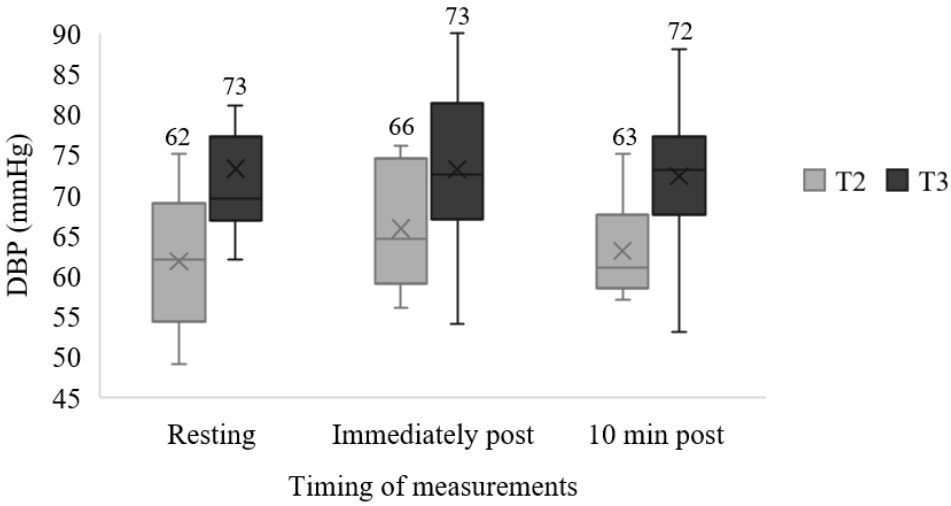



Figure 53. DBP response to VIIT sessions in T2 and T3

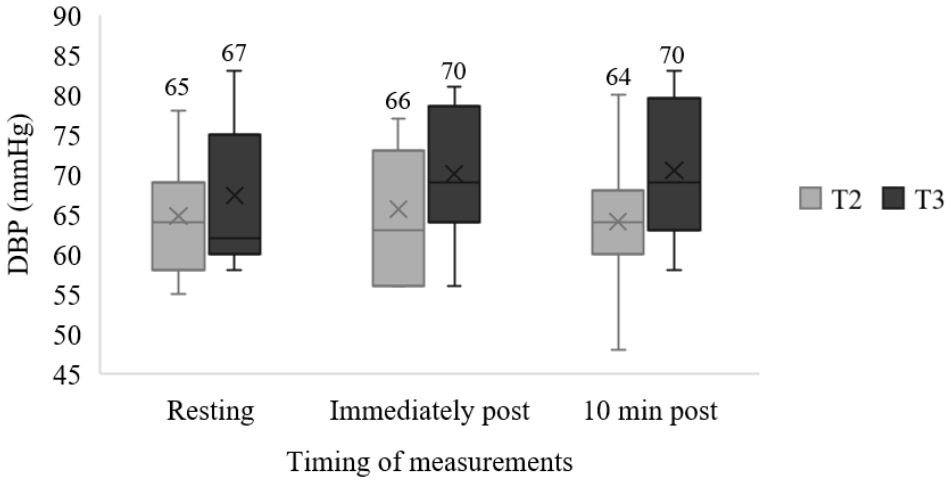



Figure 54. DBP response to RT sessions in T2 and T3

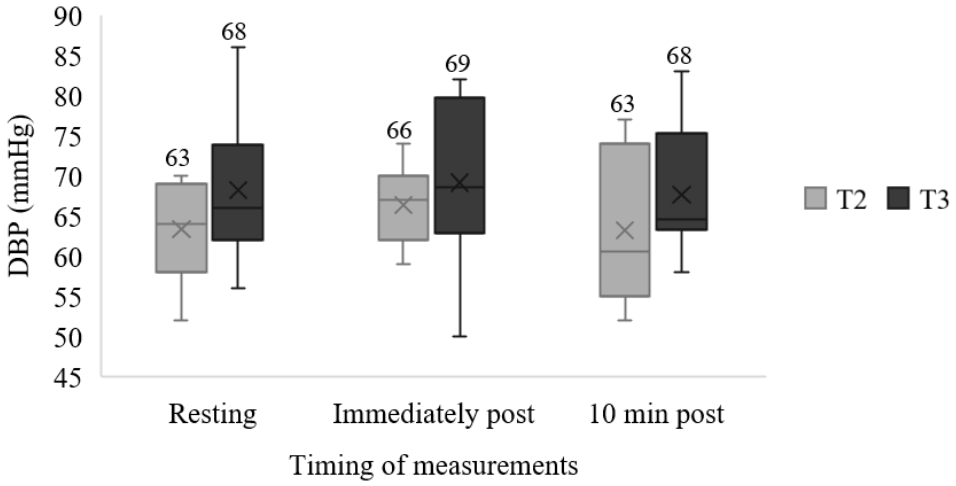



Figure 55. DBP response to PIL sessions in T2 and T3

#### *6.3.4.3 Foetal heart rate*

In both T2 and T3 the average FHR increased immediately post exercise by 4 bpm, with this change persisting 10 minutes post exercise. FHR was lower immediately following VIIT sessions in T3 compared to T2 (T2 = 154 ± 6 bpm, T3 = 145 ± 7 bpm, g = -1.28, 95%CI [-2.38- -0.17]), however resting FHR average was lower in T3 (143 ± 6 bpm) than T2 (151 ± 2 bpm) for the VIIT sessions.

### 6.3.5 Adverse events

One participant experienced transient light-headedness after a VIIT session due to a hypotensive BP response (98/72 mmHg). BP and FHR were monitored for 20 minutes following the report of transient light-headedness, with BP returning to near baseline levels (126/93 mmHg) within 20 minutes (15 minutes post = 102/72 mmHg, 20 minutes post = 122/72 mmHg) and no change in FHR > 5 bpm from resting. No other adverse maternal outcomes were reported during or following any of the exercise sessions. There was no foetal bradycardia (< 110 bpm), or tachycardia (> 160 bpm) measured throughout the study in any participant.

## 6.4 Discussion

The aim of this study was to investigate the feasibility of performing three modes of exercise (VIIT, resistance, Pilates) during the second and third trimesters of pregnancy whilst observing acute responses in arterial stiffness and BP. The findings suggest that the acute cardiovascular maternal and foetal responses to VIIT, resistance training and Pilates are

similar across modes and trimesters. These findings indicate that VIIT may be a feasible option for pregnant women who wish to exercise at a more vigorous intensity throughout gestation. Further investigation is warranted to investigate whether there is additional benefit to regular vigorous intensity exercise during pregnancy compared to more moderate intensities of exercise.

***Feasibility***

The results from this study show that VIIT is feasible in the second and third trimester of uncomplicated pregnancies. The participants in the current study were able to achieve the prescribed intensities based off $\%HR_{max}$ and RPE in T2 and T3. Measuring exercise intensity during pregnancy is challenging due to physiological changes such as increased resting HR and reduced maximal HR, which diminish the reliability of metrics like %HRmax and HRR (261). These changes can lead to underestimations of intensity at higher workloads and overestimations at lower workloads (261). Similarly, perceived exertion (RPE) may not consistently reflect intensity, with its accuracy influenced by factors such as training status, activity type, and the increased energy demands as pregnancy progresses. The results indicate that vigorous intensity exercise may be perceived as more difficult as gestation progresses, despite similar cardiovascular responses between trimesters. This could be due to an increase in fatigue and discomfort associated with progressing gestation, both of which are reported barriers to exercise (262). Evidence on RPE changes during pregnancy is conflicting, with some studies showing higher RPE in later gestation or compared to non-pregnant controls, while others report no differences across gestational stages (261). The participants in this study achieved the prescribed intensities for RT and PIL in both trimesters, with similar responses seen in RPE across T2 and T3. Coupled with the results from the VIIT sessions, this highlights that moderate intensity exercise is perceived similarly between T2 and T3, whilst exercising at a vigorous intensity in T3 may feel harder for pregnant women. (1). This finding may explain why there is a decrease in weekly PA intensity as pregnancy progresses (4).

HIIT is considered one of the leading fitness trends of the past decade (254, 255), with evidence supporting better adherence rates and enjoyment levels in HIIT than MICT in non-pregnant populations (263, 264). Most of the studies that have examined HIIT during pregnancy have noted that pregnant women found it to be more enjoyable than traditional aerobic training (113, 114, 217). Although the current study didn't compare VIIT to

moderate intensity aerobic training, VIIT was rated as the least enjoyable exercise session compared to RT and Pilates. Other studies highlighting maternal enjoyment of HIIT have generally used protocols with much shorter bouts of higher intensity exercise, for example: 18 x 20 seconds maximum effort (RPE 15-17) followed by 60 seconds active rest (114), 10 x 1 minute high intensity exercise (≥ 90% HRmax) followed by 1 min self-paced active recovery (72) and 15-60 seconds of higher intensity exercise (75-85% $PHR_{max}$/RPE 15-16) every two minutes interspersed with lower intensity exercise (55-65% $PHR_{max}$/9-11 RPE) (116). The VIIT sessions in our study included 4-minute bouts of vigorous intensity uphill treadmill walking, where the longer duration of the interval may have resulted in less engagement and enjoyment. Prior research showing high levels of enjoyment with HIIT have also used either a non-weight bearing modality (cycle ergometer) (72, 116, 217), or a resistance based circuit (114), which compared to walking may be better tolerated by pregnant women as gestation progresses.

***Cardiovascular efficacy***

Resting BP and arterial stiffness measures were lower in the second trimester compared to the third, with resting HR increasing from T2 to T3. This aligns with previous research indicating that resting maternal HR increases from early pregnancy throughout gestation by approximately 15-20 bpm, reaching a peak and plateauing in the third trimester (1, 58). Brachial systolic and diastolic BP are known to decrease from the onset of gestation into the second trimester due to a decrease in systemic vascular resistance, reaching a nadir before increasing throughout the third trimester (11, 265). It has been identified that resting PWV follows a similar trend to BP, with an initial decrease seen in trimester one and two up to around 17 weeks of gestation, before increasing throughout trimester three until around 35 weeks (58), which is consistent with the results found in this study. Despite the low-moderate intensity of the Pilates sessions, similar acute haemodynamic responses were seen following these sessions, compared to the more moderate to vigorous RT and VIIT sessions. Based on our findings and the popularity that Pilates is gaining, further research on the longitudinal effects of it during pregnancy is warranted.

There were no adverse FHR responses following any of the exercise sessions (FHR < 110 bpm or > 160 bpm), indicating that these modalities of exercise do not compromise the chronotropic response of the foetus. The current findings are supported by a systematic review which found that FHR increased during acute exercise irrespective of the intensity or

duration, with a change of 4.05 bpm seen following acute exercise (121). FHR variability (the difference between the highest and lowest FHR during 10 minutes of rest) of 5-25 bpm is indicative of healthy cardiac responsiveness, therefore an increase in FHR with maternal exercise within these parameters is considered a normal response (121). In the current study, resting average FHR decreased from the second to the third trimester, which again aligns with previous research (122, 266). There are inconsistent results from a few studies investigating the effects of vigorous to maximal intensity aerobic or resistance exercise on FHR, with some results showing increased rates of transient foetal bradycardia (78, 267), whilst others observed none (72, 114). A potential reason for these conflicting results may be the length of the high intensity bout. Our study, along with the two previous studies that observed no foetal bradycardia, utilised higher intensity intervals only up to 4 mins duration each (72, 114), conversely, participants in the studies that showed increased rates of foetal bradycardia underwent prolonged periods of high to maximal intensity exercise (> 90% $HR_{max}$, ≥ 5 min) (78, 267). The intensity of exercise in our study also remained within the moderate to vigorous threshold (<85% $HR_{max}$), therefore FHR was not expected to show any of the clinical change observed in these previous studies (78, 267).

***Strengths and limitations***

The main limitation of this study was the relatively small sample size of 11 participants, with only six participants performing the T2 sessions and 10 performing the T3 sessions. Only six of the 11 participants completed both the second and third trimester exercise sessions, with four participants enrolling in the third trimester. As such it is difficult to draw any rigorous conclusions comparing trimesters.

For logistical reasons, this study only measured the acute effects for 10 minutes following exercise. Given some research indicates lasting effects of acute bouts of exercise up to 14 hours after a session (100), future studies may provide additional findings with a longer period of observation post exercise. The participants rated their enjoyment and motivation for each type of exercise in the post-delivery questionnaires, which were often completed ~6 weeks post birth. It may have been challenging for the participants to recall their enjoyment and motivation levels for each type of exercise given the extended time between when the sessions were performed, and when the questionnaires were completed. Previous exercise experience/training status was not assessed in this study, which could influence exercise preferences and cardiovascular responses to different exercise modalities.

***Conclusions***

VIIT, RT and PIL appear to be feasible in both trimester two and trimester three of uncomplicated pregnancy. However, VIIT appears to be the least enjoyable mode of exercise, compared to resistance training and Pilates. Acute maternal and foetal cardiovascular responses to VIIT, resistance training and reformer Pilates appear similar in trimester two and three of pregnancy. The reduced motivation for vigorous intensity aerobic exercise provides important insights for optimising physical activity adherence when prescribing a balanced exercise program. Given physical inactivity is a significant problem in pregnancy, the feasibility of including VIIT in an exercise program should be further investigated in more robust large-scale trials. Further, additional research on the longitudinal effects of these exercise modalities is warranted to determine whether the cardiovascular response to exercise changes across gestation.

# Chapter 7. The effects of three different training modalities and intensities on arterial stiffness and blood pressure completed weekly throughout pregnancy: A longitudinal cross-over trial

## Abstract

### Introduction

Higher intensity exercise reduces arterial stiffness in non-pregnant populations by improving both functional and structural components of the vasculature. However, there is currently no evidence on the acute effects of exercise on arterial stiffness across pregnancy. The maternal cardiovascular system may derive more benefits from higher intensity exercise at certain timepoints throughout gestation, given the progressively changing baseline cardiovascular measures. The aim of this study was to observe the acute effects of a combined intervention of weekly vigorous intensity interval training (VIIT), resistance training (RT) and reformer Pilates (PIL) completed throughout pregnancy on measures of arterial stiffness and blood pressure (BP).

### Methods

Pregnant participants were recruited through the Australian Catholic University (ACU) Exercise Lifestyle Clinic (ELC) in Brisbane, Australia. Participants completed three times/week sessions of VIIT (work: 70-85% $HR_{max}$, recovery: ~65% $HR_{max}$), PIL (40-70% $HR_{max}$) and RT (55-70% $HR_{max}$) from recruitment until 36 weeks of gestation. Outcome measures were taken each session prior to exercise, immediately post exercise and again 10 minutes post exercise. The primary outcome measures were arterial stiffness measured by pulse wave velocity (PWV), BP and mean arterial pressure (MAP). Linear mixed effects models were used for each outcome variable of interest in SPSS.

### Results

Twenty participants (33 ± 3.9 years, GW 17 ± 6.5 weeks) completed the study through to the end of the third trimester. There was a significant increase in PWV immediately following all types of exercise (VIIT: +0.22 $m \cdot s^{-1}$, $p < 0.001$; RT: +0.27 $m \cdot s^{-1}$, $p < 0.001$; PIL: +0.27 $m \cdot s^{-1}$, $p < 0.001$). PWV remained significantly higher than rest at 10 minutes following both VIIT (+0.12 $m \cdot s^{-1}$, $p = 0.014$) and RT (+0.13 $m \cdot s^{-1}$, $p = 0.034$) but not PIL (+0.05 $m \cdot s^{-1}$, $p = 0.869$). GW had a significant effect on PWV response across all exercise types (VIIT: 0.29 $m \cdot s^{-1}$, $p < 0.001$; RT: 0.23 $m \cdot s^{-1}$, $p < 0.001$; PIL: 0.030 $m \cdot s^{-1}$, $p < 0.001$). There was a significant increase in MAP immediately following VIIT (+4.22 mmHg, $p < 0.001$) and RT (+4.33 mmHg, $p < 0.001$), which decreased significantly towards baseline levels by 10 minutes post VIIT (-3.04 mmHg, $p < 0.001$) and RT (-2.28 mmHg, $p = 0.012$).

GW had a significant effect on MAP response across all exercise types (VIIT: 0.31 mmHg, $p < 0.001$, RT: 0.41 mmHg, $p < 0.001$, PIL: 0.54 mmHg, $p < 0.001$).

**Conclusions**

The findings from this study indicate that higher intensities of exercise (VIIT and RT) are more likely to elicit larger acute changes in cardiovascular measures including BP and PWV compared to lower intensity exercises such as PIL. Moreover, the ability of exercise to elicit these acute changes seems to be influenced by the stage of pregnancy. It is hypothesised that due to the changes seen in the acute responses across gestation that any potential beneficial adaptations in vasculature that occur with repeated higher intensity exercise bouts may be optimised at specific times in pregnancy. Interestingly, the magnitude of the adaptations to acute exercise aligns with known cardio-obstetric physiology trends across gestation. These findings have important implications for optimising physical activity guidelines in pregnancy.

## 7.1 Introduction

Aerobic exercise reduces arterial stiffness by affecting both functional (endothelium, smooth muscle cells) and structural components (collagen, elastin, connective tissue) (102, 103, 268). Exercise interventions have been shown to improve markers of arterial stiffness including PWV in a range of non-pregnant populations (269, 270). There is evidence to suggest that higher levels of moderate to vigorous intensity physical activity (PA) throughout gestation may improve the arterial stiffness profiles of pregnant women (271), however further research on whether there is an optimum time for this type of exercise during pregnancy is needed.

There is limited evidence available on the effects of regular exercise during pregnancy on measures of arterial stiffness (106-108, 231), with no studies currently published on the acute vascular effects of prenatal exercise. Mode of exercise has been shown to affect the acute and chronic changes in arterial stiffness measures post exercise in non-pregnant populations (101). One systematic review comparing aerobic and resistance training in healthy young adults found that the acute vessel response appears to occur from differing cardiovascular (HR, BP, left ventricular ejection time) and non-cardiovascular (inflammatory products such as c-reactive protein and interleukin-6) modulators, due to factors like the muscle groups recruited and the addition of the Valsalva manoeuvre during intense resistance training (101). A 6.7-7.0% reduction in carotid-femoral pulse wave velocity (cfPWV) was found following aerobic exercise interventions in young and middle-aged adults, with vigorous intensity interval training (VIIT) associated with a 7.5% reduction in cfPWV (103). In non-pregnant populations resistance training (RT) interventions appear to reduce resting PWV, thereby improving arterial stiffness (272). Research suggests the mechanisms for these exercise-induced changes are through anti-oxidative and anti-inflammatory pathways, which over time can result in structural changes and lead to a decrease in arterial stiffness (102). There is a lack of evidence on the effects of RT and Pilates (PIL) on measures of arterial stiffness throughout pregnancy. Longitudinally exploring the acute effects of exercise may elucidate the mechanisms for chronic change in resting arterial stiffness during pregnancy.

Cardiovascular modulators are well known to change throughout pregnancy due to the increase in haemodynamic stress (7, 11), thus, it is important to observe the longitudinal effects of acute exercise bouts as gestation progresses. Within non-pregnant populations, measures of arterial stiffness appear to be closely related to other cardiovascular measures

including heart rate (HR) and BP (100). As such, repeated measures of acute responses to exercise in pregnancy are important to be able to determine trends across gestation. Whether there is an optimal time within pregnancy to gain the most cardiovascular benefit from exercise is not currently known. It is possible to speculate that there may be times in pregnancy where the maternal and foetal cardiovascular system may derive more benefits from higher intensity exercise than others, given that resting cardiovascular measures change across gestation. The ability of the maternal vessels to respond to a stressful environment like vigorous exercise, may reduce as pregnancy progresses given the resting levels are already increased, leaving less room for adaptation. The development of trimester specific guidelines has been identified as a priority research area in a review of international pregnancy exercise guidelines, as current international exercise guidelines provide consistent recommendations throughout the entirety of gestation (77).

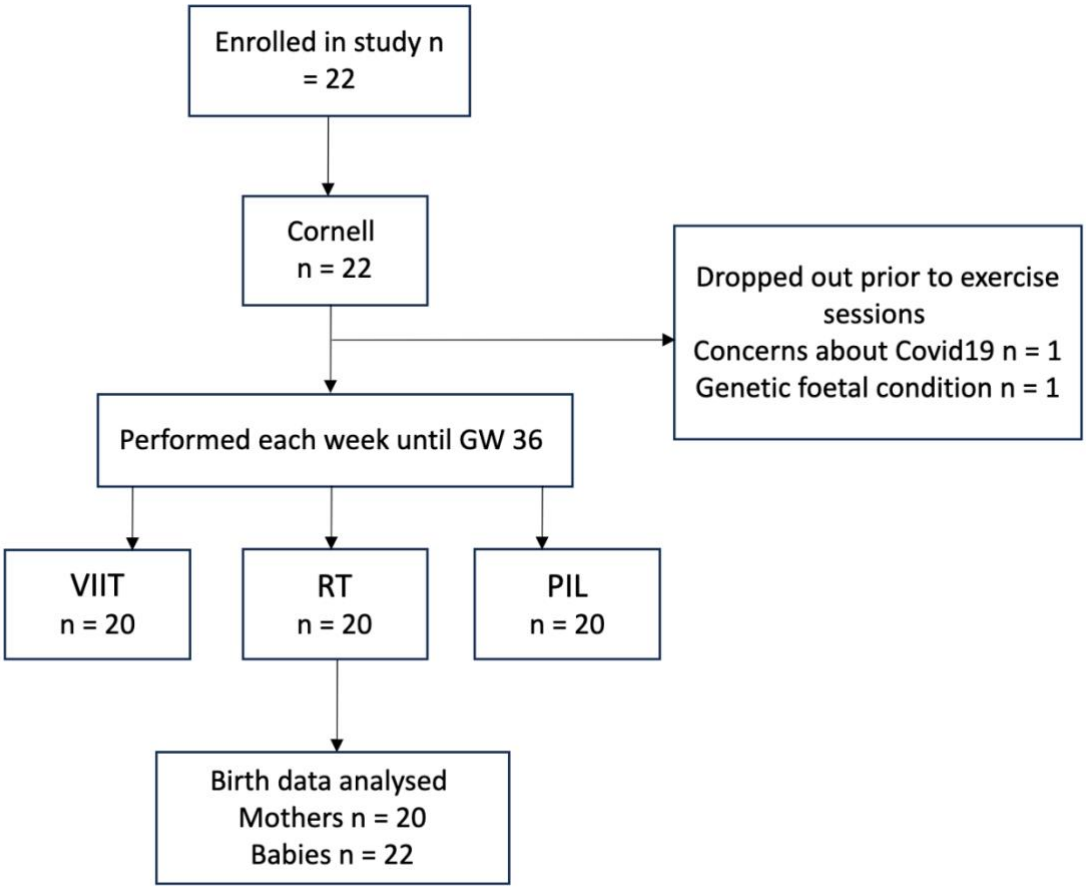
The aim of this study was to observe the acute effects of a combined intervention of VIIT, RT and PIL longitudinally throughout pregnancy on measures of arterial stiffness and BP.

## 7.2 Methods

### 7.2.1 Study participants

Twenty-two pregnant participants (age = 33 ± 3.7 years, pre-pregnancy body mass index (BMI) = 25.08 ± 3.2 kg/m$^2$) were recruited between January 2020 and November 2022 in Brisbane, Australia. Participants were aged between 18-40 years and were non-smokers with no diagnosed cardiovascular or hypertensive conditions at enrolment. Participants were recruited in any trimester of pregnancy up until 32 weeks of gestation in order to maximise recruitment in this novel, mechanistic study. Participants were required to complete the pre-exercise screening tool for pregnancy developed by Exercise and Sports Science Australia (ESSA), as well as the PARmed-X for Pregnancy to gain medical clearance from their health provider. Women with Type 1 Diabetes (T1DM) or a history of gestational diabetes (GDM), gestational hypertension (GHTN) or pre-eclampsia (PE) in previous pregnancies were accepted into the study if they were considered normotensive at the time of enrolment. Participants were also required to complete an online questionnaire through QualtricsXM which collected demographic data. The study protocol was approved by the Australian Catholic University Human Research Ethics Committee (ACU HREC), ethics register number: 2020-103H. All participants provided written informed consent prior to

participation in the study and were able to withdraw at any point without reason. This study was registered under the Australian and New Zealand Clinical Trials Registry (ANZCTR), trial ID: ACTRN12622000982718. *Figure 56* shows the flow of participant recruitment into this study.




VIIT = vigorous intensity interval training; RT = resistance training; PIL = reformer Pilates; Cornell = Cornell submaximal treadmill protocol

Figure 56. Flowchart of participant enrolment

### 7.2.2 Study design

Upon enrolment in the study, participants were required to perform a submaximal graded exercise test following the Cornell protocol, which has previously been used in pregnant populations (135). The Cornell protocol requires participants to walk on a treadmill with the speed and gradient increasing every 2 minutes until 85% of their age predicted heart rate maximum (%$PHR_{max}$) is reached. Participants were asked to avoid caffeine, alcohol and exercise for 12 hours prior to this session. Baseline measures were taken during this session and have been included in *Chapter 5.* The study then consisted of three exercise sessions per week from enrolment up until 36 weeks of gestation. The three types of exercise were VIIT

on the treadmill or cycle ergometer, moderate intensity RT and light to moderate intensity PIL. The order of sessions was randomised each week using a computer generated number randomiser where VIIT = 1, RT = 2 and PIL = 3.

#### *7.2.2.1 Vigorous intensity interval training*

The vigorous intensity interval sessions lasted 33 minutes in total and began with a light 5 min warm up on a treadmill or cycle ergometer (9-11 RPE, 45-60% $HR_{max}$). The participants then performed four, four-minute intervals of vigorous intensity walking or cycling (RPE 14-16, 70-85% $HR_{max}$) interspersed with four, three-minute intervals of moderate intensity walking or cycling (RPE 11-13, ~65% $HR_{max}$). Treadmill was the preferred mode of exercise in the VIIT sessions, however participants were given the option to perform these sessions on a cycle ergometer if they found the treadmill walking too uncomfortable. Across all 229 VIIT sessions, three (~ 1%) sessions were performed on a cycle ergometer. The workload for the VIIT intervals were calculated in metabolic equivalents (METs) using the treadmill speed and gradient in the following American College of Sports Medicine (ACSM) calculation (138):

((Speed (m/min) * 0.1)+(%incline*1.8*(speed (m/min))+3.5)/3.5

#### *7.2.2.2 Resistance training*

The RT sessions included a light 5-minute warm up involving dynamic stretches of each major muscle group. The sessions then consisted of 30 minutes of RT using bodyweight exercises, free weights, resistance bands and machine-based exercises. Exercises were performed in a tri-set, with each set including an upper body, lower body and trunk exercise. Each tri-set was performed 3-4 times, with 8-10 repetitions performed for each exercise. The load was kept to a moderate intensity throughout (RPE 11-13, 55-70%$HR_{max}$). The sessions concluded with a 5-minute cool down involving light static stretching.

#### *7.2.2.3 Reformer Pilates*

The reformer PIL sessions included a light 5-minute warm up involving dynamic stretches of each major muscle group. The sessions then consisted of 30 minutes of light to moderate (RPE 8-13, 40-70%$HR_{max}$) exercises targeting each major muscle group performed on the reformer. Exercises performed in the supine position were avoided at any stage of pregnancy

as a precaution, as supine rest has been associated with symptomatic hypotension in up to 10% of pregnant women due to vena cava compression (140). The sessions concluded with a 5-minute cool down involving light static stretching.

### 7.2.3 Outcome measures

Outcome measures included PWV, pulse wave analysis (PWA), BP, MAP, HR, RPE and foetal heart rate (FHR). Resting measures were obtained following 5 minutes of rest in the semi-recumbent position. During the VIIT sessions HR and RPE were recorded every minute, with BP recorded in the last minute of each stage. In the RT and PIL sessions HR and RPE were recorded every 5 minutes. All outcome measures were taken again immediately post-exercise once the participant had laid down on the plinth and following 10 minutes of rest in the semi-recumbent position.

#### *7.2.3.1 Pulse wave velocity and pulse wave analysis*

Arterial stiffness was measured using the semi-automatic SphygmoCor Xcel system which uses high fidelity applanation tonometry to measure cfPWV. Two measures were taken at each time point with an average of the two measures used in the analysis. Pulse wave analysis was also measured using the SphygmoCor Xcel which captures and analyses a brachial waveform to provide a central aortic waveform. Non-invasive measures of central BP including aortic BP, central pulse pressure (PP) and augmentation index (AIx) were also measured using the same device.

#### *7.2.3.2 Blood pressure and mean arterial pressure*

Resting and post-exercise BP and MAP were measured using the SphygmoCor Xcel device with a brachial cuff. Exercising BP was measured using the auscultation method in the last minute of every stage of the VIIT sessions using a stethoscope and an aneroid sphygmomanometer.

#### *7.2.3.3 Heart rate and foetal heart rate*

HR was measured using photoplethysmography with a chest strap connected via Bluetooth to a phone application. Heart rate recovery (HRR) was calculated following the graded exercise test by recording post exercise HR 1-3 minutes following exercise and subtracting these measures from the peak heart rate achieved (PHR). FHR was measured at rest and

again immediately and 10 minutes post exercise in the semi-recumbent position using a foetal doppler.

#### *7.2.3.4 Maternal and foetal birth outcomes*

Participants were required to complete an online questionnaire through QualtricsXM following delivery which collected maternal (type of delivery, labour duration, gestational week (GW) at delivery, birth complications, interventions used, time spent in hospital following delivery and diagnosed conditions during pregnancy) and foetal (sex, birth weight, height, head circumference, 1- and 5-min APGAR scores) birth outcomes.

#### *7.2.3.5 Statistical analysis*

To determine changes in haemodynamics following the different types of exercise, linear mixed effects models were used for each outcome variable of interest. The intention to treat analysis was performed using IBM SPSS Statistics (Version 29). The dependent variable was specified as the outcome of interest, with participant ID included as a random intercept term. Each type of exercise was analysed separately with age, gestational week, pre-pregnancy BMI and timing of measurement included as fixed effects in the model. Restricted estimated maximum likelihood was utilised as the estimation method for parameter estimation in the linear mixed model. Significance was set at $p < 0.05$; all data are reported as means ± standard deviation unless stated otherwise. Significance levels were adjusted using the Bonferroni correction method to account for multiple comparisons.

## 7.3 Results

A total of 22 women were enrolled in the study and completed the baseline testing session. Two participants withdrew from the study following initial testing, one due to concern about contracting Covid-19 and one due to the diagnosis of a genetic foetal condition at 20 weeks (*Figure 57*). The baseline characteristics for the participants can be seen in *Table 35.* Participants were 33 ± 3.7 years with a GW of 18 ± 6.9 weeks at baseline testing. Ten out of 22 women were primigravid, two participants were carrying twins, and two women had been diagnosed with GDM in previous pregnancies.

Table 35. Participant characteristics at baseline

| | **Total n = 20** |
|---|---|
| **Age (years)** | 33 ± 3.9 |
| **Gestational week** | 18 ± 6.3 |
| **Height (cm)** | 168 ± 6.5 |
| **Pre-pregnancy Weight (kg)** | 71 ± 12.5 |
| **Pre-pregnancy BMI ($kg/m^2$)** | 25.18 ± 3.4 |
| **Ethnicity** | |
| *Caucasian* | 19 |
| *Asian* | 1 |
| **Born in Australia** | |
| *Yes* | 18 |
| *No* | 2 |
| **Parity** | |
| *0* | 12 |
| *1* | 6 |
| *2* | 2 |
| **Gravidity** | |
| *1* | 9 |
| *2* | 7 |
| *3* | 2 |
| *4* | 1 |
| *6* | 1 |

cm = centimetres; kg = kilograms; BMI = body mass index

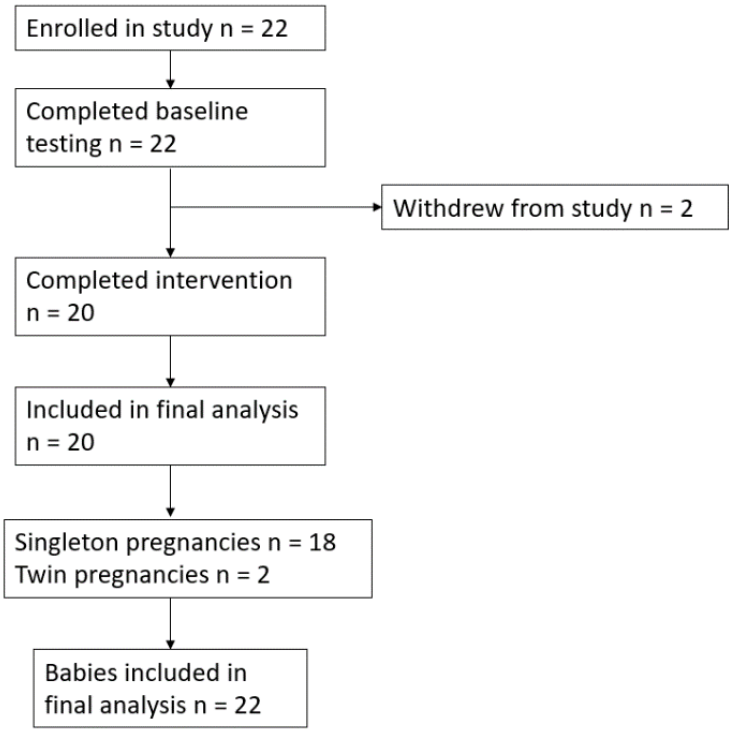



Figure 57. Consort diagram

### 7.3.1 Maternal and foetal heart rate

*Table 36* shows the peak maternal HR (PHR) recorded during each type of exercise across the three trimesters. PHR was highest in the VIIT sessions, and lowest in the PIL sessions. The PHR values indicate that participants achieved the prescribed intensity for each type of exercise across pregnancy. However, PHR decreased slightly in the VIIT and RT sessions from T1-T3, however remained within target ranges. In the PIL sessions PHR decreased from T1-T2, then increased in T3. The maternal HR and FHR responses at rest and following each type of exercise are seen in *Table 37*, showing a decrease in resting maternal HR from T1 to T2 before increasing again in T3. Resting FHR increased by 1 bpm from T2 to T3. Maternal HR showed the greatest increases immediately post VIIT compared to resting levels. FHR showed similar responses to all types of exercise.

Table 36. Peak maternal HR and BP responses to each type of exercise in each trimester

| | | T1 | T2 | T3 |
|---|---|---|---|---|
| **PHR (bpm)** | *VIIT* | 152 ± 6.9 | 148 ± 7.7 | 143 ± 7.9 |
| | *RT* | 131 ± 20 | 129 ± 12.3 | 128 ± 12.6 |
| | *PIL* | 118 ± 9.7 | 114 ± 12.4 | 118 ± 12.0 |
| **PkSBP** | *VIIT* | 145 ± 7.3 | 142 ± 12.8 | 144 ± 13.2 |
| **(mmHg)** | *RT* | N/A | N/A | N/A |
| | *PIL* | N/A | N/A | N/A |
| **PkDBP** | *VIIT* | 62 ± 7.0 | 61 ± 6.7 | 62 ± 4.5 |
| **(mmHg)** | *RT* | N/A | N/A | N/A |
| | *PIL* | N/A | N/A | N/A |

PHR = peak maternal heart rate; PkSBP = peak systolic blood pressure; PkDBP = peak diastolic blood pressure; T1 = trimester 1; T2 = trimester 2; T3 = trimester 3; VIIT = vigorous intensity interval training; RT= resistance training; PIL = Pilates

Table 37. Haemodynamic responses to each type of exercise in each trimester

| | | Trimester 1 (n = 3) | | | Trimester 2 (n =19) | | | Trimester 3 (n = 20) | | | All trimesters | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Variable*** | **Resting** | **1 min post** | **10 min post** | **Resting** | **1 min post** | **10 min post** | **Resting** | **1 min post** | **10 min post** | **Resting** | **1 min post** | **10 min post** |
| **VIIT** | ***PWV ($m.s^{-1}$)*** | 5.83 ± 0.37 | 5.92 ± 0.44 | 5.92 ± 0.48 | 5.19 ± 0.79 | 5.42 ± 0.81 | 5.31 ± 0.84 | 5.75 ± 0.70 | 5.94 ± 0.66 | 5.83 ± 0.71 | 5.52 ± 0.79 | 5.73 ± 0.77$^{\#***}$ | 5.61 ± 0.81$^{\sim**}$ |
| | ***AIx75 (%)*** | 5 ± 10 | 12 ± 32 | 3 ± 14 | 8 ± 22 | 20 ± 16 | 15 ± 117 | 7 ± 18 | 16 ± 21 | 15 ± 19 | 7 ± 19 | 18 ± 20$^{\#***}$ | 14 ± 18$^{\sim***}$ |
| | ***PSBP (mmHg)*** | 119 ± 6 | 132 ± 13 | 122 ± 8 | 115 ± 15 | 121 ± 15 | 114 ± 13 | 118 ± 13 | 123 ± 17 | 118 ± 17 | 117 ± 14 | 122 ± 16$^{\#***}$ | 117 ± 16$^{\wedge***}$ |
| | ***PDBP (mmHg)*** | 66 ± 3 | 71 ± 6 | 69 ± 5 | 68 ± 11 | 71 ± 9 | 70 ± 8 | 74 ± 10 | 75 ± 9 | 75 ± 7 | 71 ± 11 | 74 ± 9$^{\#***}$ | 73 ± 8 |
| | ***MAP (mmHg)*** | 83 ± 3 | 93 ± 10 | 86 ± 6 | 84 ± 12 | 88 ± 10 | 85 ± 9 | 89 ± 11 | 92 ± 12 | 90 ± 10 | 86 ± 13 | 81 ± 11$^{\#***}$ | 88 ± 10$^{\wedge***}$ |
| | ***HR (bpm)*** | 78 ± 4 | 98 ± 10 | 87 ± 4 | 79 ± 13 | 98 ± 10 | 90 ± 10 | 82 ± 10 | 99 ± 11 | 93 ± 12 | 81 ± 11 | 99 ± 11 | 92 ± 11 |
| | ***ASBP (mmHg)*** | 100 ± 4 | 113 ± 11 | 102 ± 6 | 101 ± 13 | 106 ± 13 | 101 ±11 | 104 ±13 | 108 ±14 | 105 ±14 | 103 ±13 | 122 ± 16 | 103 ± 13 |
| | ***ADBP (mmHg)*** | 68 ± 3 | 75 ± 5 | 72 ± 6 | 71 ± 13 | 74 ± 9 | 73 ± 8 | 76 ± 10 | 78 ± 10 | 77 ± 8 | 74 ± 12 | 74 ± 9 | 75 ± 8 |
| | ***PPP (mmHg)*** | 53 ± 6 | 61 ± 9 | 53 ± 5 | 46 ± 12 | 49 ± 11 | 44 ± 9 | 45 ± 10 | 48 ± 12 | 43 ± 13 | 46 ± 11 | 49 ± 11 | 44 ± 12 |
| | ***APP (mmHg)*** | 32 ± 3 | 37 ± 7 | 31 ± 3 | 30 ± 8 | 33 ± 9 | 28 ± 6 | 28 ± 7 | 30 ± 8 | 28 ± 10 | 29 ± 7 | 31 ± 9 | 28 ± 9 |
| | ***FHR (bpm)*** | N/A | N/A | N/A | 147 ± 10 | 147 ± 9 | 147 ± 9 | 147 ± 9 | 149 ± 9 | 147 ± 9 | 147 ± 9 | 148 ± 9 | 148 ± 9 |
| | ***AP (mmHg)*** | 1 ± 4 | 6 ± 14 | -1 ± 3 | 3 ± 6 | 5 ± 6 | 3 ± 6 | 2 ± 5 | 3 ± 6 | 3 ± 6 | 2 ± 6 | 4 ± 7 | 3 ± 6 |
| **RT** | ***PWV ($m.s^{-1}$)*** | 5.98 ± 0.84 | 6.03 ± 0.77 | 5.85 ± 0.51 | 5.39 ± 0.75 | 5.69 ± 0.76 | 5.53 ± 0.70 | 5.68 ± 0.78 | 5.96 ± 0.87 | 5.82 ± 0.80 | 5.56 ± 0.78 | 5.84 ± 0.83$^{\#***}$ | 5.69 ± 0.76$^{\sim*, \wedge**}$ |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***AIx75 (%)*** | 5 ± 13 | 25 ± 15 | 14 ± 15 | 10 ± 24 | 24 ± 20 | 17 ± 16 | 8 ± 20 | 21 ± 20 | 18 ± 21 | 9 ± 22 | 22 ± 20$^{\#***}$ | 17 ± 19$^{\sim***,\ \wedge*}$ |
| | ***PSBP (mmHg)*** | 120 ± 11 | 123 ± 8 | 115 ± 2 | 115 ± 14 | 120 ± 16 | 115 ± 15 | 118 ± 13 | 123 ± 17 | 118 ± 15 | 117 ± 14 | 122 ± 17$^{\#***}$ | 117 ± 15$^{\sim*,\ \wedge*}$ |
| | ***PDBP (mmHg)*** | 65 ± 5 | 64 ± 5 | 66 ± 2 | 68 ± 10 | 70 ± 9 | 70 ± 9 | 72 ± 9 | 75 ± 9 | 75 ± 8 | 70 ± 10 | 73 ± 10$^{\#**}$ | 72 ± 9$^{\sim**}$ |
| | ***MAP (mmHg)*** | 81 ± 6 | 84 ± 4 | 82 ± 5 | 84 ± 12 | 87 ± 12 | 86 ± 11 | 87 ± 10 | 92 ± 11 | 90 ± 10 | 86 ± 11 | 90 ± 12$^{\#***}$ | 88 ± 11$^{\sim*,\ \wedge*}$ |
| | ***HR (bpm)*** | 78 ± 5 | 87 ± 8 | 85 ± 13 | 77 ± 10 | 91 ± 11 | 88 ± 12 | 83 ± 10 | 95 ± 11 | 93 ± 11 | 81 ± 10 | 93 ± 11 | 91 ± 12 |
| | ***ASBP (mmHg)*** | 100 ± 8 | 105 ± 6 | 99 ± 3 | 101 ± 12 | 107 ± 14 | 102 ± 13 | 103 ± 12 | 109 ± 14 | 105 ± 13 | 102 ± 12 | 108 ± 14 | 103 ± 13 |
| | ***ADBP (mmHg)*** | 67 ± 6 | 66 ± 5 | 69 ± 3 | 70 ± 11 | 107 ± 14 | 72 ± 10 | 74 ± 9 | 78 ± 10 | 77 ± 8 | 72 ± 10 | 75 ± 10 | 75 ± 9 |
| | ***PPP (mmHg)*** | 54 ± 13 | 59 ± 8 | 50 ± 2 | 47 ± 11 | 50 ± 13 | 45 ± 10 | 46 ± 9 | 48 ± 13 | 43 ± 10 | 47 ± 10 | 49 ± 13 | 44 ± 10 |
| | ***APP (mmHg)*** | 33 ± 8 | 40 ± 6 | 30 ± 2 | 31 ± 8 | 35 ± 10 | 30 ± 8 | 29 ± 7 | 21 ± 9 | 28 ± 8 | 30 ± 7 | 33 ± 10 | 29 ± 8 |
| | ***FHR (bpm)*** | N/A | N/A | N/A | 146 ± 10 | 147 ± 9 | 147 ± 9 | 146 ± 9 | 148 ± 9 | 148 ± 9 | 146 ± 10 | 147 ± 9 | 148 ± 9 |
| | ***AP (mmHg)*** | 2 ± 4 | 8 ± 8 | 3 ± 3 | 4 ± 10 | 7 ± 8 | 4 ± 5 | 2 ± 7 | 5 ± 8 | 3 ± 7 | 3 ± 8 | 6 ± 8 | 10 ± 20 |
| **PIL** | ***PWV ($m.s^{-1}$)*** | 5.58 ± 0.25 | 5.86 ± 0.45 | 5.87 ± 0.23 | 5.26 ± 0.76 | 5.37 ± 0.71 | 5.21 ± 0.71 | 5.53 ± 0.75 | 5.78 ± 0.71 | 5.62 ± 0.77 | 5.41 ± 0.76 | 5.59 ± 0.73$^{\#***}$ | 5.44 ± 0.77$^{\wedge*}$ |
| | ***AIx75 (%)*** | 12 ± 8 | 13 ± 10 | 13 ± 12 | 11 ± 20 | 17 ± 16 | 16 ± 14 | 11 ± 21 | 14 ± 19 | 17 ± 19 | 11 ± 20 | 15 ± 17 | 17 ± 17 |
| | ***PSBP (mmHg)*** | 121 ± 3 | 125 ± 7 | 120 ± 4 | 113 ± 15 | 113 ± 12 | 112 ± 10 | 118 ± 13 | 120 ± 16 | 117 ± 15 | 116 ± 14 | 117 ± 14 | 115 ± 13 |
| | ***PDBP (mmHg)*** | 67 ± 3 | 63 ± 4 | 66 ± 2 | 66 ± 9 | 66 ± 8 | 67 ± 7 | 74 ± 10 | 73 ± 10 | 74 ± 9 | 70 ± 10 | 69 ± 10 | 71 ± 9 |
| | ***MAP (mmHg)*** | 89 ± 12 | 81 ± 4 | 82 ± 4 | 82 ± 11 | 81 ± 10 | 83 ± 9 | 88 ± 10 | 89 ± 12 | 89 ± 10 | 85 ± 11 | 85 ± 11 | 86 ± 10 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***HR (bpm)*** | 88 ± 20 | 82 ± 4 | 83 ± 4 | 76 ± 9 | 88 ± 12 | 82 ± 11 | 82 ± 9 | 92 ± 12 | 85 ± 9 | 80 ± 10 | 90 ± 12 | 84 ± 10 |
| | ***ASBP (mmHg)*** | 108 ± 13 | 103 ± 4 | 100 ± 5 | 99 ± 14 | 100 ± 11 | 99 ± 9 | 104 ± 11 | 105 ± 14 | 104 ± 13 | 102 ± 13 | 103 ± 13 | 102 ± 11 |
| | ***ADBP (mmHg)*** | 72 ± 9 | 64 ± 3 | 67 ± 2 | 68 ± 9 | 67 ± 8 | 69 ± 7 | 75 ± 10 | 75 ± 10 | 76 ± 9 | 72 ± 10 | 71 ± 10 | 73 ± 9 |
| | ***PPP (mmHg)*** | 54 ± 3 | 61 ± 9 | 54 ± 6 | 48 ± 12 | 48 ± 9 | 45 ± 9 | 45 ± 10 | 47 ± 10 | 43 ± 9 | 46 ± 11 | 48 ± 10 | 44 ± 9 |
| | ***APP (mmHg)*** | 36 ± 6 | 39 ± 6 | 33 ± 5 | 31 ± 9 | 33 ± 7 | 30 ± 7 | 29 ± 7 | 30 ± 8 | 28 ± 7 | 30 ± 8 | 31 ± 8 | 29 ± 7 |
| | ***FHR (bpm)*** | N/A | N/A | N/A | 145 ± 10 | 147 ± 9 | 148 ± 10 | 148 ± 7 | 148 ± 8 | 149 ± 9 | 147 ± 9 | 148 ± 8 | 148 ± 10 |
| | ***AP (mmHg)*** | 4 ± 4 | 4 ± 4 | 4 ± 3 | 5 ± 11 | 6 ± 6 | 5 ± 6 | 3 ± 7 | 3 ± 8 | 4 ± 6 | 4 ± 9 | 4 ± 7 | 4 ± 6 |
| **Total** | ***PWV ($m.s^{-1}$)*** | 5.74 ± 0.56 | 5.89 ± 0.54 | 5.83 ± 0.45 | 5.28 ± 0.77 | 5.51 ± 0.78 | 5.38 ± 0.78 | 5.67 ± 0.75 | 5.90 ± 0.76 | 5.76 ± 0.77 | 5.50 ± 0.78 | 5.73 ± 0.79 | 5.59 ± 0.79 |
| | ***AIx75 (%)*** | 7 ± 10 | 20 ± 22 | 11 ± 14 | 11 ± 22 | 21 ± 17 | 16 ± 16 | 9 ± 19 | 17 ± 20 | 17 ± 20 | 9 ± 20 | 19 ± 19 | 16 ± 18 |
| | ***PSBP (mmHg)*** | 120 ± 7 | 127 ±9.7 | 118 ± 6.2 | 115 ± 14 | 119 ± 15 | 114 ± 13 | 118 ± 13 | 122 ± 17 | 105 ± 14 | 117 ± 14 | 121 ± 16 | 116 ± 15 |
| | ***PDBP (mmHg)*** | 67 ± 6 | 68 ± 7.4 | 67 ± 3.8 | 68 ± 10 | 69 ± 9 | 69 ± 8 | 73 ± 10 | 75 ± 9 | 77 ± 8 | 70 ± 10 | 72 ± 10 | 72 ± 9 |
| | ***MAP (mmHg)*** | 85 ± 8 | 88 ± 8.2 | 84 ± 4.7 | 83 ± 12 | 87 ± 11 | 85 ± 10 | 88 ± 11 | 91 ± 12 | 90 ± 10 | 86 ± 11 | 89 ± 12 | 87 ± 10 |
| | ***HR (bpm)*** | 81 ± 12 | 91 ± 12 | 86 ± 7 | 78 ± 11 | 93 ± 12 | 87 ± 12 | 83 ± 10 | 96 ± 12 | 91 ± 11 | 81 ± 11 | 94 ± 12 | 89 ± 12 |
| | ***ASBP (mmHg)*** | 103 ± 9 | 108 ± 9 | 100 ± 5 | 101 ± 13 | 105 ± 13 | 101 ± 11 | 104 ± 12 | 107 ± 14 | 105 ± 14 | 102 ± 13 | 106 ± 14 | 103 ± 13 |
| | ***ADBP (mmHg)*** | 70 ± 7 | 70 ± 8 | 70 ± 4 | 70 ± 11 | 71 ± 9 | 72 ± 9 | 75 ± 10 | 77 ± 10 | 77 ± 8 | 73 ± 11 | 74 ± 10 | 74 ± 9 |
| | ***PPP (mmHg)*** | 53 ± 9 | 59 ± 9 | 51 ± 6 | 47 ± 12 | 50 ± 11 | 45 ± 9 | 45 ± 10 | 48 ± 12 | 43 ± 11 | 46 ± 11 | 49 ± 12 | 44 ± 10 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***APP (mmHg)*** | 33 ± 5 | 38 ± 6 | 31 ± 4 | 31 ± 8 | 34 ± 9 | 29 ± 7 | 28.6 ± 7.1 | 30 ± 9 | 28 ± 9 | 30 ± 8 | 32 ± 9 | 29 ± 8 |
| | ***FHR (bpm)*** | N/A | N/A | N/A | 146 ± 10 | 147 ± 9 | 147 ± 9 | 147 ± 9 | 148 ± 9 | 148 ± 9 | 147 ± 9 | 148 ± 9 | 148 ± 9 |
| | ***AP (mmHg)*** | 2 ± 4 | 6 ± 9 | 2 ± 4 | 4 ± 9 | 6 ± 7 | 4 ± 6 | 2 ± 6 | 4 ± 8 | 3 ± 6 | 3 ± 8 | 5 ± 7 | 4 ± 6 |

PWV pulse wave velocity, AIx75 augmentation index normalised to HR:75bpm, PSBP peripheral systolic blood pressure, PDBP peripheral diastolic blood pressure, MAP mean arterial pressure, HR maternal heart rate, ASBP aortic systolic blood pressure, ADBP aortic diastolic blood pressure, PPP peripheral pulse pressure, APP aortic pulse pressure, AP aortic augmented pressure

# significant difference from rest to immediately post exercise, ~ significant difference from rest to 10 minutes post exercise, ^ significant difference from immediately post to 10 minutes post exercise. $p < 0.05$ *, $p < 0.01$ **, $p < 0.001$ ***

### 7.3.2 Pulse wave velocity

*Figure 58* shows the resting PWV and responses to all exercise types across gestation, with the solid lines representing the average across all participants, and each dot representing one participant at each time point during each GW. Resting PWV decreased into T2, reaching a nadir at 17-18 weeks before increasing into T3. This plateaus in T3 at around 29-30 weeks before increasing again up to 36 weeks of gestation. *Figure 59* shows the PWV responses to each type of exercise across the gestational weeks.

There was a significant increase in PWV immediately following (+0.22 $m \cdot s^{-1}$) and 10 minutes (+0.12 $m \cdot s^{-1}$) post exercise in the VIIT sessions. Age (0.79 $m \cdot s^{-1}$, $p = 0.020$, 95% CI [0.14-0.14]), GW (0.29 $m \cdot s^{-1}$, $p < 0.001$, 95% CI [0.24-0.35]) and pre-pregnancy BMI (PreBMI) (0.86 $m \cdot s^{-1}$, $p = 0.026$, 95% CI [0.12-0.16]) all had a significant effect on PWV. There was a significant increase in PWV immediately (+0.27 $m \cdot s^{-1}$) and 10 minutes (+0.13 $m \cdot s^{-1}$) post exercise in the RT sessions. There was a significant decrease in PWV from immediately post to 10 minutes post exercise (-0.15 $m \cdot s^{-1}$). GW (0.23 $m \cdot s^{-1}$, $p < 0.001$, 95% CI [0.17-0.30]) and PreBMI (0.09 $m \cdot s^{-1}$, $p = 0.034$, 95% CI [0.01-0.16) had a significant effect on PWV in the RT sessions, with no significant effect of age (0.06 $m \cdot s^{-1}$, $p = 0.099$, 95% CI [-0.01-0.12]). There was a significant increase in PWV immediately following PIL sessions (+0.18 $m \cdot s^{-1}$), with no significant difference seen between PWV at rest and 10 minutes post PIL sessions (0.05 $m \cdot s^{-1}$). There was a significant decrease in PWV from immediately post to 10 minutes post PIL (-0.13 $m \cdot s^{-1}$). Age (0.07 $m \cdot s^{-1}$, $p = 0.027$, 95% CI [0.01-0.13]), GW (0.03 $m \cdot s^{-1}$, $p < 0.001$, 95% CI [0.02-0.04) and PreBMI (0.09 $m \cdot s^{-1}$, $p = 0.017$, 95% CI [0.02-0.16]) all had a significant effect on PWV in the PIL sessions.

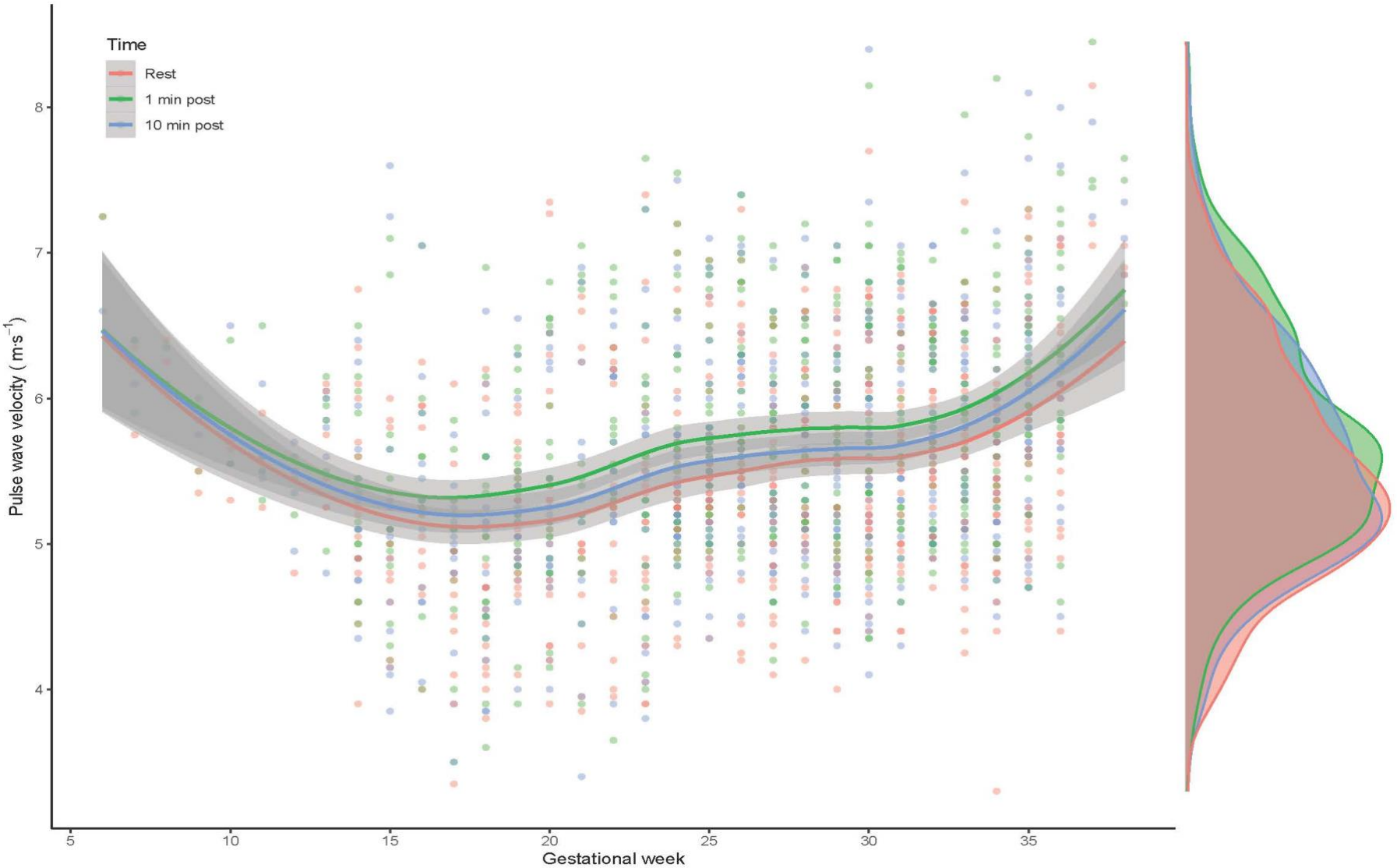



Figure 58. PWV responses to exercise (all types) across gestational weeks (rest, immediately post and 10 minutes post)

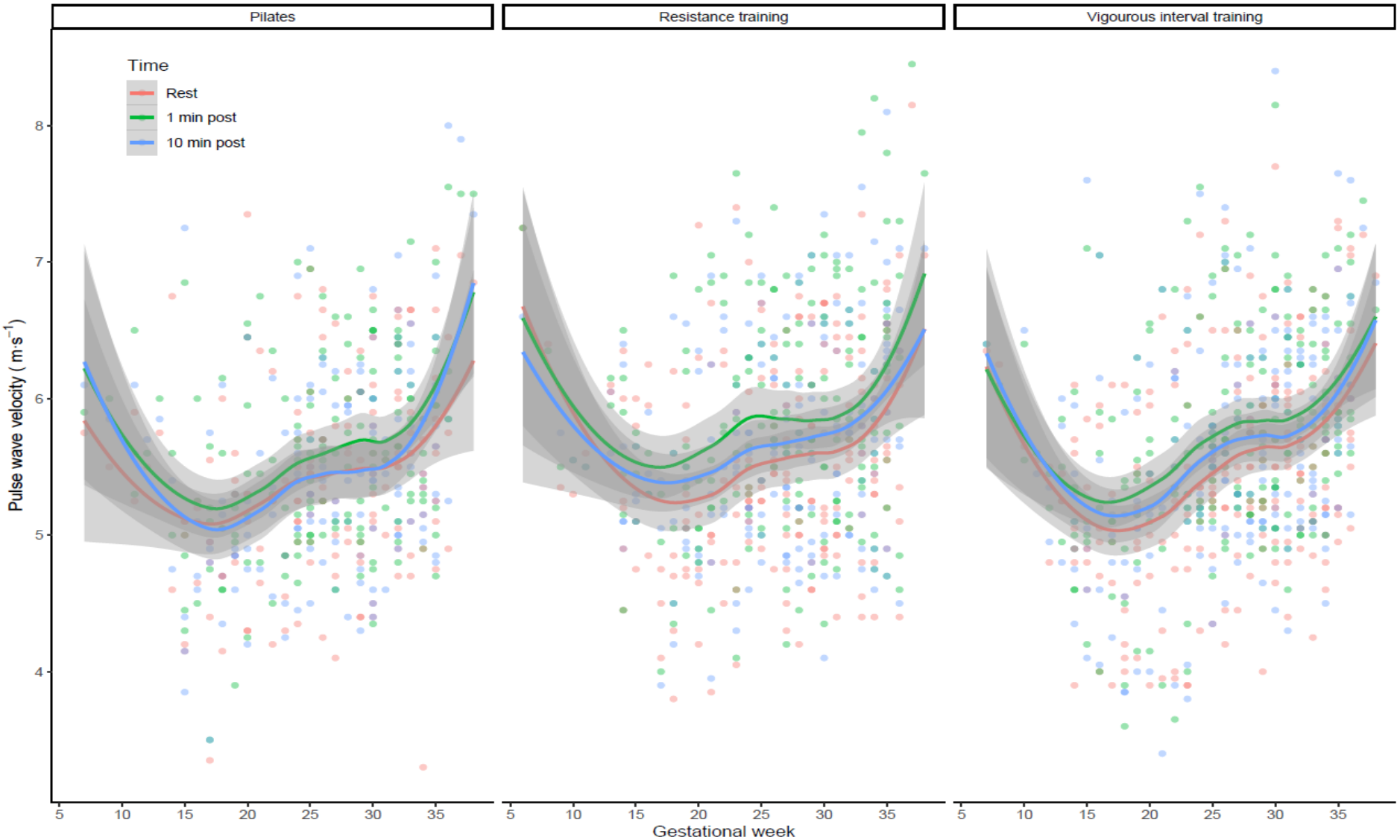



Figure 59. PWV responses to exercise by type across gestational weeks (rest, immediately post and 10 minutes post)

### 7.3.3 Augmentation index

*Figure 60* shows the resting AIx75 and responses to exercise across gestation for all exercise types combined and *Figure 61* shows the responses in AIx75 to each type of exercise at each time point. Average resting AIx75 increased slightly from T1 to T2, before decreasing again in T3. Compared with rest, there was a significant increase in AIx75 immediately following (+9.90%) and at 10 minutes post VIIT sessions (+6.24%). There was a non-significant decrease in AIx75 from immediately to 10 minutes post VIIT (-3.66%). Gestational week (-0.31%) had a significant effect on AIx75 in the VIIT sessions, with no significant effect of age (0.84%, p = 0.139, 95% CI [-0.30-1.98]) or PreBMI (0.87%, p = 0.187, 95% CI [-0.46-2.19]). There was a significant increase in AIx75 immediately (+13.55%) and 10 minutes (+8.49%) following RT. There was a significant decrease in AIx75 seen from immediately to 10 minutes post RT (-5.06%). There was no significant effect of age (0.74%, p = 0.196, 95% CI [-0.41-1.88]), GW (-0.18%, p = 0.144, 95% CI [-0.42-0.06]) or PreBMI (0.67%, p = 0.297, 95% CI [-0.64-1.97]) in the RT sessions. Age (0.83%, p = 0.172, 95% CI [-0.39-2.05]), GW (-0.03%, p = 0.823, 95% CI [ -0.29-0.24]) and PreBMI (0.97%, p = 0.172, 95% CI [-0.46-2.41]) did not have a significant effect on AIx75 in the PIL sessions.

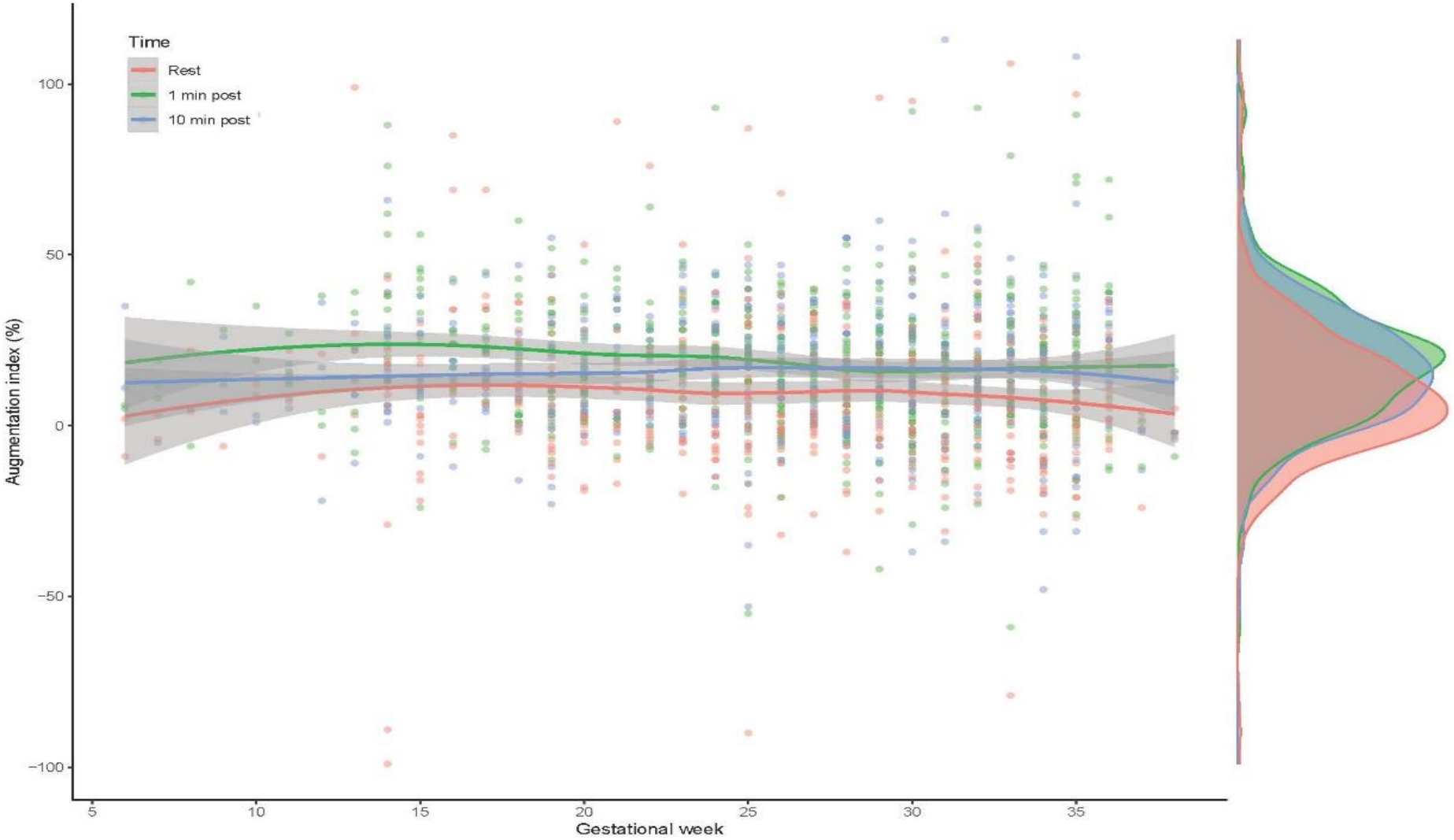



Figure 60. AIx75 responses to exercise (all types) across gestational weeks (rest, immediately post and 10 minutes post)

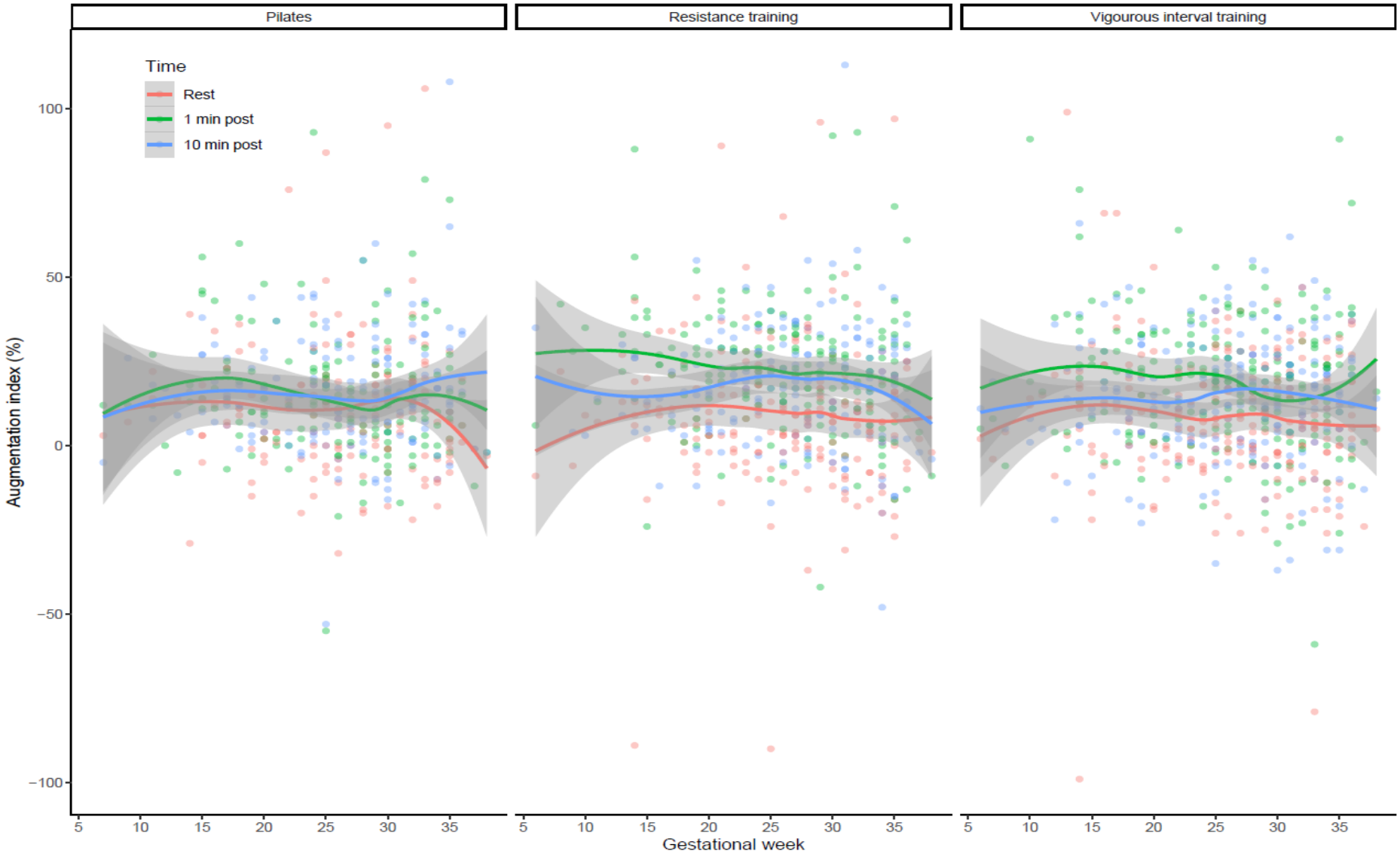



Figure 61. AIx75 responses to exercise by type across gestational weeks (rest, immediately post and 10 minutes post)

### 7.3.4 Peripheral mean arterial pressure

*Figure 62* shows the resting MAP and responses to exercise across gestation. Average resting MAP decreased from T1 to T2, before increasing gradually from ~20 weeks throughout T3. *Figure 63* shows the MAP responses to each type of exercise across gestation. There was a significant increase in MAP immediately following VIIT (+4.22 mmHg), with no significant difference seen in MAP from rest to 10 minutes post VIIT. MAP then decreased significantly towards resting levels from immediately to 10 minutes post exercise (-3.04 mmHg). GW (0.31 mmHg, $p < 0.001$, 95% CI [0.21-0.40]) and PreBMI (1.28 mmHg, $p = 0.009$, 95% CI [0.36-2.21]) had a significant effect on MAP in the VIIT sessions, whilst age had no significant effect (-0.06 mmHg, $p = 0.887$, 95% CI [-0.85-0.74]). There was a significant increase in MAP immediately (+4.33 mmHg) and 10 minutes (+2.05 mmHg) post RT. MAP then decreased significantly towards resting levels from immediately to 10 minutes post exercise (-2.28 mmHg). GW (0.41 mmHg, $p < 0.001$, 95% CI [0.30-0.51]) and PreBMI (1.33 mmHg, $p = 0.012$, 95% CI [0.32-2.35]) had a significant effect on MAP in the RT sessions, whilst age had no significant effect (0.09 mmHg, $p = 0.827$, 95% CI [-0.79-0.97). Gestational week had a significant effect on MAP in the PIL sessions (0.54 mmHg, $p < 0.001$, 95% CI [0.42-0.67]), whilst PreBMI neared significance (1.05 mmHg, $p = 0.053$, 95%CI [-0.01-2.21]), and there was no significant effect of age (-0.33 mmHg, $p = 0.457$, 95% CI [-1.24-0.58]).

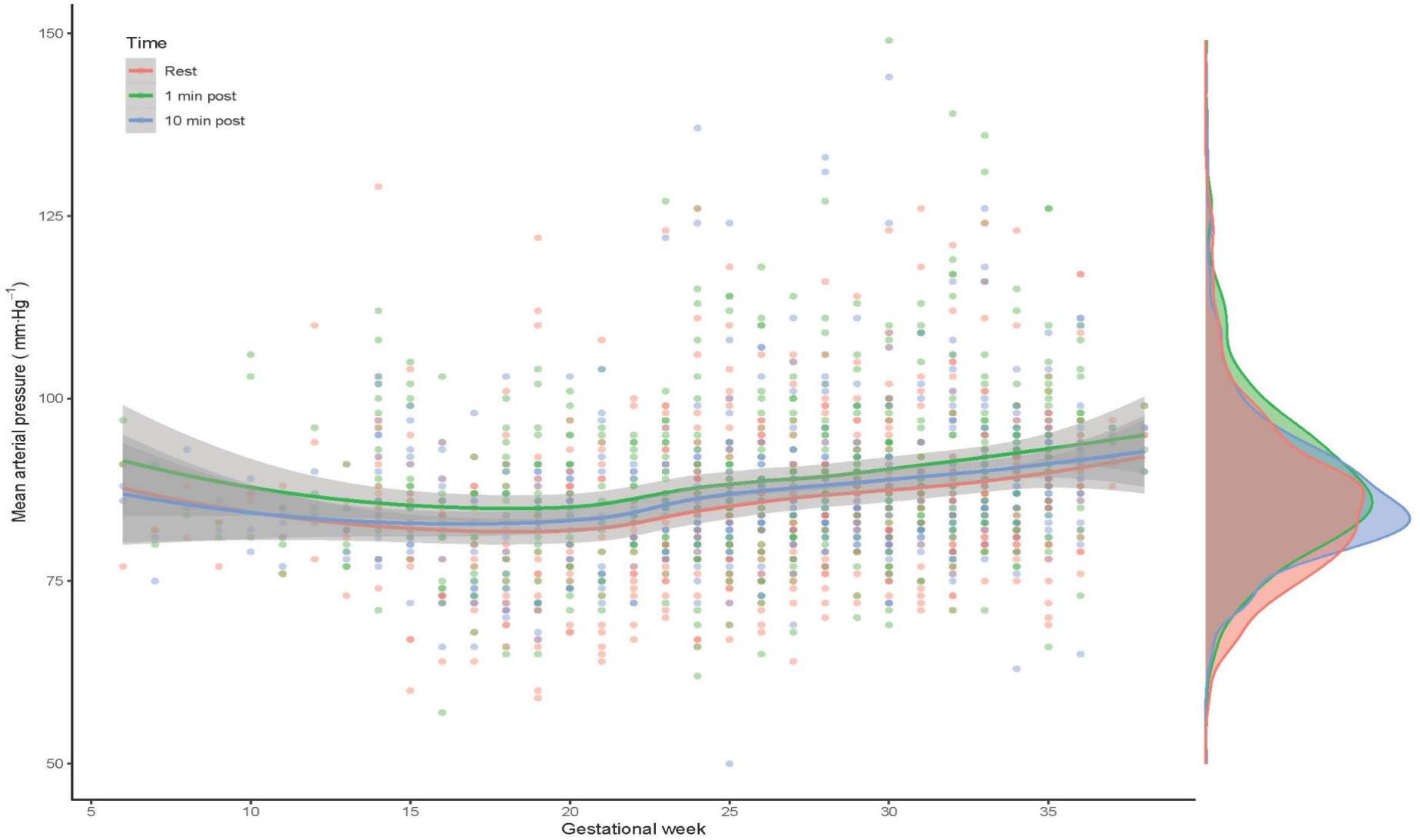



Figure 62. MAP responses to exercise (all types) across gestational weeks (rest, immediately post and 10 minutes post exercise)

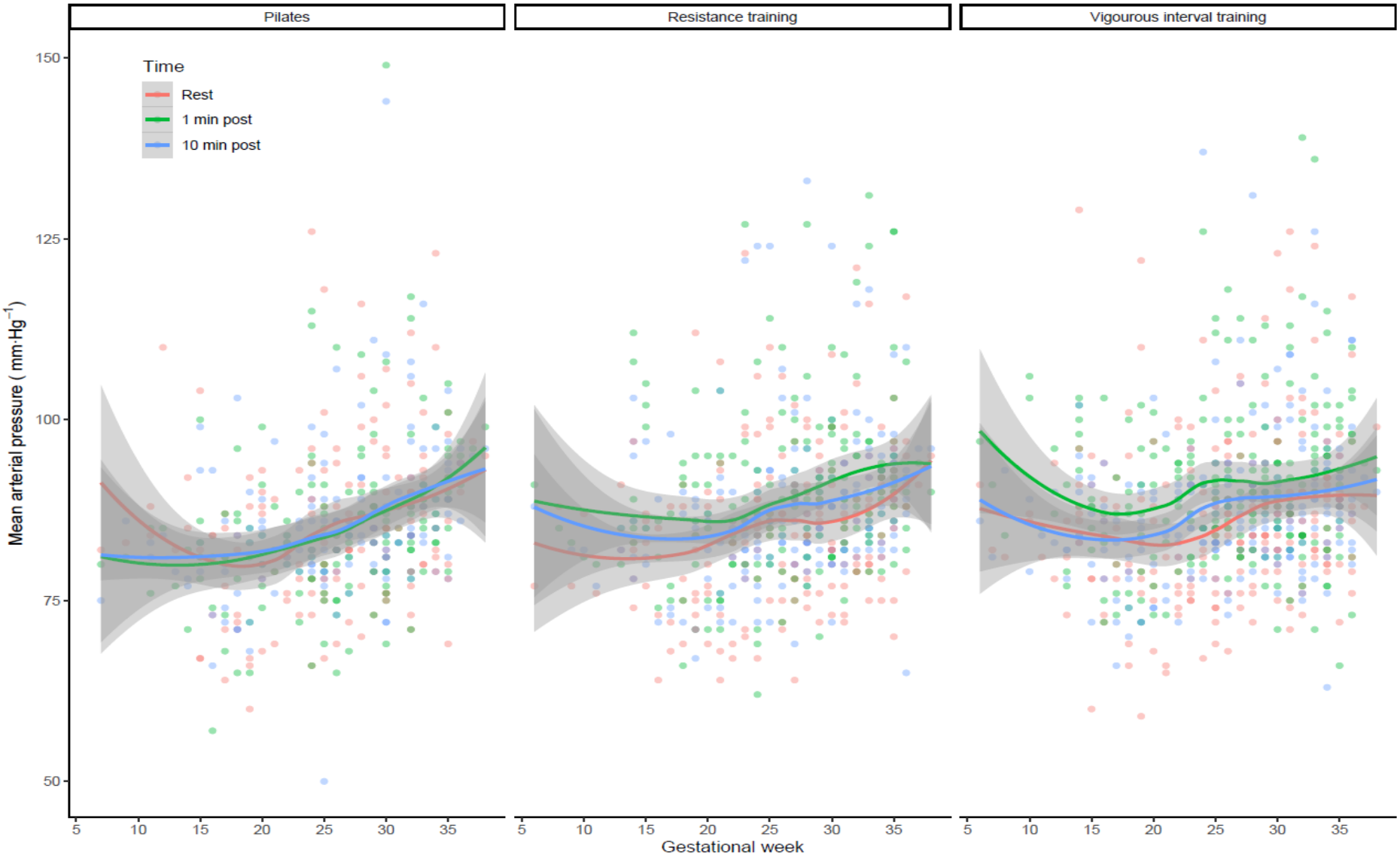



Figure 63. MAP responses to exercise by type across gestational weeks (rest, immediately post and 10 minutes post)

### 7.3.5 Blood pressure

Average resting PSBP decreased from T1 to T2, before increasing again in T3. There was a significant increase in PSBP immediately following VIIT (+5.79 mmHg), with no significant difference seen 10 minutes post exercise (-0.83 mmHg). There was a significant decrease in PSBP from immediately to 10 minutes post VIIT (-6.62 mmHg). GW (0.22 mmHg, p = 0.002, 95% CI [0.79-0.36]) and PreBMI (2.01 mmHg, p = 0.001, 95% CI [0.89-3.13]) had a significant effect on PSBP in VIIT sessions, with no significant effect of age (0.61 mmHg, p = 0.89, 95% CI [-0.91-1.03]). Peak SBP (PkSBP) during VIIT sessions decreased slightly from T1 to T2, then increased in T3 (*Table 36*). PSBP increased significantly immediately following RT (+5.15 mmHg). There was a significant decrease from immediately to 10 minutes post exercise (-5.38 mmHg). GW (0.35 mmHg, p < 0.001, 95% CI [0.21-0.49]) and PreBMI (1.97 mmHg, p = 0.009, 95% CI [0.55-3.38]) had a significant effect on PSBP in RT sessions, with no significant effect of age (0.09 mmHg, p = 0.89, 95% CI [-1.14-1.31]). GW (0.38 mmHg, p < 0.001, 95% CI [0.22-0.55]) and PreBMI (1.44 mmHg, p = 0.035, 95% CI [0.11-2.77]) had a significant effect on PSBP in PIL sessions, with no significant effect of age (-3.39 mmHg, p = 0.475, 95% CI [-1.53-0.74]).

Average resting PDBP increasing gradually from T1, to T2 and T3. There was a significant increase in PDBP immediately following VIIT (+2.36 mmHg). GW (0.38 mmHg, p < 0.001, 95% CI [0.29-0.46]) and PreBMI (0.95 mmHg, p = 0.013, 95% CI [0.23-1.68]) had a significant effect on PDBP in VIIT sessions, with no significant effect of age (-0.18 mmHg, p = 0.562, 95% CI [-0.79-0.45]). Peak DBP (PkDBP) during the VIIT sessions did not change across gestation (*Table 36*). There was a significant increase in PDBP immediately (+2.55 mmHg) and 10 minutes (+2.23 mmHg) post RT. GW (0.49 mmHg, p < 0.001, 95% CI [0.39-0.58]) and PreBMI (1.08 mmHg, p = 0.006, 95% CI [0.35-1.82]) had a significant effect on PDBP in RT sessions, with no significant effect of age (-0.03 mmHg, p = 0.920, 95% CI [-0.67-0.61]). GW (0.64 mmHg, p < 0.001, 95% CI [0.54-0.75]) had a significant effect on PDBP in PIL sessions, with no significant effect of PreBMI (0.71 mmHg, p = 0.096, 95%CI [-0.14-1.55]) age (-0.39 mmHg, p = 0.261, 95% CI [-1.12-0.32]).

### 7.3.6 Adherence

The adherence to the intervention ranged from as low as 30% to as high as 98%. On average the participants attended 55 ± 16% of the exercise sessions. Adherence increased slightly

from T1 (50.8 ± 13.7%) to T2 (58.5 ± 19.1%), then declined as gestation progressed into T3 (52.3 ± 19.9%). Adherence to each type of exercise ranged from 44.1 ± 17.3% for PIL, 53.9 ± 18.4% for RT and 63.6 ± 19.5% for VIIT.

### 7.3.7 Maternal and foetal delivery outcomes

Maternal and foetal birth outcomes can be viewed in *Table 38* and *39*. The two participants that withdrew from the study after the initial testing session did not provide responses to the post intervention questionnaire. There were two twin pregnancies in the study, therefore 22 babies were included in the final analysis. Nineteen out of 22 babies were born within the healthy weight range (2500-4500 g) and 21/22 babies received 5 min APGAR score: ≥ 7. Two babies (twins) were born preterm at 32 weeks with low birth weights of 1.8 kg and 1.7 kg. Despite being born preterm and low birth weight, both babies received a 9/9 5-minute APGAR score. One baby was born large for gestational age at 40 + 1 weeks weighing 4.87 kg, and received a 5-minute APGAR score of 7/9. Only one out of 22 babies received a 5-minute APGAR score < 7 (6/9). This baby (GA at delivery 38 + 6 weeks, birthweight 3.60 kg) reportedly suffered from respiratory distress syndrome and was required to stay in hospital for 10 days following delivery. The average gestational age at delivery was 39 ± 2 weeks (range 32-41.5 weeks). The average labour lasted 14 ± 16.4 hours (range 2-73), and the participants spent on average 3.0 ± 2.3 days (range 6 hours – 10 days) in hospital following delivery. Following completion of the study one participant was diagnosed with GHTN and PE (GW 36) whilst another was diagnosed with GHTN (GW 32, delivered twins at 32 weeks). During the intervention two participants were diagnosed with GDM (GW 24 & 28), both of whom were considered to have a higher risk of developing GDM due to a diagnosis in a previous pregnancy, or carrying twins.

Table 38. Maternal and foetal delivery outcomes

| **Maternal delivery outcomes** | **n = 20** |
|---|---|
| **Type of delivery** | |
| *Vaginal* | 15 |
| *C section* | 2 |
| *Water birth* | 2 |
| *Emergency C section* | 1 |
| **Labour duration (hrs)** | 14 ± 16.4 |
| **GW at delivery** | 39 ± 1.9 |
| **Complications** | |
| *Perineal tears* | 7 |
| *Foetal distress* | 6 |
| *Labour that did not progress* | 2 |
| *Excessive bleeding* | 2 |
| *Umbilical cord problems* | 1 |
| *Clitoral tears* | 1 |
| *Shoulder dystocia* | 1 |
| *Breech* | 1 |
| *Placental abruption* | 1 |
| *Preterm Labour* | 0 |
| **Interventions used** | |
| *Epidural* | 7 |
| *Episiotomy* | 7 |
| *Vacuum* | 4 |
| *Induction* | 3 |
| *Forceps* | 1 |
| **Time spent in hospital following delivery (days)** | 3.0 ± 2.3 |
| **Diagnosed conditions during pregnancy** | |
| *GHTN* | 2 |
| *GDM* | 2 |
| *PE* | 1 |

C section = Caesarean section; GW = gestational week; GHTN = gestational hypertension; GDM = gestational diabetes mellitus; PE = pre-eclampsia

Table 39. Foetal birth outcomes

| **Foetal outcomes** | n = **22** | **Range** |
|---|---|---|
| **Sex** | | |
| *Female* | 10 | |
| *Male* | 12 | |
| **Weight (kg)** | 3.36 ± 0.69 | 1.70-4.87 |
| **Length (cm)** | 51.62 ± 3.54 | 42.5-59 |
| **Head Circumference** | 34.65 ± 1.78 | 31.5-39 |
| **APGAR 1** | 8 ± 2 | 4-9 |
| **APGAR 5** | 9 ± 1 | 6-9 |

APGAR 1 and 5 are tests given to newborns 1 and 5 minutes after birth; scored out of 10 with a score > 7 considered in good health, and < 7 requiring further medical care. Acronym stands for: Appearance, Pulse, Grimace, Activity, Respiration.

### 7.3.8 Enjoyment/preferences

In the post-delivery questionnaire participants were asked: "On a scale of 0-10 how much did you enjoy the VIIT/RT/PIL sessions?" and "On a scale of 0-10 how motivated were you to complete the VIIT/RT/PIL sessions?" Where 0 = not at all and 10 = extremely motivated. They were also asked to rank the three modes of exercise in order of first, second and third preference. The results can be seen in *Table 40* and *41*. The VIIT sessions were ranked the least enjoyable (6/10 ± 2, range 0-10/10), with only one out of twenty participants listing VIIT as their first preference. RT and PIL measured similarly in terms of enjoyment and motivation (Enjoyment: RT 9/10 ± 2, range 3-10; PIL 9/10 ± 1, range 7-10; Motivation: RT 9/10 ± 2, range 3-10, PIL 9/10 ± 1, range 6-10).

Table 40. Enjoyment and motivation levels of each type of exercise

| | | **Mean ± SD** | **Range** |
|---|---|---|---|
| **Enjoyment /10** | *VIIT* | 6 ± 2 | 0-10 |
| | *RT* | 9 ± 2 | 3-10 |
| | *PIL* | 9 ± 1 | 7-10 |
| **Motivation /10** | *VIIT* | 6 ± 3 | 0-10 |
| | *RT* | 9 ± 2 | 3-10 |
| | *PIL* | 9 ± 1 | 6-10 |

VIIT = vigorous intensity interval training; RT = resistance training; PIL = Pilates

Table 41. Exercise preferences

| Exercise Preferences | n = 20 |
|---|---|
| **1st preference** | |
| *VIIT* | 1 |
| *RT* | 9 |
| *PIL* | 10 |
| **2nd Preference** | |
| *VIIT* | 3 |
| *RT* | 10 |
| *PIL* | 7 |
| **3rd Preference** | |
| *VIIT* | 16 |
| *RT* | 1 |
| *PIL* | 3 |

VIIT = vigorous intensity interval training; RT = resistance training; PIL = Pilates

## 7.4 Discussion

The aim of this study was to longitudinally observe the acute effects of a combined intervention of VIIT, RT and reformer PIL on measures of arterial stiffness and BP throughout gestation. The study found that all resting measures of arterial stiffness and BP changed across gestation, with PWV and BP reaching a nadir in the second trimester before increasing again in the third trimester. All types of exercise resulted, on average, in an acute increase in PWV, which decreased back towards resting levels by 10 minutes post exercise. The magnitude of this change was associated with the gestational week the session was performed in. BP and MAP increased significantly with VIIT and RT, with no significant change seen in these measures with PIL. Despite greater increases in maternal HR during and following the vigorous exercise sessions, FHR responses remained similar (and within normal clinical ranges) across exercise types. PIL and RT were rated similarly by participants in terms of enjoyment and motivation, with VIIT being scored the least enjoyable and motivating.

***Exercise haemodynamics***

In the current study, a significant increase in PWV was seen immediately and 10 minutes post VIIT and RT, with an increase immediately post PIL but not at 10 minutes post PIL. This aligns with previous systematic evidence in non-pregnant healthy adults which saw an increase in central PWV immediately following exercise (aerobic and resistance), and a

decrease within 30 minutes post exercise (100). Exercise mode, the arterial segment being analysed, and the timing of measurement post exercise are important considerations when assessing the acute impact of exercise on arterial stiffness (100, 101). In non-pregnant populations RT has been associated with greater increases in PWV immediately following exercise compared to aerobic exercise (101). One systematic review found no change in cfPWV following aerobic exercise in healthy young adults, however authors highlighted that the timing of measurements in the included studies varied from 0-60 minutes post exercise (101). Further analysis revealed that measurements taken sooner post exercise were more likely to show an increase in arterial stiffness with AE, than those taken later (101). This supports the findings from this study, with increases in cfPWV seen immediately post VIIT and RT, before decreasing as rest continued.

The mechanisms through which exercise elicits acute changes in arterial stiffness are complex, and not yet fully understood (100, 101). It has been suggested that the difference in acute arterial stiffness responses following aerobic and resistance exercise may be due to distinct BP changes (101). Aerobic exercise causes sustained elevations in BP, whilst intense RT leads to brief, intermittent spikes in BP due to muscle engagement patterns, and physiological responses like the Valsalva manoeuvre (101, 105). Consequently, these high intermittent pressures may temporarily shift the burden of load bearing from elastin to collagen fibres within the arteries, leading to an increase in PWV (101, 105). This may also explain why in this study we observed increases in PWV immediately following VIIT *and* RT, as the vigorous intervals likely caused similar intermittent increases in BP to the RT sessions. Indeed, significant increases in SBP, DBP and MAP were seen immediately post VIIT and RT, and not PIL. BP was not measured *during* exercise in the RT sessions, however peak SBP during the VIIT sessions decreased slightly as gestation progressed, which may indicate that the maternal body's ability to adapt to vigorous intensity exercise may decrease as gestation progresses.

The trends seen in resting measures and acute PWV, MAP and BP responses across gestation in this study reinforce the importance of measuring these responses repeatedly across gestation rather than cross-sectionally, as there appears to be some dissociation between the changes in central PWV and MAP. This conflicts with previous research in non-pregnant participants which reported that acute PWV responses to exercise are influenced by acute changes in BP with exercise (100). This study demonstrated varied central PWV responses

following exercise over the course of gestation. On average, PWV increased post-exercise, however, some participants exhibited a decrease in PWV. These findings may suggest a potential disconnect between maternal cardiovascular adaptations and arterial stiffness. The underlying mechanisms driving these differential responses remain unclear and warrant further investigation through larger scale longitudinal studies.

Gestational week appears to be associated with the amount of change in PWV and BP following acute bouts of exercise. This supports the notion that there may be times in pregnancy when the cardiovascular benefits derived from exercise can be optimised. Resting PWV and BP measures are at their lowest in the second trimester of pregnancy, increasing into the third trimester (13, 58, 106). The ability of the maternal vessels to respond to exercise may decrease as gestation progresses, with the increase in resting values (PWV, BP) seen in the third trimester leaving less room for acute adaptation to exercise. Higher exercise intensities provoke more pronounced acute cardiovascular responses in non-pregnant populations, which, with consistent training has the potential to lead to chronic adaptations, enhancing cardiovascular efficiency and health (273). As such, it is hypothesised that vigorous intensity exercise has the potential to elicit greater benefits to the cardiovascular system in the first and second trimester, when the capacity for acute changes in PWV and BP is greatest.

***Maternal and foetal heart rate***

Australian guidelines published by the Department of Health now include, for the first time, vigorous intensity exercise as part of their recommendations for healthy pregnant women (5). Given this inclusion into the guidelines it is important to understand the effects of exercising at this intensity across gestation. The results from this study indicate that vigorous exercise appears safe throughout pregnancy, with no adverse maternal or foetal responses. The MHR responses to each type of exercise highlight that the participants reached the desired intensities across the three types of exercise. MHR showed similar recovery patterns following VIIT and RT, despite a greater increase in HR (PHR) seen during VIIT compared to RT sessions. This indicates that the maternal vascular system is still able to recover quickly following higher intensities of exercise as gestation progresses.

The results of our study showed slight increases (~1-3bpm) in FHR from resting to immediately and 10 minutes post exercise. During exercise, maternal blood flow is

redirected towards exercising muscles, which has previously led to concerns for foetal wellbeing (bradycardia and hypoxia) during higher intensity bouts of exercise (274). A systematic review of 54 studies examining the acute change in FHR from resting to post exercise found a mean increase in FHR of ~4bpm (95%CI [2.98-5.12], $I^2 = 83\%$, $p < 0.001$) following exercise (121). The acute changes seen in FHR in this study were slightly less on average, with no differences seen between the modes of exercise. This indicates that the VIIT sessions did not negatively affect foetal blood flow, despite greater increases in MHR and BP compared to RT and PIL. This aligns with two previous studies examining HIIT during pregnancy which found no signs of foetal bradycardia or changes in umbilical blood flow following aerobic (72) and resistance (114) HIIT when bouts ≤ 60 seconds high intensity were performed.

***Enjoyment and adherence***

It has been shown that weekly PA frequency and intensity decrease as pregnancy progresses, along with an increase in sedentary behaviour (81, 82). The adherence in this study decreased from T2 to T3 across all modes. Reported adherence to aerobic and resistance exercise interventions in pregnancy vary across the literature, ranging from 3-95% (235), similar to the individual results shown in this study. It has been well established by previous studies that the enjoyment of exercise is a predictor of exercise adherence (275-277). In this study VIIT was rated as the least enjoyable and motivating exercise mode, with RT and PIL being ranked similarly in terms of enjoyment and motivation. These results differ from previous studies in pregnancy, in where HIIT has been found to be more enjoyable than moderate intensity continuous training (113, 114, 217, 260).

There were significant differences in the exercise protocols employed in these previous studies, all of which used shorter bouts of vigorous-high intensity exercise (15-60 seconds) compared to our study (4 minutes) (114, 116, 217, 260). Three of these studies utilised stationary cycling (116, 217, 260), with a resistance circuit included in another (114) which may be better tolerated due to the non-weightbearing nature, or due to a lower perceived effort required as gestation progresses. Perceived enjoyment of exercise has been identified as a psychological motivator for increasing exercise (260, 276), as well as an important predictor of exercise adherence (113, 278). Due to the randomised nature of this study, participants were unaware of which type of exercise they would be performing for the first and second sessions each week, however, were able to deduce which exercise session would

be performed third based on what had already been completed for the week. The VIIT sessions showed the highest adherence rate across trimesters, however rated the least enjoyable. It is therefore unlikely that mode of exercise effected adherence in this study, as we would expect VIIT to have the lowest adherence rates given the lack of enjoyment reported in these sessions. Moreso, it is likely the attendance of the clinic 3x/week was the limiting factor. It should be noted that the modelling used in the statistical analysis accounted for variations in adherence as well as GW at enrolment.

Current exercise guidelines which recommend that all women without contraindication should aim to accumulate 150 to 300 minutes of moderate to vigorous intensity physical activity (MVPA) per week throughout pregnancy, in order to achieve clinically meaningful benefits (67, 68). In addition, it is recommended that this is achieved over most, if not all days of the week and that different modes of exercise including both aerobic and resistance training (RT) are incorporated (67). Whilst the weekly exercise dose in this study would not meet these guidelines, this study was not designed as a training study, as we were not investigating a pre-post intervention effect, but rather observing the acute changes across pregnancy following three common exercise modalities. Further research may aim to observe the effects of a combined intervention of these three exercise modalities on measures of arterial stiffness and BP in pregnancy.

***Strengths and limitations***

To our knowledge, this is the first study to investigate the acute effects of different types of exercise on measures of arterial stiffness and maternal BP longitudinally in pregnancy. One of the main limitations of this study was the low sample size in T1. It is challenging to recruit pregnant women in the first trimester of pregnancy, as many women do not announce their pregnancies until the 12-week mark (118). Given the magnitude of changes in the cardiovascular system across pregnancy, it is important to understand how different types and intensities of exercise effect the mother and foetus across the entirety of gestation. Therefore, further research should aim to recruit women as early in T1 as possible, if not pre-pregnancy. Future research should look at the effects of exercise beyond 36 weeks, as many pregnant women continue exercising up until delivery.

The acute effects of exercise were only assessed up until 10 minutes following exercise cessation. Given some research indicates lasting effects of acute bouts of exercise up to 14

hours after a session (279), future studies may provide additional insight with a longer period of observation post exercise. We were unable to directly compare the acute responses by exercise type, as the time between the end of each exercise session to the start of the first post-exercise measurement differed. For example, the post-exercise measures following the VIIT bouts were performed within one minute from the end of the last stage as the treadmill was located directly next to the testing station (~1-2 meters), whilst the resistance sessions were performed at the other end of the clinic space – approximately 10-15 meters away from the testing station. As the questionnaire was provided up to two months after participation in the study had ended, the ability to recall enjoyment and motivation levels for each type of exercise may also have been impaired.

***Conclusion***

The findings from this study indicate that higher intensities of exercise (VIIT and RT) are more likely to elicit larger acute changes in cardiovascular measures including BP and PWV compared to lower intensity exercises such as PIL. Moreover, the ability of exercise to elicit these acute changes seems to be influenced by the stage of pregnancy. It is hypothesised that due to the changes seen in the acute responses across gestation that any potential beneficial adaptations in vasculature that occur with repeated higher intensity exercise bouts may be optimised at specific times in pregnancy. Interestingly, the magnitude of the adaptations to acute exercise aligns with known cardio-obstetric physiology trends across gestation. These findings have important implications for optimising exercise prescription in pregnancy. Further longitudinal research is needed to determine the chronic effects on the maternal cardiovascular system, in particular arterial stiffness, with combined exercise interventions. This may help to inform trimester specific guidelines surrounding vigorous to high intensity exercise in pregnancy.

# Chapter 8. General discussion and conclusions

The overall aim of the thesis was to provide novel insight into the acute effects of exercise on haemodynamics during pregnancy. The main findings and overall significance from each study will be discussed below, with the strengths and limitations of this work outlined. The wider practical implications of the research outcomes, including advancing the broader research field are presented. This program of research may help to inform exercise guidelines in pregnancy, provide possible methods of measuring haemodynamics during pregnancy for potential identification of maladaptive changes, with the goal of improving maternal and foetal health outcomes.

The specific aims of this thesis were:

1. To review the literature on all topics covered in the thesis including cardiovascular adaptations to pregnancy, exercise during pregnancy and the effects of exercise on measures of arterial stiffness (Chapter 1)
2. To systematically review and meta-analyse the effects of acute and chronic exercise in uncomplicated and at-risk pregnancies on BP and MAP (Chapter 3)
3. To observe the acute effects of a weekly submaximal exercise test on measures of arterial stiffness and blood pressure throughout pregnancy (Chapter 4)
4. To observe the effects of a submaximal graded exercise (vigorous intensity) test during pregnancy on measures of vascular function including MAP and arterial stiffness. (Chapter 5)
5. To determine the feasibility of VIIT, RT and reformer Pilates in the second and third trimesters of pregnancy (Chapter 6)
6. To observe the acute effects of different types and intensities of exercise longitudinally throughout gestation (Chapter 7)

## 8.1 Summary of main findings

*Chapter 1*. is a narrative review exploring gestational hypertensive conditions and arterial function in pregnancy, exercise guidelines in pregnancy, and the effects of exercise on arterial function in pregnant and non-pregnant populations. The literature identifies the high prevalence of gestational hypertensive conditions (gestational hypertension (GHTN) and pre-eclampsia (PE)) and short and long-term consequences of such conditions. It is also identified that there is a significant lack of treatment options for these conditions. Regular exercise is a known contributor to improving cardiovascular function in both pregnant and non-pregnant populations, however the risks associated with not meeting exercise guidelines are often not emphasised appropriately to at-risk populations and obstetric professionals (280). Whilst current international guidelines recommend women with uncomplicated pregnancies complete 150 to 300 minutes of moderate to vigorous aerobic and resistance exercise per week (73), it is estimated that only 15-30% of pregnant women meet these guidelines (67, 73). In non-pregnant populations, higher intensity aerobic exercise has been associated with greater cardiovascular benefits, however the evidence on higher intensity exercise in pregnancy is limited due to fear and uncertainty surrounding the effects on foetal wellbeing (118, 274). However, by extrapolating evidence on non-pregnant populations, we can postulate that higher intensity exercise may elicit greater benefits to the maternal and foetal cardiovascular system than traditional moderate intensity exercise.

Arterial stiffness has been identified as an important marker of cardiovascular health in non-pregnant populations, and furthermore has been identified as a potential predictor of GHTN and PE (38). Within non-pregnant populations, higher intensity exercise has been associated with greater improvements in arterial function than low-moderate intensity exercise. Regular moderate-vigorous intensity exercise is known to reduce the risk of developing hypertensive conditions in pregnancy, yet historically women have been discouraged from exercising at intensities greater than light-moderate (33, 73). *Chapter 1* highlights that the attitudes towards more vigorous exercise in pregnancy are changing, with a growing pool of evidence exploring the effects of vigorous to high intensity exercise in uncomplicated pregnancies.

Whilst it is well documented that regular moderate intensity exercise throughout pregnancy significantly reduces the risk of developing gestational hypertensive, there is a lack of understanding on how different types and intensities of exercise effect maternal BP. Furthermore, there is a lack of research on the effects of prenatal exercise in at risk

populations. *Chapter 3* is entitled "The effects of aerobic and resistance exercise on blood pressure in uncomplicated and at risk pregnancies: A systematic review and meta-analysis." This paper explored the chronic effects of aerobic and resistance exercise interventions as well as the acute effects of aerobic and resistance exercise bouts on BP and MAP in two groups: uncomplicated and at risk pregnancies. The findings from this review suggest that women who are at a higher risk of gestational hypertensive conditions (due to GDM, obesity or overweight) who perform moderate to vigorous aerobic exercise throughout pregnancy, may either reduce or attenuate an increase in BP that is commonly associated with these conditions. This highlights the need for further research on the safety of exercise training in pregnancies complicated by gestational hypertensive conditions, given GHTN and PE have previously been considered contraindications to exercise (91). Furthermore, there is limited research available on the feasibility of vigorous intensity exercise interventions throughout pregnancy, with most available literature focusing on moderate intensity exercise.

Twenty-seven studies included in the *Chapter 3* review reported an acute increase in systolic and diastolic BP during aerobic or resistance exercise, with no difference found between uncomplicated and at risk pregnancies. Of these acute studies, only eight investigated the effects of resistance training, highlighting that the focus of research has predominantly been aerobic training. It was challenging to directly compare the included studies on acute changes in BP, as the gestational age varied from 12-38 weeks, and the exercise sessions included ranged from 5-60 minute bouts. Additionally, this review reported that whilst the acute effects of different exercise modes on BP during pregnancy have been studied, there is limited evidence available looking at the acute changes with exercise across gestation, particularly vigorous intensity exercise. The outcomes of this study emphasised the need for extensive research on the immediate effects of various types of exercise across pregnancy, in order to ascertain whether acute cardiovascular responses to exercise change as gestation progresses.

*Chapter 4* is a longitudinal case study which aimed to compare the acute effects of a submaximal graded exercise test on arterial stiffness and BP measured each week throughout pregnancy (5-35 weeks gestation) to an age-matched non-pregnant control. As gestation progressed, resting PWV decreased through to 35 weeks gestation. On the other hand, resting SBP, DBP and MAP decreased from T1-T2 then increased in T3. An increase in PWV was seen immediately following exercise in the first trimester, but not in the second or third

trimesters. These results suggest that the ability of the maternal body to respond acutely to a stressful environment (i.e. vigorous intensity exercise) may decrease as pregnancy progresses.

Pregnancy has previously been described as a '9-month stress test' (223). Blood vessels are already more 'stressed' (vasodilated) at rest, and therefore have less ability to change in response to exercise as gestation progresses. Based on the findings from this study we have speculated that exercising at more vigorous intensities later in pregnancy may not elicit the same response in the cardiovascular system as it does pre-pregnancy and through the first trimester. This chapter provided useful information in the generation of hypotheses in this novel area of research in regard to the influence of gestational week on acute cardiovascular responses to vigorous exercise. However, given the n = 1 study design, the results were not indicative of the general population. Exploring whether the acute changes in PWV and BP seen in the pregnant participant with submaximal exercise across a diverse group of women was needed.

Based on pregnancy physiology principles and corroborated by findings in *Chapter 4*, it was hypothesised that gestational week may influence the haemodynamic response to a submaximal exercise test, and that the maternal body's ability to adapt to higher intensities of exercise may change across gestation. As such, the cross-sectional sub-study included in *Chapter 5* included pregnant participants from gestational weeks 5-33. *Chapter 5* aimed to measure the acute effects of a submaximal graded exercise test during pregnancy on measures of vascular function including MAP and arterial stiffness. To achieve this aim, we recruited women across gestation to perform a stress test up to 85%$HR_{max}$ and measure their vascular response (PWV, BP, MAP, HR). The intensity of exercise was significantly associated with the magnitude of vascular response, whereby participants who were able to achieve a higher intensity (%$HR_{max}$) and longer time on test saw greater increases in MAP post exercise. This highlights that even short duration bouts of vigorous intensity exercise (< 17 min total time on test) may provide enough stimulus to elicit potentially positive cardiovascular adaptations if performed regularly throughout pregnancy. Although not statistically significant, there was a trend towards a reduced vascular response the further along the pregnancy was.

*Chapter 6* presents research to test the feasibility (enjoyment, achieved intensity) of vigorous intensity interval training (VIIT), along with resistance training (RT) and reformer Pilates (PIL) in the second and third trimesters of uncomplicated pregnancies. Most of the available research to date on the acute effects of exercise in pregnancy has focused on one type or intensity of exercise (e.g. walking/cycling at moderate intensity). Given the varied benefits derived from a balanced exercise program incorporating aerobic and resistance exercise, it is important to understand the acute physiological effects of these different modes. Pilates was identified as a low to moderate intensity mode of exercise which has a paucity of evidence in pregnancy despite its increase in popularity over the past decade (139). The three modes of exercise in this study proved feasible in all participants (n = 11). All participants were able to achieve the prescribed intensities for VIIT, RT and PIL, with VIIT perceived as more difficult later in gestation despite similar cardiovascular responses between modes. This could be due to an increase in fatigue and discomfort associated with progressing gestation rather than an increased cardiovascular response.

The outcomes of *Chapter 6* illustrate that VIIT is a feasible option for pregnant women who decide to continue exercising at a vigorous intensity during gestation. However, we could not ascertain from the results whether VIIT resulted in significantly greater acute cardiovascular changes compared to RT and PIL. Whilst VIIT is a feasible modality in pregnancy, these sessions scored poorly in terms of enjoyment and motivation when compared to the less intense RT and Pilates sessions. One limitation of *Chapter 6* was the small sample size, with participants only completing each type of exercise once or twice during pregnancy. As such, it is difficult to draw any rigorous conclusions comparing the acute effects of these different modes as gestation progresses.

To extend on the findings of *Chapter 6*, a longitudinal crossover trial was employed to observe the effects of VIIT, RT and PIL on arterial stiffness and BP completed weekly throughout pregnancy (*Chapter 7*). We specifically wanted to observe whether the acute response to these three modes of exercise changed as pregnancy progressed. As expected, peak exercising HR was highest during VIIT, then RT and lowest with PIL. Resting measures of arterial stiffness, BP and HR followed trends previously outlined in longitudinal studies of pregnancy. PWV was significantly higher immediately *and* 10 minutes following VIIT and RT, but only immediately post Pilates returning to baseline by 10 minutes, indicating a greater response with more intense exercise. Similarly, significant increases in

MAP and BP were seen following VIIT and RT but not Pilates. The trends seen in the acute PWV, MAP and BP responses across gestation in this study reinforce the importance of measuring these responses repeatedly across gestation rather than cross-sectionally, as there appears to be some dissociation between the changes in central PWV and MAP. Despite these differences in arterial pressure, along with a greater increase in MHR with more intense exercise, FHR responses remained similar and within normal clinical limits in all exercise sessions regardless of modality or intensity. One of the major barriers to exercising at higher intensities throughout gestation has been the fear and uncertainty surrounding the effect on foetal wellbeing (118, 274). The findings in *Chapter 7* support VIIT as a seemingly safe an effective mode of exercise throughout gestation, with 229 VIIT sessions in 20 participants closely monitored across the course of the study.

There were no adverse maternal responses to the low volume bout of vigorous intensity exercise in *Chapter 5* ($\leq$ 85%$HR_{max}$) or the VIIT sessions (4 x 4 min @ 70% $HR_{max}$, 3 min @ 55-70% $HR_{max}$) in *Chapter 7*. In previous research, the increase in maternal blood flow to exercising muscles with increasing exercise intensity led to the hypothesis that prenatal exercise would result in a reduction in uteroplacental blood flow and consequential foetal hypoxia (121, 281). Only one participant experienced transient light-headedness following a VIIT session in *Chapter 6*, which resolved following 10 minutes of semi-recumbent rest. No adverse responses in FHR were recorded in any of the included participants. The findings in *Chapters 5, 6* and *7* indicate that exercising at a vigorous intensity during pregnancy does not result in adverse responses in FHR. This growing body of evidence may help to dispel the fears around foetal wellbeing with higher intensities of exercise. However, more research is needed before high intensity exercise (> 90% $HR_{max}$) can be recommended in pregnancy, given that high doses appear potentially detrimental (78, 274). Moreover, high volumes of exercise in pregnancy are not well studied and requires more research before being included in exercise recommendations.

### 8.1.1 Practical implications

***Exercise recommendations***

High intensity exercise, particularly HIIT is growing in popularity, and the body of evidence on the safety and efficacy of HIIT during pregnancy is expanding. Whilst the effects of *high* intensity exercise in pregnancy remain uncertain, *vigorous* intensity exercise appears safe throughout gestation. Vigorous intensity exercise may provide a more achievable intensity

goal for prenatal exercise compared to high intensity, given the increase in discomforts of pregnancy as gestation progresses (due to increased weight, dyspnoea, musculoskeletal pains).

Based on the findings on acute exercise responses from this thesis, one might conjecture that during pregnancy there may be times (trimester 1-2) when both the maternal and foetal cardiovascular systems could potentially reap greater advantages from engaging in higher intensity exercise, considering the fluctuation of resting cardiovascular parameters throughout gestation. As pregnancy advances and resting cardiovascular levels are already elevated, the capacity of the maternal vessels to adapt to a stressful environment, i.e. vigorous exercise, may decrease, leaving less room for adaptation. Whilst the benefits derived from vigorous intensity exercise later in pregnancy may not outweigh those resulting from moderate intensity exercise, women with uncomplicated pregnancies who wish to continue exercising at a vigorous intensity throughout gestation appear safe to do so. This should be considered in the development of exercise guidelines in pregnancy, with trimester specific guidelines identified as a priority area of research in a review of current international guidelines (77).

***Enjoyment***

Whilst VIIT appears safe throughout uncomplicated pregnancies, it was rated as the least enjoyable mode of exercise in our studies when compared to RT and PIL. Exercise frequency appears to decrease as gestation increases, with an increase in sedentary behaviour reported (81, 82). Enjoyment of exercise has been well established as a predictor of exercise adherence (276, 277), as such enhancing the enjoyment of exercise sessions is paramount in ensuring continued participation during pregnancy. Whilst VIIT was rated poorly in terms of enjoyment in our study, others that have highlighted maternal enjoyment of HIIT have generally used protocols with shorter 'working' bouts (20 seconds to 60 seconds) (72, 114, 116). As such, if exercise professionals are prescribing VIIT in pregnancy, the length of the vigorous intensity may play an important role in optimising adherence.

### 8.1.2 Limitations

Recruiting women prior to or early (T1) in pregnancy poses a significant challenge in determining the effects of exercise across the entirety of gestation. Of the 34 participants that were recruited across all experiments, only seven enrolled in the first trimester (5-12

weeks gestation), four of which enrolled in gestational week 12. Thus, whilst baseline testing (analysed in *Chapter 5*) was performed in T1 for these four participants, all subsequent exercise sessions were performed from T2-T3. Only 18/584 exercise sessions (VIIT = 8, RT = 5, PIL = 5) reported in *Chapter 7* were performed in the first trimester, making it difficult to draw strong conclusions on the acute effects of these exercise modes/intensities in early pregnancy. Furthermore, these studies were limited to exercising up until 36 weeks of gestation due to a lack of evidence supporting the safety of any exercise from 36-40 weeks. International exercise guidelines recommend pregnant women incorporate both aerobic and resistance exercise into their routine. As such our longitudinal study was designed to reflect a real-world scenario in which three different modes of exercise were performed each week. This volume of exercise (90-105 minutes) remains below current guidelines (150-300 minutes). Participants were not instructed on exercise outside of these sessions and may still have achieved the guidelines through their own initiative. Unfortunately measuring physical activity (PA) participation across the entire week was outside the scope of this thesis. Given there was no control group included in our study, and each participant performed each type of exercise, we were unable to comment on the longitudinal effects of the intervention.

We were also unable to directly compare exercise types in the statistical analysis in *Chapter 7*, as the timing of post-exercise measurements varied slightly between modes due to the location of the testing equipment within the clinic. The participants in all experiments were monitored for 10-15 minutes post exercise, with outcome measures taken for the final time between 10-15 minutes of semi-recumbent rest. This timeframe was selected as we believed asking participants to rest for longer than this post exercise may have resulted in low recruitment rates, given that lack of time is often reported as a barrier to exercise in pregnancy (118). Our focus was also on the immediate changes and recovery post exercise. In order to reflect 'real-world' exercise sessions, cool downs were included in the RT and PIL sessions, during which time some measures may have changed. Given the longitudinal nature of the studies, we were not willing to not provide a cool-down after exercise for the entirety of pregnancy. We recognise that FHR may change during this time, however research suggests that with the intensities used in these studies there should not be a clinical change in FHR. Whilst this is a limitation to measuring FHR in these studies, it would not have been possible to assess the primary outcome of change in arterial stiffness after real-world exercise sessions (which include cool-downs). The timing of measurement post exercise has been highlighted as an important factor in assessing the acute response in arterial

stiffness to exercise in non-pregnant populations (98, 100). Longer post-exercise measurements (30-60 minutes) are often used in other populations (clinical and healthy). Prolonged monitoring post exercise will be valuable in understanding haemodynamic recovery in pregnancy and is an important area for future research.

Whilst the SphygmoCor Xcel device has been validated across a range of populations (59) and has previously been used within obstetric populations (128), there is evidence in non-pregnant populations to suggest that it may underestimate central BP when the default cuff calibration method is used, as was the case in these studies (282). Furthermore, this device has been validated against invasive testing in non-pregnant populations, however not in pregnancy (55). As such the central BP results should be interpreted with caution.

Accurately measuring exercise intensity during pregnancy presents unique challenges due to the physiological changes that alter traditional metrics. Increased resting HR and a blunted maximal HR during pregnancy reduce the HR reserve at rest and during submaximal exercise, making methods such as %HRmax and HR reserve less reliable (261). The higher resting HR and lower maximal HR result in HR-based intensity measures becoming less precise, as they may underestimate intensity at higher work rates and overestimate it at lower work rates (261). Similarly, perceived exertion (RPE) may not consistently reflect exercise intensity during pregnancy, as its accuracy can vary depending on the training status of the individual and whether the activity is weight-bearing or non-weight-bearing (261). Additionally, as pregnancy progresses, the energy costs of PA increase compared to early pregnancy and postpartum, potentially influencing a pregnant woman's perception of moderate and vigorous intensity. There is conflicting evidence on whether women perceive PA to be more challenging as gestation progresses, with some studies indicating a higher RPE later in pregnancy or when pregnant vs non-pregnant controls are compared, whilst others reported no differences in perceived exertion at moderate or vigorous intensities during treadmill exercise when measured at different gestational weeks (261). We used $\%HR_{max}$ as well as RPE to determine the workloads in Studies 4 and 5, it is likely that a combination of the two measures will provide the best representation of intensity.

### 8.1.3 Future research directions

***Duration***

A longitudinal approach spanning from preconception to post-partum phases could offer a holistic view of the impact of exercise on pregnancy outcomes. Furthermore, longitudinal research efforts are needed to establish trimester-specific exercise guidelines, considering the unique physiological changes experienced by pregnant individuals throughout each stage of pregnancy. Given the apparent dissociation between MAP and PWV observed during pregnancy in our study, further research should explore this relationship across gestation. By tracking PA patterns and overall volume of exercise alongside cardiovascular markers over this continuum, researchers can elucidate the chronic effects of exercise on maternal health. Moreover, investigating the volume of exercise rather than solely focusing on frequency could provide a more nuanced understanding of the dose-response relationship between PA and pregnancy-related outcomes, particularly at higher intensities.

Extending the measurement of outcomes for longer durations after exercise interventions could provide a more comprehensive understanding of the sustained effects on haemodynamics and maternal and foetal health. Additionally, future research should explore the potential benefits of shorter VIIT bouts in pregnancy (1-2 minutes), particularly if this modification increases enjoyment and adherence to exercise regimens. Understanding how pregnant individuals respond to shorter bursts of higher-intensity exercise could offer insights into optimising PA recommendations. Furthermore, exploring exercise responses in clinical populations may uncover abnormal physiological responses to stress in pregnancy, informing tailored exercise prescriptions for individuals with specific medical conditions.

***Endothelial function***

Whilst this thesis focused on arterial stiffness as a primary marker for cardiovascular health in pregnancy, further investigation into the role of endothelial function in pregnancy and the response to acute exercise may provide further insight into the 'normal' haemodynamic response to prenatal exercise across gestation. Endothelial dysfunction contributes to the physiological hardening of the arterial system and as such is used to predict cardiovascular morbidity and mortality (283, 284). Upper arm flow mediated dilation (FMD) assessed non-invasively via ultrasound is commonly used to assess endothelial function, and refers to the dilation of the brachial artery primarily caused by the release of nitric oxide by the endothelial cells (55). Research in pregnancy has shown that women who meet or exceed

exercise guidelines (150 min per week of MVPA) have better endothelial function compared with women who do not meet this threshold in pregnancy (284). Despite the established association between regular exercise and endothelial function, research on the acute effects of exercise bouts on endothelial function is currently lacking (285). Systemic endothelial dysfunction has been identified as a critical component in the pathophysiology of pre-eclampsia (PE), with women diagnosed with the condition exhibiting lower FMD from before the clinical diagnosis of PE, through to 3 years postpartum (44). As such, investigating the acute vascular response to exercise in pregnancy on both arterial stiffness and FMD may contribute to the understanding around what is considered a 'normal' haemodynamic response to maternal exercise in uncomplicated pregnancies. With further research, there is the potential for these measures to be used in conjunction with cardiopulmonary exercise testing as predictive tools for gestational hypertensive conditions.

### 8.1.4 Conclusions

This thesis provides novel findings on acute haemodynamic changes with different modes of exercise throughout pregnancy. The findings from these studies indicate that acute cardiovascular responses to exercise change as gestation increases, with greater acute increases in PWV with exercise in early pregnancy. Further longitudinal research is imperative throughout pregnancy to facilitate the development of trimester-specific guidelines for exercise. VIIT, RT and reformer PIL all present as feasible options throughout gestation, with greater acute cardiovascular responses following VIIT and RT compared to PIL. While vigorous exercise seems to be safe and achievable during gestation, incorporating shorter bouts of higher intensities may enhance enjoyment and therefore adherence in pregnancy. Nonetheless, it is worth noting that it is hypothesised that engaging in higher intensity exercise during the later stages of pregnancy may not yield significantly greater benefits compared to moderate intensity workouts, due to alterations in resting cardiovascular measures.

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# Chapter 10. Appendices

## 10.1 Appendix 1. Published manuscript in Women's Health

*Maternal Health Considerations: Psychological Physiological Wellbeing – Systematic Review*

WOMEN'S HEALTH

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# The effects of aerobic and resistance exercise on blood pressure in uncomplicated and at risk pregnancies: A systematic review and meta-analysis

**Courtney Giles[1], Rich Johnston[1,2,3], Jade Kubler[4], Jemima Spathis[1] and Kassia Beetham[1,2]**

**Abstract**

**Background:** Regular exercise performed during pregnancy has been shown to reduce the risk of developing perinatal gestational hypertensive conditions. Further evidence on the exact parameters of exercise needed to explain these beneficial responses is required, within both uncomplicated and at-risk pregnancies.

**Objective:** The aim of this systematic review and meta-analysis was to investigate the effects of aerobic and resistance exercise on blood pressure during pregnancy.

**Design:** Systematic review and meta-analysis.

**Data Sources and Methods:** An online search of six search engines was conducted up to February 2023. Randomized controlled trials, quasi-experimental, cohort, and longitudinal studies were included. Studies included an acute exercise bout or intervention of land-based aerobic and/or resistance exercise during any trimester in uncomplicated and at-risk pregnancies. Outcomes included mean arterial pressure (MAP), or systolic blood pressure (SBP) and diastolic blood pressure (DBP).

**Results:** Following the removal of duplicates, 1538 articles were screened with 59 studies meeting the inclusion criteria for the review (randomized controlled trials (RCTs) n = 34, clinical trials n = 19, cohort n = 5 and cross-sectional n = 2), and 21 studies included in the meta-analysis. A random effects model was used with mean difference calculated in mmHg. Overall, there were no statistically significant effects of exercise on resting blood pressure (BP) outcomes in pregnant women with normal blood pressure compared to control/usual care populations following intervention (SBP mean diff -1.54 mmHg (favours intervention), $p = 0.38$; DBP mean diff -2.25 mmHg (favours intervention), $p = 0.1$; MAP mean diff -1.75 mmHg (favours intervention), $p = 0.31$). In at-risk pregnant women, both aerobic and combination exercise significantly reduced BP outcomes compared to control (SBP mean diff -3.91 mmHg, $p < 0.01$; DBP mean diff -2.9 mmHg, $p = 0.01$; MAP mean diff -2.38 mmHg, $p = 0.01$). Twenty-seven studies reported an acute increase in SBP and DBP during aerobic exercise, with no difference found between uncomplicated and at-risk pregnancies.

**Conclusions:** Compared to usual care, aerobic and/or resistance exercise performed throughout uncomplicated pregnancy had no influence on blood pressure. Pregnant women with no diagnosed complications should be encouraged to exercise regularly due to the multitude of known benefits. In women who are at risk of, or diagnosed, with gestational hypertensive conditions during pregnancy, moderate to vigorous exercise during pregnancy improves blood pressure outcomes. Higher risk pregnancies may reduce their risk of future cardiovascular complications through regular exercise training during pregnancy.

**Registration:** CRD42020159998.

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**Keywords**
blood pressure, exercise, gestational hypertension, haemodynamics, pregnancy

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## Introduction

Pregnancy is a period characterized by significant physiological adaptations, particularly within the cardiovascular system.[1] Maternal haemodynamic alterations within the cardiovascular system are evident from the first few weeks of gestation.[2,3] These rapid changes are necessary to ensure sufficient uteroplacental blood flow to transfer oxygen and nutrients from the mother to the foetus, to optimize foetal development.[4,5] An increase in heart rate (HR), cardiac output (CO), stroke volume (SV), and plasma volume are observed in healthy pregnancies and associated with a concomitant fall in total vascular resistance and systemic vascular tone.[6,7] Maladaptive changes to these maternal haemodynamic processes can occur during gestation, increasing the risk of gestational hypertensive conditions.[2,4]

Pre-eclampsia (PE) and gestational hypertension (GHTN) are pregnancy-specific disorders that pose a significant risk to pregnant women, with the World Health Organization (WHO) recognizing these conditions among the leading causes of maternal and foetal morbidity and mortality worldwide, along with haemorrhage and sepsis.[8–10] The exact cause of GHTN and PE are not well established; however, it has been identified that hypertensive conditions that present prior to 20 weeks of gestation (chronic HTN, GHTN) often advance to PE.[9,11–13] The vascular dysfunction that is associated with gestational hypertensive conditions is considered systemic and persistent resulting in a significantly increased risk of future cardiovascular disease (CVD).[5,9,14] Infants born following pre-eclamptic pregnancy have also been shown to be at an increased risk for childhood obesity and CVD later in life.[12,15] Other clinical conditions such as gestational diabetes mellitus (GDM) and overweight/obesity significantly increase the risk of developing hypertensive conditions in pregnancy.[16]

There is convincing evidence that both acute and long-term aerobic, and resistance, exercise, from light to vigorous intensity, lowers resting blood pressure (BP) in both hypertensive and normotensive non-pregnant populations.[17,18,19] Regular physical activity has been shown to positively enhance metabolic and musculoskeletal changes associated with pregnancy; however, the mechanisms of prenatal exercise on blood pressure are not yet well understood.[14,20] Two recent systematic reviews looked at the effects of prenatal exercise on measures of cardiovascular health including blood pressure, and found that resting blood pressure was reduced following prenatal exercise interventions.[21] Furthermore, the risk of developing major clinical conditions such as GHTN, PE, and GDM is significantly reduced in women who engaged in regular prenatal exercise.[22] There is, however, a lack of understanding surrounding the effects of different types and intensities of prenatal exercise on maternal blood pressure,[14] as well as whether uncomplicated and at-risk populations respond differently to prenatal exercise. Further evidence on the exact parameters of exercise needed to elucidate these beneficial responses is required.

The primary aim of this systematic review and meta-analysis is to determine the effects of acute and long-term aerobic exercise, resistance exercise and a combination of both, on blood pressure outcomes in uncomplicated and at-risk pregnant populations. It is hypothesized that acute bouts of aerobic exercise will result in post exercise hypotensive responses, and that long-term aerobic exercise during pregnancy will reduce blood pressure and help prevent the onset of gestational hypertensive disorders, particularly within populations who are at increased risk of these conditions.

## Methods

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[23] The review was registered with PROSPERO (International Prospective Register for Systematic Reviews) under the registration number CRD42020159998.[24]

### *Search strategy*

Six online search engines (CINAHL, Cochrane, Embase, Medline, PubMed, Web of Science) were used to search databases up to February 2023. Standardized search terms were established with pregnant women as the population, aerobic or resistance exercise as the intervention, and MAP or BP as the primary outcome measures. All synonymous terms that may be used to describe the population, intervention and outcome were included. Medical Subject headings (MeSH), truncation, and Boolean operators were used to ensure that all relevant articles were found in the database searches. Filters were applied to ensure searches were limited to studies on humans and reported in English. The reference lists of included articles were screened to

ensure that any relevant studies missed in the database searches could be included in the review. The complete search strategy for each search engine can be viewed in Supplementary File 1.

### Eligibility criteria

The types of studies eligible to be included in this review were randomized controlled trials (RCTs), quasi-experimental, cohort, longitudinal, case-control, or non-randomized intervention studies. To be eligible for inclusion in the review, studies needed to be peer-reviewed articles including (1) pregnant women completing either an acute bout or an intervention of land-based aerobic or resistance exercise during any trimester, and (2) maternal MAP or SBP/DBP reported as either a primary or secondary outcome measure. To be included in the meta-analysis, studies required the above listed criteria, along with a comparator/control group treated with standard prenatal care. Studies that reported on water-based activities were excluded due to the thermal effects of both warm and cold-water immersion on the cardiovascular system.[25] Only primary studies were included in the review, to ensure that data from these studies were only taken into consideration once. Both uncomplicated and at-risk pregnant populations were included.

### Definitions

The methodologies of the articles were reviewed in detail to determine whether the exercise intervention included in the study met the criteria for land-based aerobic, resistance, or combination exercise. The American College of Sports Medicine (ACSM) defines aerobic exercise as any activity that uses large muscle groups, is rhythmic in nature, and can be maintained continuously, while resistance exercise involves exercising muscles against an external load or resistance in order to improve muscular fitness.[26] Studies including aerobic or resistance land-based exercise at any intensity were included.[27] Acute exercise is defined as a single bout of exercise following which researchers observed any changes between pre- and post-exercise outcome measures. Exercise interventions are defined as repeated bouts of exercise across a period of time (in this case ≥ 3 weeks) following which researchers observed any changes between pre- and post-intervention outcome measures. The intensity of exercise was determined based on percentage of heart rate max (%HRmax) and rating of perceived exertion (RPE) on the Borg Scale and rated as light (40%–55% HRmax, RPE: 8-10), moderate (55%–70% HRmax, RPE: 11-13), vigorous (70 < 90% HRmax, RPE 14-16), or high (≥ 90% HRmax, RPE: > 17).[27] In this review, an at risk pregnancy is defined as one with diagnosed conditions that increase the pregnant woman's risk of developing gestational hypertensive conditions, including but not limited to: GDM, overweight/obesity, chronic hypertension, and/or previous pre-eclampsia.[16] Uncomplicated pregnancies are defined as those with no pre-existing medical comorbidities (e.g. HTN, type 2 diabetes) and no pre-existing or new-onset obstetric complications (e.g. PE, GDM).[28]

### Assessment of risk of bias

The Cochrane Risk of Bias for Randomized Controlled Trials tool was used to assess the risk of bias in the RCTs and randomized clinical trials (Supplementary File 2).[29] This assessment tool allowed the authors to assess the bias in each study as low, high, or unclear across six domains including: selection bias, reporting bias, detection bias, performance bias, attrition bias, and other bias. Based on the scores in each domain an overall risk of bias score was generated as low, unclear, or high risk.

The Newcastle-Ottawa Scale was used to assess the cohort and case control studies. Eight questions are used to assess quality based on comparability, selection, outcomes for the cohort studies, and exposure for the case-control studies.[30] A total of the scores out of nine is then calculated to provide an overall quality assessment. Three reviewers (C.G., J.S., and J.K.) conducted the bias assessments separately and discussed any discrepancies to come to a consensus.

The Revised Cochrane risk of bias tool for randomized trials (RoB 2) with additional considerations for crossover trials was used to assess the bias present in the crossover trial.[31] This tool assesses risk of bias across five domains including (1) randomization process, (2) deviations from intended intervention, (3) missing outcome data, (4) measurement of the outcome, and (5) reporting of results. Each domain is judged as low, some concern, or high risk, and then an overall risk of bias is determined. In order to determine the risk of bias in non-randomized single-arm clinical trials, five questions were selected from the Newcastle-Ottawa scale, which has been previously described as a method of assessing these studies.[32]

### Data collection process

The results from the database searches were exported to EndNote X9 for the screening process. Duplicates were removed, and the titles and abstracts were screened by C.G.. The full texts of the included articles were retrieved for screening and reviewed in full by CG and JK. The data extracted from the studies was screened separately by two reviewers (C.G. & J.K.) to ensure the studies met the eligibility criteria. A third reviewer (J.S.) provided an evaluation if there were any discrepancies. The following information was extracted from the studies: study design, sample size, year and location, participant characteristics, intervention and control conditions, SBP, DBP and MAP

(calculated) as well as information used to conduct the risk of bias assessment (Supplementary File 3).

### Statistical analysis

The primary outcomes in this study were the impact of exercise during pregnancy on SBP, DBP and MAP. Meta-analyses were conducted for all instances in which two or more studies reported data on comparable outcomes, interventions, participants and comparators as recommended by Ioannidis and Rothstein.[33] Only two studies reported MAP as an outcome measure; therefore, the SBP and DBP reported in each of the studies was used to calculate the MAP for the control and exercising groups using the equation[34]

$$\frac{SBP+(2DBP)}{3}=MAP$$

The sample standard deviation for each of the calculated MAPs was found using the standard variances for each measure. The following equations were used, where SD1 is the SBP SD and SD2 is the DBP SD

$$SD1^2=SV1$$

$$SD2^2=SV2$$

$$\frac{SV1+(2SV2)}{3}=MAPSV$$

$$\sqrt{MAPSV}=MAPSD$$

The software Review Manager 5 (RevMan V5, The Cochrane Collaboration) was utilized to run random effects meta-analysis using the DerSimonian and Laird method to estimate between-study variance. Meta-analyses were conducted separately for each outcome – SBP, DBP, and MAP. Subgroup analysis was performed to determine any effect of exercise type on outcome measures. As all resting blood pressure measures were recorded in mmHg, unstandardised mean differences were calculated for these continuous outcomes within each study. Standard variance was used to calculate the standard deviation when these were not reported by studies. Heterogeneity between studies was then assessed based on the $I^2$ value for each analysis, with an $I^2$ value between 30% and 60% considered moderate, and any value higher than 60% considered substantial heterogeneity.[35] Leave-one-out analysis was performed to determine the effect of each study on the heterogeneity.

## Results

### Study selection

The screening process of the studies can be viewed in Figure 1. In the initial search, 2055 articles were identified (CINAHL: 216, Cochrane: 1072, Embase: 107, Medline: 441, PubMed: 115, Web of Science: 104). Filters were applied, duplicates were removed and the titles and abstracts were screened for eligibility. Full texts were screened, and 59 articles were found to be eligible for the review. There were 32 exercise intervention studies and 27 acute exercise studies. Four of the intervention studies also reported acute responses to exercise. The types of studies included were RCTs (n= 33), clinical trials (n= 19), cohort (n= 5), and cross-sectional (n= 2). Eight intervention studies were included in the review that discussed BP, however did not report either pre or post SBP, DBP, or MAP values, or did not include a control/comparator group.[36–43] These studies were not included in the meta-analysis, along with one study which failed to report SD for SBP or DBP,[44] leaving 21 intervention studies in the statistical analysis. In the 27 acute studies, the gestational age at the time of the study, modality of exercise, and whether the final outcome measure was measured at rest or during exercise varied considerably; therefore, the acute studies were not included in the meta-analysis and are narratively presented. Six studies were excluded as they included water-based activities rather than land-based aerobic or resistance exercise.[45–50] These aquatic-based studies did not fit within the inclusion criteria for this review; however, this is an important area of research given that swimming is a popular, low-impact exercise during pregnancy.

### Risk of bias

The risk of bias can be viewed in Supplementary file 2 (Tables S1–S5). Overall, the risk of bias in the RCTs and randomized clinical trials was low, with 27 (71%) studies assessed as low risk,[20,34,36–39,41,42,51–69] 10 (27%) studies classified as unclear[44,69–76] and one (2%) study considered high risk.[77] The cohort[78–84] and case control studies[85–90] were all classified as low (71%) to moderate (29%) risk of bias (Tables S2 and S3), as were the two crossover studies (Table S4).[91,92] One (15%) of the single-arm clinical trials was found to have an unclear risk of bias,[93] while the other six (85%) studies were deemed to be low risk (Table S5).[40,43,94–97]

### Characteristics of acute and long-term exercise interventions

The characteristics of the participants included in the intervention and acute studies can be found in Tables S6 and S7, respectively (Supplementary File 3). The designs

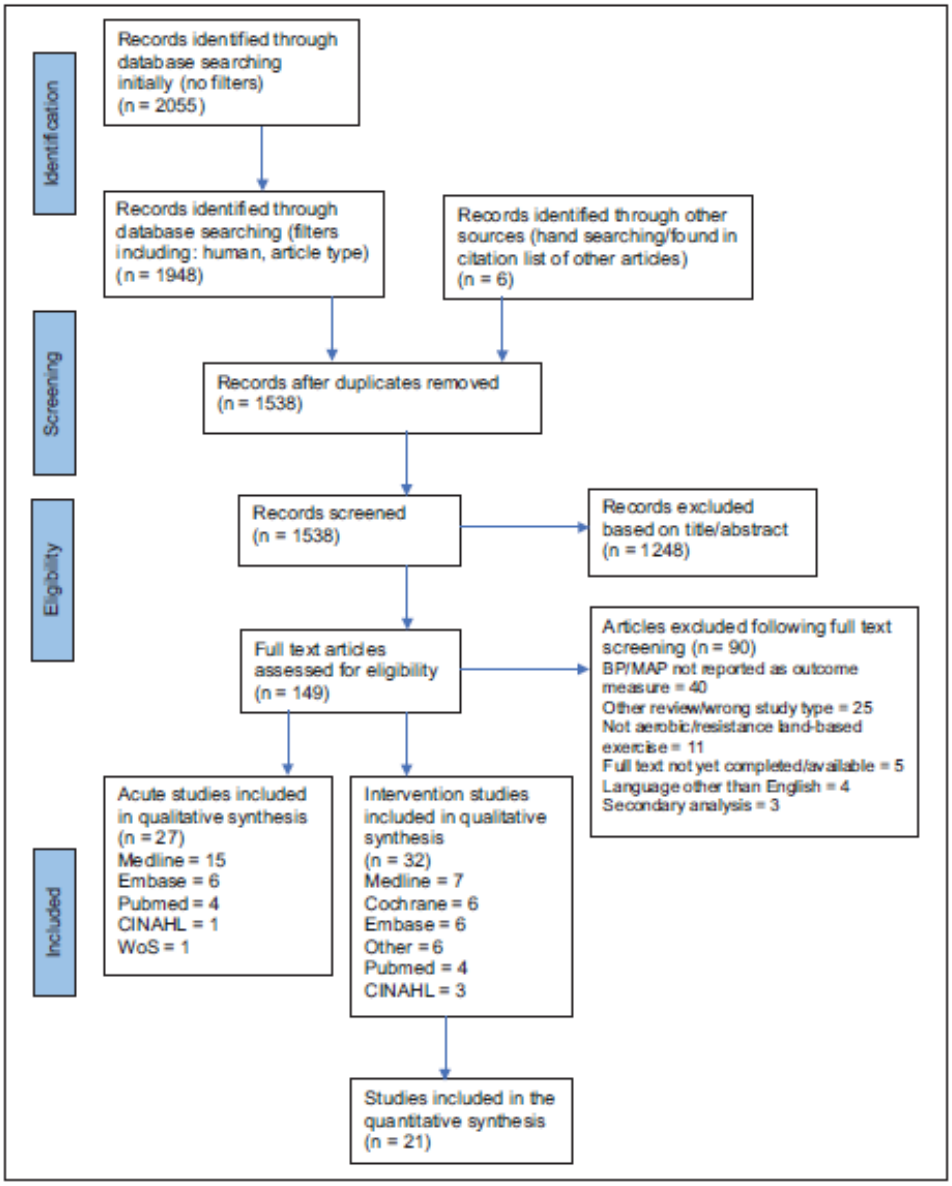


**Figure 1.** PRISMA flow chart.

of the exercise interventions and acute studies can be viewed in Table S8 (Supplementary File 3) and Table S9 (Supplementary File 3) respectively.

## Meta-analysis

*Pooled results–uncomplicated pregnancies.* Data were pooled from 13 studies to assess the effect of a long-term exercise intervention on SBP, and from 12 studies to assess DBP and MAP in uncomplicated pregnancies. There was no significant effect of exercise compared to control on the change in SBP (mean difference [95% CL] -1.54 mmHg [-5, 1.93], p = 0.38, $Tau^2 = 37.34$, $Chi^2 = 1792.51$, df = 12, $I^2 = 99\%$), DBP (mean difference [95% CL] –2.25 mmHg [-4.96, 0.45], p = 0.1, $Tau^2 = 20.78$, $Chi^2 = 774.07$, df = 11, $I^2 = 99\%$), or MAP (mean difference [95% CL] -1.75 mmHg [-5.13–1.63], p = 0.31, $Tau^2 = 31.75$, $Chi^2 = 1000.16$, df = 11, $I^2 = 99\%$) when aerobic, resistance, and combination exercise studies were pooled.

*Pooled results – at risk population.* Within the 10 at-risk studies the pooled data showed a significant effect of

exercise on SBP (mean difference [95% CL] –3.91 mmHg, [-6.74, -1.08], p=<0.01, $Tau^2$=16.52, $Chi^2$=160.29, df=9, $I^2$=94%), DBP (mean difference [95% CL] -2.9 mmHg [-5.11, -0.68], p=0.01, $Tau^2$=10.47, $Chi^2$=244.97, df=9, $I^2$=96%), and MAP (mean difference [95% CL] -2.38 mmHg [-4.27, -0.48], p=0.01, $Tau^2$=6.61, $Chi^2$=255.06, df=8, $I^2$=97%) compared to the control group.

### Aerobic exercise interventions

*Uncomplicated pregnancies.* Six studies included aerobic exercise interventions within uncomplicated pregnant populations,[39,53,66,70,72,74] with only one study not meeting the inclusion criteria for the meta-analysis.[39] The meta-analysis showed no significant difference in SBP (mean difference [95% CL]=-0.70 mmHg [-6.95, 5.55], p=0.83, $Tau^2$=42.43, $Chi^2$=160.21, df=4, $I^2$=98%) (Figure 2), DBP (mean difference [95% CL]=1.30 mmHg [-1.43, 4.02], p=0.35, $Tau^2$=6.93, Chi2=37.09, df=4, $I^2$=89%) (Figure 3), and MAP (mean difference [95% CL]=0.28 mmHg [-2.48, 3.05], p=0.84, $Tau^2$=5.23, $Chi^2$=13.59, df=4, $I^2$=71%) (Figure 4) between healthy exercising and control groups following aerobic exercise interventions. The leave-one-out analysis showed a large drop in heterogeneity when one study[53] was excluded from the SBP data (mean difference [95% CL]=3.26 mmHg [1.62, 4.89], p=0.08, $Tau^2$=1.35, $Chi^2$=6.84, df=3, $I^2$=56%) and the MAP data (mean difference [95% CL]=1.45 mmHg [-0.38, 3.29], p=0.12, $Tau^2$=1.21, $Chi^2$=4.68, df=3, $I^2$=36%).

*At risk populations.* Ten studies included at risk populations performing aerobic exercise interventions, seven of which were included in the statistical analysis.[54,57,58,60,66–68] The clinical conditions included: overweight/obesity (body mass index (BMI) > 25 kg/m$^2$),[66,98] GDM or history of GDM,[54,57,58] anaemia,[67] or high risk of GHTN/PE due to chronic or mild HTN, previous GHTN/PE or family history of HTN/PE.[41,44,60,68] Following aerobic exercise, a near significant difference was found for SBP (mean difference [95% CL]=-3.02 mmHg [-6.3, 0.26], p=0.07, $Tau^2$=17.54, $Chi^2$=153.64, df=7, $I^2$=95%) (Figure 5) and MAP (mean difference [95% CL]=-1.92 mmHg [-4.2, 0.37], p=0.1, $Tau^2$=7.12, $Chi^2$=227.38, df=6, $I^2$=97%) (Figure 7) between exercising and control groups. A statistically significant reduction in DBP (mean difference [95% CL]=-3.09 mmHg [-5.9, -0.28], p=0.03, $Tau^2$=13.18, $Chi^2$=208.71, df=7, $I^2$=97%) (Figure 6) was found in the at risk population following aerobic exercise compared to control.

The three studies excluded from the analysis did not report baseline and post-intervention SBP and DBP; therefore, the mean change in these measures could not be calculated to be used in the analysis.[41,44,98] No significant differences in SBP or DBP were discussed by the studies. Long-term changes in SBP and DBP were not reported by Khoram et al.[41]; however, acute responses to exercise were discussed. There was a significantly lower incidence of PE and GHTN in the exercising group compared to control (p=<0.05). Results from Yeo et al.[44] showed no significant difference in BP between groups; however, both SBP and DBP reduced in the exercising group and increased in the control group with a near significant difference in DBP found with a reduction of 3.5 mmHg in the exercising group and an increase of 1.1 mmHg in the control group (p=0.05). Changes in BP from baseline were not reported by Senevirante et al.[98]; however, there were no significant differences in mean SBP (p=0.25) or DBP (p=0.68) between exercising and control groups.

### Resistance exercise interventions

*Uncomplicated pregnancies.* Four studies included in the review involved an intervention of supervised low to moderate intensity strength training.[40,43,63,64] Two of these did not include a comparator/control group leaving only two studies eligible for inclusion in the analysis.[63,64] No significant differences were seen between groups in the two studies included in the meta-analysis for SBP (mean difference [95% CL]=-5.18 mmHg [-19.18, 8.81], p=0.47, $Tau^2$=101.03, $Chi^2$=110.19, df=1, $I^2$=99%) (Figure 2), DBP (mean difference [95% CL]=-8.28 mmHg [-24.14, 7.57], p=0.31, $Tau^2$=130.62, $Chi^2$=469.24, df=1, $I^2$=100%) (Figure 3), or MAP (mean difference [95% CL]=-5.36 mmHg [-16.91, 6.18], p=0.36, $Tau^2$=69.11, $Chi^2$=256.19, df=1, $I^2$=100%) (Figure 4). The results from the two studies not included in the meta-analysis showed no significant changes in SBP (113.5 ± 8.4 mmHg to 113.9 ± 10 mmHg;[43] 108 ± 13.5 mmHg to 113.1 ± 9.12)[40] or DBP (71.9 ± 6.8 mmHg to 73.3 ± 7.1 mmHg;[43] 66.8 ± 10.1 mmHg to 70.6 ± 10.4 mmHg)[40] following the interventions.

*At risk populations.* Two studies included at-risk populations performing resistance training[42,59]; however, only one of these reported baseline and postintervention SBP and DBP[59]; therefore, no subgroup analysis could be run, as at least two studies are required.[33] One study reported a significant decrease in SBP (Pre: 121.37 ± 15.83 mmHg, Post: 112.12 ± 13.87 mmHg; p=<0.001) and DBP (Pre: 75.63 ± 8.96 mmHg, Post: 70.23 ± 7.38 mmHg; p<0.001) in the intervention group compared to control (SBP Pre: 119.8 ± 17.47 mmHg, Post: 118.96 ± 17.38; p=0.12; DBP Pre: 75.65 ± 10.86 mmHg, Post: 74.59 ± 10.94 mmHg; p=0.15).[59] Arterial BP was reported as a secondary outcome measure in the other RCT with no significant differences found for either SBP or DBP following resistance training.[42]

### Combination interventions

*Uncomplicated pregnancies.* No significant differences were found in SBP (mean difference [95% CL]=-0.85

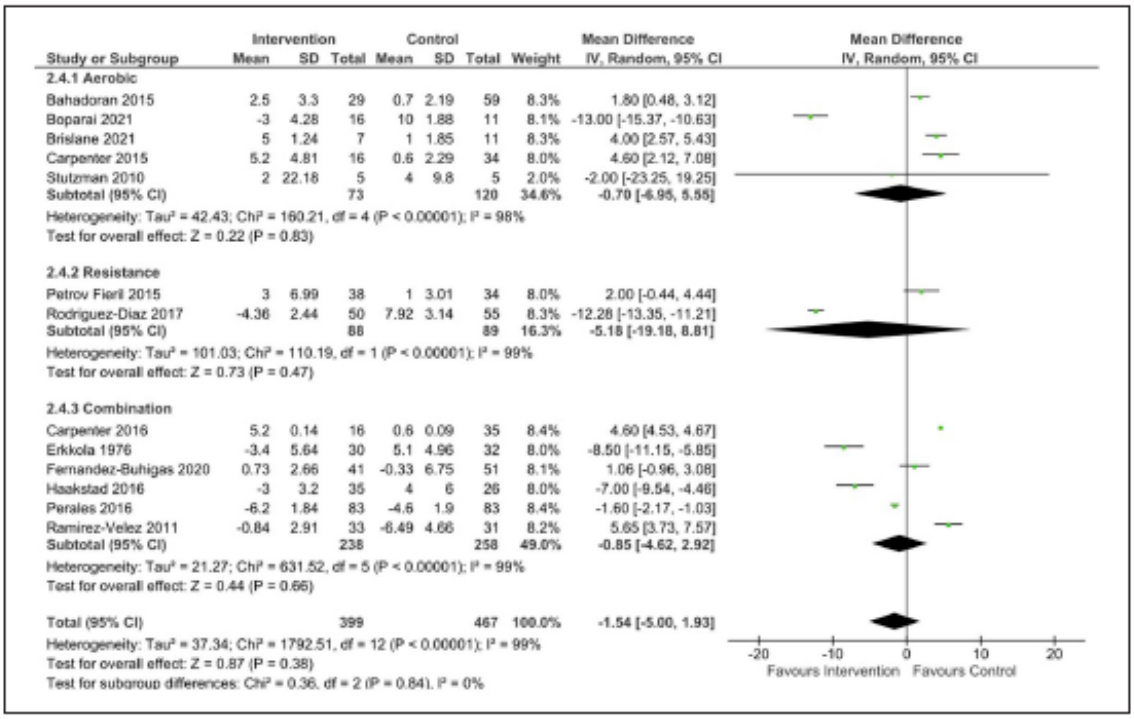


**Figure 2.** SBP changes following exercise in uncomplicated pregnancies.

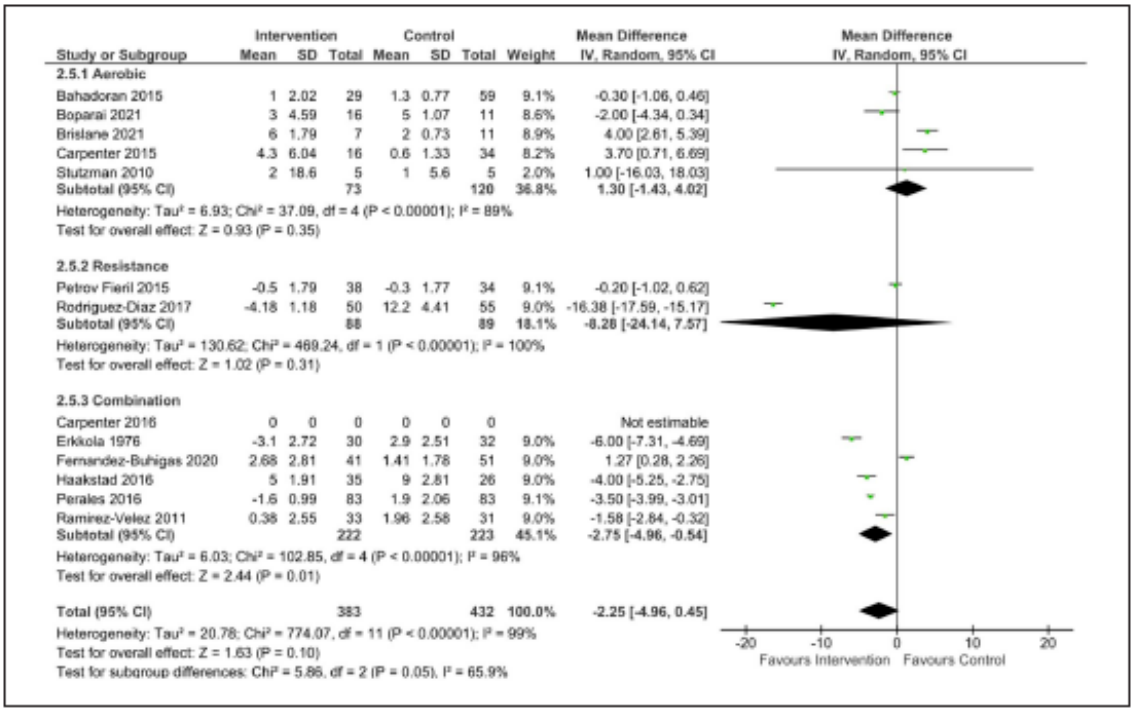


**Figure 3.** DBP changes following exercise in uncomplicated pregnancies.

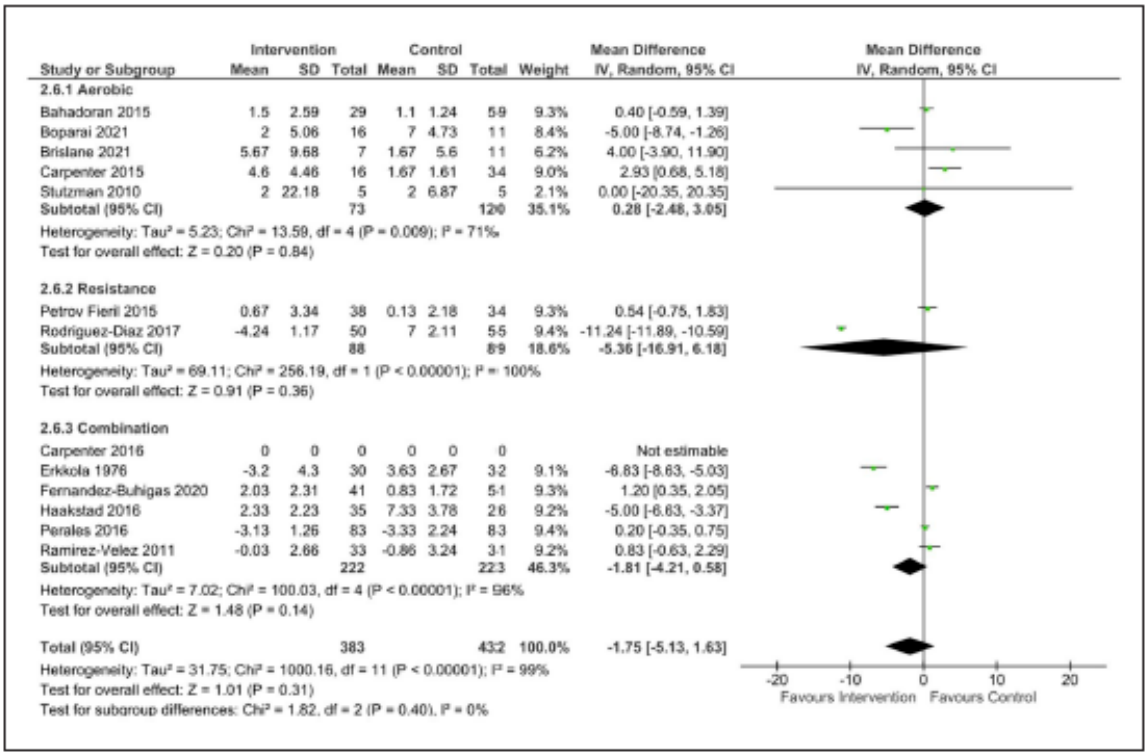


**Figure 4.** MAP changes following exercise in uncomplicated pregnancies.

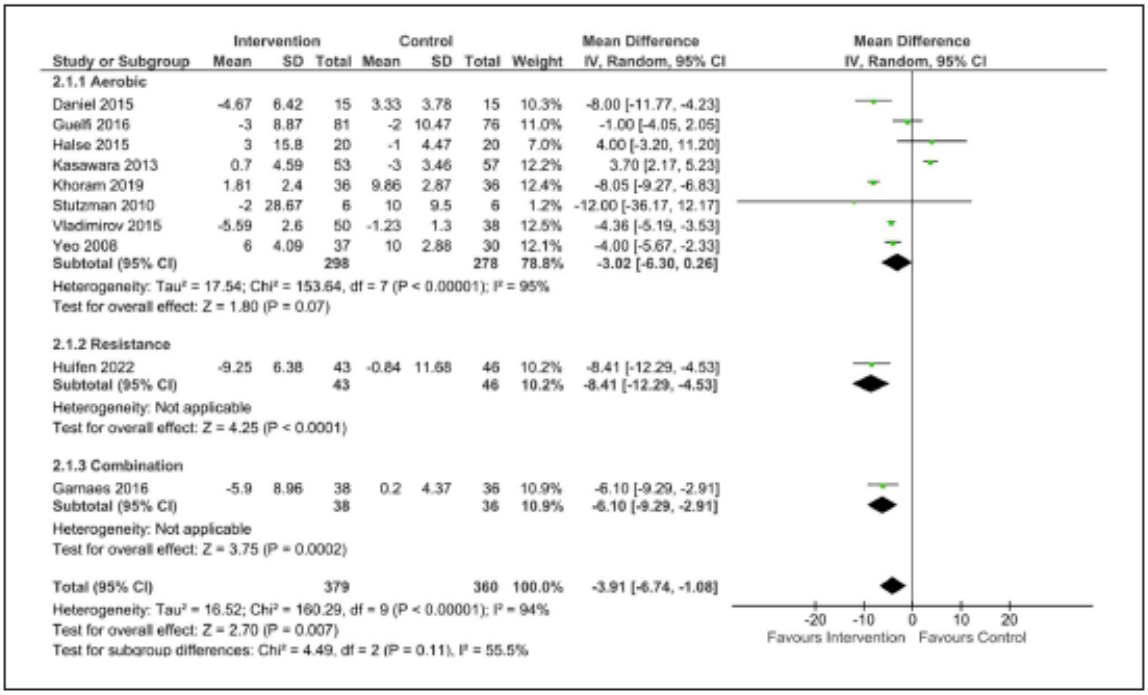


**Figure 5.** SBP changes following exercise in at risk populations.

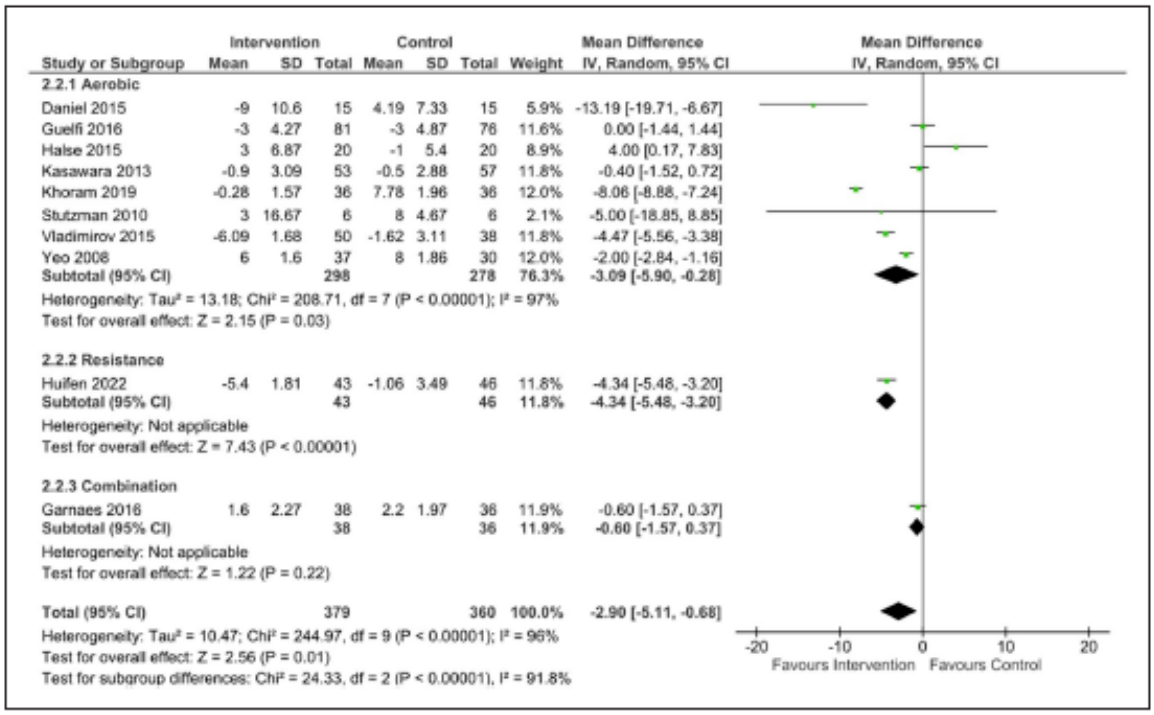


**Figure 6.** DBP changes following exercise in at risk populations.

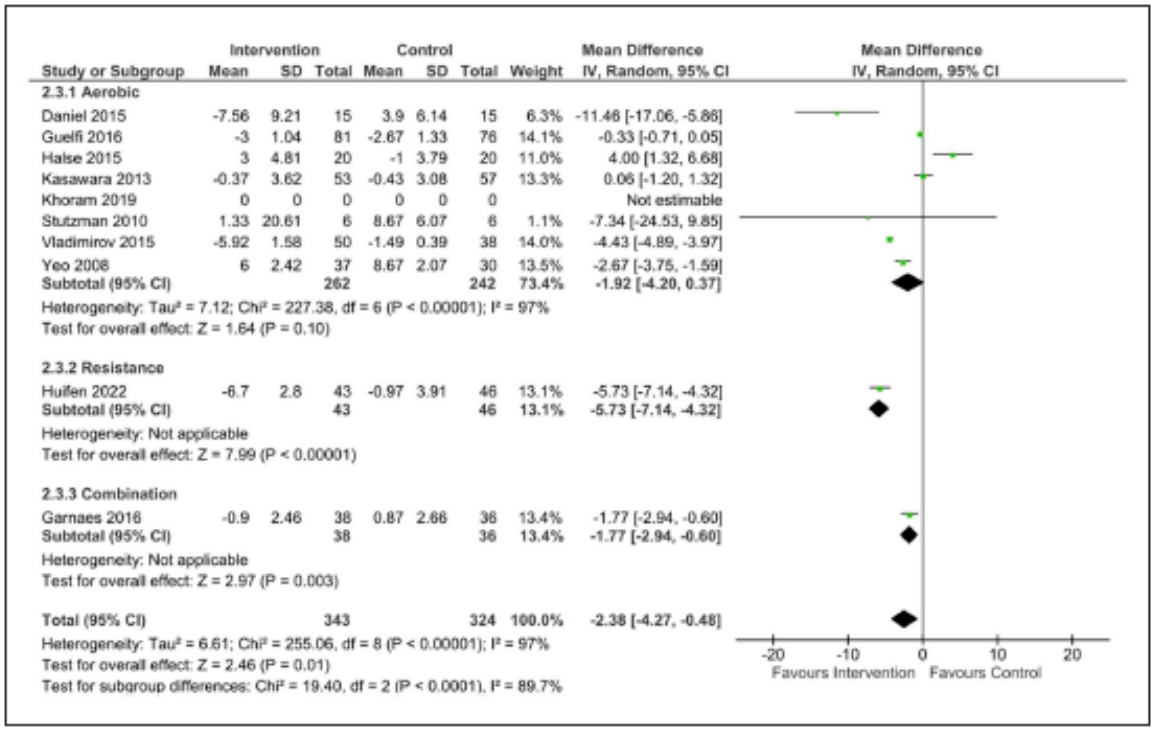


**Figure 7.** MAP changes following exercise in at risk populations.

mmHg [-4.62, 2.92], p=0.66, $Tau^2$=21.27, $Chi^2$=631.52, df=5, $I^2$=99%) (Figure 2) or MAP (mean difference [95% CL]=-1.81 mmHg [-4.21, 0.58], p=0.14, $Tau^2$=7.02, $Chi^2$=100.03, df=4, $I^2$=96%) (Figure 4). A small but statistically significant reduction in DBP was found following an intervention of combined aerobic and resistance exercise compared to control (mean difference [95% CL]=-2.75 mmHg [-4.96, -0.54], p=0.01, $Tau^2$=6.03, $Chi^2$=102.85, df=4, $I^2$=96%) (Figure 3). Four studies were not included in the analysis as they did not report on the change in BP from baseline.[36–38,65] Three studies did not report baseline BP, however, found no significant differences between groups for SBP (p=>0.05;[37] p=0.25;[36] p=0.49)[38] or DBP (p=>0.05;[37] p=0.29;[36] p=0.74)[38] postintervention. One study found no differences in SBP or DBP across the three trimesters between intervention and control in a study of 72 women.[65]

*At-risk populations.* Only one study reported changes in BP following an intervention of combination exercise in an at risk population and found the mean SBP of the exercising group was significantly lower than the control group following intervention, with a mean reduction of 7.7 mmHg (95% CI −13.23, −2.22; p<0.001) and no significant difference in DBP or MAP between groups.[56]

## Acute aerobic exercise

*Uncomplicated pregnancies.* Eighteen studies were identified that looked at the blood pressure response both during and following an acute bout of aerobic exercise in uncomplicated pregnancies.[51,73,75,77–79,82–84,87,89–96] All studies reported an acute increase in SBP and DBP during aerobic exercise. One study comparing stationary cycling and treadmill walking found similar increases in SBP irrespective of the mode (bike: + 8 mmHg p=0.06, treadmill: + 8 mmHg p=0.02) and DBP (bike: + 5 mmHg p=0.39, treadmill: + 6 mmHg p=0.18).[51] Fieril et al.[92] also reported an increase in SBP and DBP following 15 and 30 min of aerobic exercise (p=0.01 and p=0.001 respectively). These two studies, along with De Olivieria et al.[91] found a post exercise hypotensive response, in which BP dropped below baseline levels from 50 min to 14 hours post exercise.[51] Two studies that observed BP responses to peak/max cycle tests found lower absolute BP responses in the first and second trimesters, increasing back to non-pregnant levels or above in the third trimester.[90,93] One study found a positive correlation between resting SBP and DBP in the second trimester and BP response to submaximal aerobic exercise on the treadmill.[94]

*At risk populations.* Four studies measured acute BP response to aerobic exercise in at risk populations. The participants in two of these studies took part in an intervention of exercise during pregnancy however the authors reported acute BP responses to exercise rather than changes from baseline to post intervention.[41,76] Mean SBP rose significantly after five minutes of exercise in one study from 149 mmHg (range 130 ± 170 mmHg) to 171 mmHg (range 150 ± 190 mmHg) in participants with pregnancy-induced hypertension.[80] Diastolic BP also rose however was not significant in this study (102 mmHg, range 100 ± 110 mmHg to 106 mmHg, range 100 ± 115 mmHg).[80] Another study[41] found a significant difference in mean SBP (exercise: 1.81 ± 2.4 mmHg, control: 9.86 ± 2.87 mmHg p=0.03) and DBP (exercise: -0.28 ± 1.57 mmHg. control: 7.78 ± 1.96 mmHg p=0.002) changes after walking compared with pre-walking. A study comparing responses to aerobic and resistance exercise found no significant change in SBP and DBP from baseline following exercise, with the intervention group recording a significantly higher SBP during aerobic exercise than resistance (p=<0.01).[76] No significant differences were found in BP responses following exercise when groups with PE, GDM and Cholestasis were compared.[81]

## Acute resistance exercise

*Uncomplicated pregnancies.* Eight studies measured BP following an acute bout of resistance training during healthy pregnancy.[40,43,52,85,86,88,92,97] The participants in two studies[40,43] took part in resistance interventions described earlier under 'Resistance Exercise Interventions – Healthy Populations'; however, the authors reported both acute and long-term responses to exercise.

Overall SBP and DBP increased significantly from baseline during exercise and returned to pre-exercise levels within 5 min following exercise, with four studies reporting no significant difference between pre and post BP.[40,43,52,92] One study comparing pregnant and non-pregnant women found that the SBP, DBP and MAP responses during exercise were all lower (p=0.03, 0.02, 0.01, respectively) within the pregnant group.[86] In comparison, another study[85] found no significant differences between SBP and DBP responses between pregnant and non-pregnant groups. One study compared BP responses to 40% 10RM resistance exercises with and without the use of the Valsalva manoeuvre and found a significantly increases MAP when the Valsalva manoeuvre was performed compared to free breathing due to significantly higher systolic (121 ± 15 mmHg vs 116 ± 12 mmHg, p=0.001) and diastolic blood pressures (79 ± 8 mmHg vs 77 ± 8 mmHg, p=0.02).[88]

*At risk populations.* Three studies found no difference between pre and post SBP or DBP following light[61,71] and moderate to vigorous[76] resistance exercise in at risk pregnant women.

*Adherence.* Adherence was reported in 21 of the 32 intervention studies, with varied results across the studies with both low (n=7; 33%–62.5%)[20,42,56,57,60,68,98] and high rates of adherence (n=14; 75%–95%) reported.[34,36–38,44,53,54,57,62–66,70]

Yeo et al.[68] found that adherence rates decreased over time, with their participants instructed to exercise five times per week and only completing on average 2.5–4.5 sessions per week. One study reported that 28 of the 69 participants in the intervention group completed less than 70% of the exercise sessions and were therefore excluded from the study.[55]

## Discussion

The aims of this review were to assess the effects of exercise interventions on blood pressure during pregnancy and to understand acute changes in blood pressure during a single bout of exercise in pregnant women. Significant differences in favour of the exercise group were found in SBP, DBP and MAP following exercise interventions in at-risk populations. This indicates that pregnant women at a higher risk for cardiovascular conditions may use aerobic or a combination of aerobic and resistance exercise to help prevent an increase in BP often associated with these conditions. For uncomplicated pregnancies, light to moderate intensity aerobic or resistance exercise had no effect on resting BP throughout pregnancy. Blood pressure showed greater increases with acute aerobic exercise than resistance exercise in uncomplicated and at-risk populations, returning to baseline levels post-exercise. A post-exercise hypotensive response in BP may occur following acute aerobic exercise, indicating that acute bouts of aerobic exercise may help lower BP in at risk populations with higher resting BP levels. Compared to usual care, aerobic, and/or resistance exercise performed throughout uncomplicated pregnancy had no influence on blood pressure; however, higher risk pregnancies may reduce their risk of elevated BP through regular exercise training during pregnancy.

This review found no differences in SBP or MAP in the uncomplicated pregnant population and only a small yet significant decrease in DBP following combined aerobic and resistance exercise intervention. Reassuringly, these participants remained normotensive throughout gestation. In response to vasoactive substances, growth factors and haemodynamic stimuli, the structural components of blood vessel walls are altered through the dynamic process of vascular remodelling during pregnancy.[4,14] The structure and function of arteries are remodelled to accommodate an increased blood volume and cardiac output, and to ensure that the endothelial shear rates remain within healthy limits.[6,14] A curvilinear reduction in blood pressure associated with vascular remodelling and vasodilation has been observed in uncomplicated pregnancies, with a nadir reached between the end of the first and beginning of the second trimester.[14,99] The results from this meta-analysis support previous evidence which indicate that regular exercise during pregnancy does not influence these normal physiological changes that occur during gestation.[55] Women with uncomplicated pregnancies can be confident that there are no adverse effects of exercise on haemodynamics during gestation. They should be encouraged to continue exercising throughout their pregnancy where possible.

The physiological changes present throughout gestation have been shown to differ between uncomplicated and pathological pregnancies.[2,4] Where normal pregnancy is characterized by a low systemic vascular resistance and an increased cardiac output, the adaptations are often reversed in hypertensive pregnancies.[18,100,101] Women with insulin resistance or GDM have an increased risk of developing GHTN and PE, and these conditions share several risk factors and pathophysiological features including maternal obesity, excessive gestational weight gain, vascular dysfunction, and inflammation.[22,54,76] This review found exercising participants diagnosed with clinical conditions showed lower resting BP's following intervention than the non-exercising controls, indicating that regular exercise may help prevent the onset of GHTN or PE in this population.[54,59]

The studies in this review that measured incidence of PE and GHTN identified significantly lower rates of these two conditions in exercising groups compared to non-exercising controls.[41,56,68] Furthermore, no adverse events were reported by any of the interventions involving at-risk pregnancies, even those at high risk for GHTN and PE. This is supported by a systematic review which reported a 39% and 41% reduction in the odds of developing GHTN and a PE, respectively, when exercise was performed during pregnancy.[22] Preeclampsia and GHTN have long been recognized as absolute and relative contraindications to exercise in international exercise and pregnancy guidelines.[102] A review evaluating which clinical conditions may be contraindications to exercise determined that only severe PE should still be considered an absolute contraindication, with mild PE categorized as a relative contraindication, and gestational hypertension (in isolation) no longer considered a contraindication.[102] The review highlighted that light to moderate prenatal exercise in women with mild pre-eclampsia caused no adverse changes in BP, uterine blood flow and FHR, and can provide a multitude of maternal and foetal benefits.[102] It is crucial that pregnant women with these clinical conditions are provided with appropriate guidance based on the most recent evidence to improve maternal and foetal outcomes. More research is needed on the effects of exercise on BP regulation during pregnancy in those at a higher risk of developing gestational hypertensive conditions.[94]

Adherence appears to be a limitation in most studies involving overweight or obese pregnant women, with adherence rates between 33% and 75% reported in exercise interventions.[56,98] Exercise adherence within at risk pregnant populations, particularly women who are overweight or have obesity, is considered a major challenge, therefore finding methods to reduce participant attrition rates is vital.[56] It has been suggested that including higher intensity

intervals into training may be one method of increasing energy expenditure while enhancing enjoyment levels and reducing the time spent exercising.[103] Six of the studies included more vigorous intensity exercise,[34,56–58,63,73] with adherence rates varying from 50%[56] to 96%.[58] Systematic evidence has found that vigorous intensity exercise appears safe for most uncomplicated pregnancies when completed into the third trimester,[30] however further research is needed within the first and second trimester as well as within higher risk populations.

No significant differences in BP were found following resistance training alone, however only a limited number of studies reported the effects of resistance training during pregnancy. More research is needed on this modality of exercise throughout pregnancy to determine the long-term effects of resistance training on BP, specifically in at risk populations. Similar changes were seen with aerobic and combination exercise in both uncomplicated and at risk populations. It has previously been suggested that aerobic exercise should be supplemented with resistance exercise to aid in the prevention of hypertension in non-pregnant populations,[104,105] however more recent evidence including a systematic review[106] has identified that there is little to no difference in BP between aerobic exercise alone and a combination of aerobic and resistance in non-pregnant populations.[104,106] The findings from this review suggest that within at risk populations aerobic and combination exercise should be prioritized to prevent an increase in BP and reduce the risk of developing gestational hypertensive conditions. Although resistance training may not significantly affect blood pressure changes throughout uncomplicated or at risk pregnancies, it is still recommended as standard exercise prescription due to the benefits to increase/maintain strength and decrease urinary incontinence.[107]

As expected, all of the acute studies found significant increases in SBP during exercise, with hypotensive BP responses found following aerobic exercise from 50 to 60 min[91] to 13 to 14 h post exercise.[51] Post exercise hypotension (PEH) is commonly seen following acute bouts of aerobic exercise in both normotensive and hypertensive non-pregnant people.[86,91] Findings suggest that BP responses to acute aerobic exercise in pregnant women participating in regular aerobic exercise are significantly lower than non-exercising women. This indicates a training response to regular aerobic exercise with adaptations occurring within the cardiovascular system.[18] Previous studies have suggested that some of the physiological mechanisms that reduce BP following chronic exercise may be present in the onset of PEH following acute exercise bouts. Indeed, a systemic adaptation of the arterial wall increasing arterial compliance occurs following an exercise session, thereby decreasing peripheral resistance.[18] Characterized by a sustained decrease in blood pressure following a single bout of exercise, PEH has been shown to vary in magnitude and duration, indicating that exercise characteristics may have an influence on levels of PEH.[105,108] It has been suggested that PEH responses are clinically important as they may help cause an adaptation which results in a lowering of BP.[43] A reduction in SBP of as little as 2 mmHg in non-pregnant populations has been shown to reduce the risk of cardiovascular disease by 4-6%.[18] The results of this review support previous research indicating that regular bouts of aerobic exercise may help pregnant women reduce their risk of developing gestational hypertensive conditions.

### Limitations

A limitation in the current review and meta-analysis was the heterogeneity of the research designs. A random effects meta-analysis was used to account for this. The $I^2$ values were high for the uncomplicated and at risk groups when the exercise types were grouped ($I^2$=94%–99%), and although they dropped slightly when subgroup analysis was performed for exercise type they remained high ($I^2$=71%–98%) indicating that there may be heterogeneity in the outcomes that are not able to be explained by the studies in this systematic review. The leave-one-out analysis showed slight decreases in heterogeneity when certain studies were removed, however generally remained high (80%–99%). This can be expected as the session duration, intensity, frequency, exercise mode and length of intervention varied significantly across the studies, even within the subgroups presented (study variables can be viewed in Supplementary File 1. Tables S8 and S9). The mode, length (3–31 weeks), frequency (1–5 sessions/week), and duration (15–60 min), varied across interventions, making it hard to distinguish which of these factors may have contributed to changes in BP. A large decrease in heterogeneity was only seen when one study[53] was removed. One notable difference in this study is that BP was measured through finger photoplethysmography with a Finometer (Finometer Pro; Finapres Medical Systems, Amsterdam, the Netherlands), rather than the more common method of brachial auscultation. Research has shown however, that the Finometer is a suitable measure of BP with no significant differences seen between auscultatory measures and Finometer measures when compared.[109]

The same issue was faced when comparing the acute studies, as the bouts ranged from 5- to 60-min bouts and were measured at different time points during pregnancy (12–38 weeks gestation). Most of the control groups were treated with routine prenatal care or continued with their usual physical activity levels, and as such may have participated in exercise throughout pregnancy of their own accord, potentially influencing results. Furthermore, there were low adherence rates and small sample sizes observed in many of the studies.

## Conclusion

The findings from this review indicate that moderate to vigorous aerobic exercise during pregnancies complicated with clinical conditions including GDM, overweight and obesity may either reduce, or attenuate an increase in blood pressure that commonly occurs with these conditions. These findings have important implications for pregnant women at risk of developing gestational hypertension and pre-eclampsia. Indeed, particular focus on providing exercise support to clinical pregnancies may have significant impact on future maternal and infant cardiovascular morbidity and mortality.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Author contribution(s)

**Courtney Giles:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Writing – original draft; Writing – review and editing.
**Rich Johnston:** Conceptualization; Formal analysis; Supervision; Writing – review and editing.
**Jade Kubler:** Data curation; Writing – review & editing.
**Jemima Spathis:** Conceptualization; Data curation; Supervision; Writing – review and editing.
**Kassia Beetham:** Conceptualization; Project administration; Supervision; Writing – review and editing.

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### Competing interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### Availability of data and materials

All supplementary files have been provided.

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## Supplemental material

Supplemental material for this article is available online.

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## 10.2 Appendix 2 – Informed consent form Study 2

CONSENT FORM

TITLE OF PROJECT: The acute effects of a weekly submaximal aerobic exercise test on arterial stiffness and blood pressure from embryo implantation until birth: a longitudinal case study

PRINCIPAL INVESTIGATOR/SUPERVISOR: Dr Rich Johnston

STUDENT RESEARCHER: Miss Courtney Giles

I ..... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this exercise trial in which results will be digitally recorded, realising that I can withdraw my consent at any time without adverse consequences. I understand that my data will be stored electronically on a password secured hard drive for up to 5 years. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

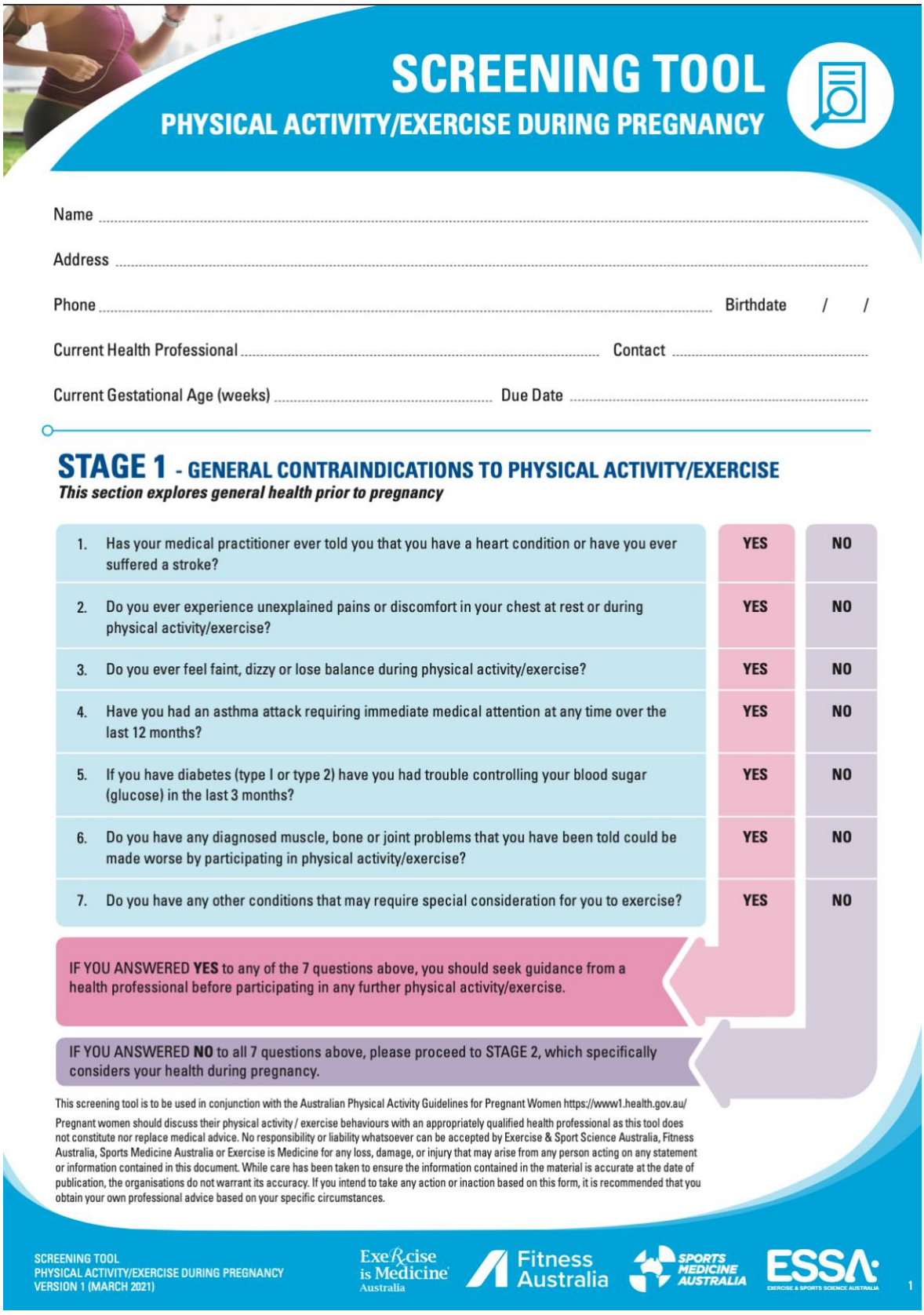
NAME OF PARTICIPANT:

SIGNATURE ..... DATE .....

SIGNATURE OF PRINCIPAL INVESTIGATOR (or SUPERVISOR): .....
DATE: ……

SIGNATURE OF STUDENT RESEARCHER: .....

## 10.3 Appendix 3 - ESSA Screening tool



# SCREENING TOOL

## PHYSICAL ACTIVITY/EXERCISE DURING PREGNANCY

Name .....

Address .....

Phone ..... Birthdate / /

Current Health Professional ..... Contact .....

Current Gestational Age (weeks) ..... Due Date .....

## STAGE 1 - GENERAL CONTRAINDICATIONS TO PHYSICAL ACTIVITY/EXERCISE

***This section explores general health prior to pregnancy***

| | | |
|---|---|---|
| 1. Has your medical practitioner ever told you that you have a heart condition or have you ever suffered a stroke? | YES | NO |
| 2. Do you ever experience unexplained pains or discomfort in your chest at rest or during physical activity/exercise? | YES | NO |
| 3. Do you ever feel faint, dizzy or lose balance during physical activity/exercise? | YES | NO |
| 4. Have you had an asthma attack requiring immediate medical attention at any time over the last 12 months? | YES | NO |
| 5. If you have diabetes (type I or type 2) have you had trouble controlling your blood sugar (glucose) in the last 3 months? | YES | NO |
| 6. Do you have any diagnosed muscle, bone or joint problems that you have been told could be made worse by participating in physical activity/exercise? | YES | NO |
| 7. Do you have any other conditions that may require special consideration for you to exercise? | YES | NO |

IF YOU ANSWERED **YES** to any of the 7 questions above, you should seek guidance from a health professional before participating in any further physical activity/exercise.

IF YOU ANSWERED **NO** to all 7 questions above, please proceed to STAGE 2, which specifically considers your health during pregnancy.

This screening tool is to be used in conjunction with the Australian Physical Activity Guidelines for Pregnant Women https://www1.health.gov.au/

Pregnant women should discuss their physical activity / exercise behaviours with an appropriately qualified health professional as this tool does not constitute nor replace medical advice. No responsibility or liability whatsoever can be accepted by Exercise & Sport Science Australia, Fitness Australia, Sports Medicine Australia or Exercise is Medicine for any loss, damage, or injury that may arise from any person acting on any statement or information contained in this document. While care has been taken to ensure the information contained in the material is accurate at the date of publication, the organisations do not warrant its accuracy. If you intend to take any action or inaction based on this form, it is recommended that you obtain your own professional advice based on your specific circumstances.

# STAGE 2 - CONTRAINDICATIONS TO PHYSICAL ACTIVITY/EXERCISE DURING PREGNANCY

## ABSOLUTE CONTRAINDICATIONS DURING PREGNANCY

***Have you ever been told that you have any of the following contraindications to physical activity/exercise:***

| | | | |
|---|---|---|---|
| 1. | Incompetent cervix | YES | NO |
| 2. | Ruptured membranes, premature labour | YES | NO |
| 3. | Persistant second or third trimester bleeding | YES | NO |
| 4. | Placenta previa | YES | NO |
| 5. | Pre-eclampsia | YES | NO |
| 6. | Evidence of intrauterine growth restriction | YES | NO |
| 7. | Multiple gestation (eg: triplets or higher number) | YES | NO |
| 8. | Poorly controlled Type I diabetes, hypertension or thyroid disease | YES | NO |
| 9. | Other serious cardiovascular, respiratory or systemic disorder | YES | NO |

IF YOU ANSWERED **YES** to any of the 9 questions above, you should discuss opportunities to modify your physical activity/exercise with a health professional before participating in any further physical activity/exercise. It is still important that you avoid sitting for long periods of time.

IF YOU ANSWERED **NO** to all 9 questions above, please proceed to RELATIVE CONTRAINDICTIONS.

## RELATIVE CONTRAINDICATIONS DURING PREGNANCY

***Have you ever been told that you have any of the following contraindications to physical activity/exercise:***

| | | | |
|---|---|---|---|
| 1. | History of spontaneous miscarriage, premature labour or fetal growth restriction | YES | NO |
| 2. | Mild/moderate cardiovascular or chronic respiratory disease | YES | NO |
| 3. | Pregnancy-induced hypertension | YES | NO |
| 4. | Poorly controlled seizure disorder | YES | NO |
| 5. | Type 1 diabetes | YES | NO |
| 6. | Symptomatic anaemia | YES | NO |
| 7. | Malnutrition, significantly underweight or eating disorder | YES | NO |
| 8. | Twin pregnancy after the 28th week | YES | NO |
| 9. | Other significant medical condition/s (Please detail below) | YES | NO |

.....

IF YOU ANSWERED **YES** to any of the 9 questions above, you should discuss opportunities to modify your physical activity/exercise with a health professional before participating in any further physical activity/exercise. It is still important that you move about frequently and avoid sitting for long periods of time.

IF YOU ANSWERED **NO** to all 9 questions above, please follow the physical activity/exercise guidelines on the next page.

**IMPORTANT:** Where physical activity/exercise is safe, health professionals should encourage physical activity/exercise in accordance with the Australian Physical Activity Guidelines for Pregnant women, with the key messages being **Move more - Sit less - Be active during pregnancy!**

# STAGE 3 - PHYSICAL ACTIVITY/EXERCISE GUIDELINES

## DOSE: *HOW MUCH PHYSICAL ACTIVITY SHOULD I DO?*

| IF YOU ARE: | SEDENTARY | ACTIVE BUT NOT MEETING GUIDELINES | MEETING GUIDELINES BETWEEN 150-300 MINS PER WEEK | EXCEEDING GUIDELINES |
|---|---|---|---|---|
| | Doing any physical activity is better than doing none<br><br>If you currently do no physical activity, start slowly and progress towards meeting the guidelines | • Be active on most, preferably all, days every week<br>• Accumulate 150 to 300 minutes (2 ½ to 5 hours) of moderate intensity physical activity or 75 to 150 minutes (1 ¼ to 2 ½ hours) of vigorous intensity physical activity, or an equivalent combination of both moderate and vigorous activities, each week<br>• Do muscle strengthening activities on at least 2 days each week targeting large muscle groups<br>• Minimise the amount of time spent in prolonged sitting<br>• Break up long periods of sitting as often as possible | | • Upper intensity limit for exercise during pregnancy is not known<br>• To ensure safety and wellbeing, highly active women, including athletes, should have their physical/activity program overseen and managed by an informed health professional<br>• May continue with current program, as long as necessary modifications are made as the pregnancy progresses |

## TYPE: *WHAT SORT OF ACTIVITY SHOULD I DO / NOT DO?*

**Physical activities/exercises that are considered SAFE:**

National guidelines concur that the following activities are considered to be generally safe for pregnant women with an uncomplicated pregnancy:

- Aerobic physical activity/exercise
- Muscle strengthening exercises using body weight, weights or resistance bands
- Pelvic floor muscle exercises
- Pregnancy specific classes

**Physical activities/exercises that are considered UNSAFE:**

Pregnant women are advised to avoid activities that involve:

- Significant changes in pressure (eg. sky diving, scuba diving etc.)
- Risk of contact / collision
- Risk of falling (ie. activities that require high levels of balance, coordination and agility)
- Heavy lifting

Women who are healthy and already active do not need to seek medical clearance for physical activity / exercise during pregnancy, but those who are considering high volumes of exercise training (high intensity, prolonged duration, heavy weights, etc) should seek advice and guidance from a health professional who is knowledgable about the effects of high level training on maternal and fetal outcomes.

## INTENSITY: *HOW HARD SHOULD I EXERCISE?*

**Rating of Perceived Exertion for Physical Activities**

- Current PA guidelines recommend both moderate and vigorous intensity activities
- Use this RPE scale to judge the intensity of activities
- On this scale, where 1 is sedentary (not moving), and 10 is maximal effort, activities in the range 3-7 are considered safe and are recommended for health benefits in pregnant women
- Intensity may also be judged using the 'talk test'; in moderate intensity activities women should be able to carry on a conversation, while in vigorous activities they would find this difficult

| | |
|---|---|
| 1 | Sedentary |
| 2 | Light |
| 3 | Moderate |
| 4 | |
| 5 | |
| 6 | Vigorous |
| 7 | |
| 8 | High Intensity |
| 9 | |
| 10 | |

## REASONS TO STOP EXERCISE AND CONSULT YOUR HEALTH CARE PROVIDER

- Chest pain
- Persistant excessive shortness of breath - that does not resolve with rest
- Severe headache
- Persistant dizziness/feeling faint - that does not resolve with rest
- Regular painful uterine contractions
- Vaginal bleeding
- Persistant loss of fluid from the vagina - indicating possible ruptured membrane

## ADDITIONAL SAFETY PRECAUTIONS - WHAT TO AVOID?

- Avoid dehydration and inadequate nutrition. Stay well hydrated and try to ensure energy intake is in line with recommended gestational weight gain
- Avoid heat stress/hyperthermia in the first trimester. Adjust physical activity / exercise in excessively hot weather, especially when there is high humidity
- Avoid long periods of motionless posture (standing still, or lying in a supine position), especially if this causes light headedness or dizziness
- Avoid physical activity/exercise at high altitude (above 2000m) unless acclimatised and trained to do this prior to pregnancy
- Always wear appropriate shoes for the activity, non-restrictive clothing and a supportive bra

Developed by Hayman M, Brown WJ, Haakstad LAH, Mielke GI, Mena GP, Lamerton T, Green A, Keating SE, Gomes GAO, Coombes JS (2021)

SCREENING TOOL
PHYSICAL ACTIVITY/EXERCISE DURING PREGNANCY
VERSION 1 (MARCH 2021)

Exercise is Medicine Australia · Fitness Australia · Sports Medicine Australia · ESSA Exercise & Sports Science Australia

# 10.4 Appendix 4 - PARmed X for PREGNANCY

Physical Activity Readiness
Medical Examination for
Pregnancy (2002)

## PARmed-X for PREGNANCY PHYSICAL ACTIVITY READINESS MEDICAL EXAMINATION

**PARmed-X for PREGNANCY is a guideline for health screening prior to participation in a prenatal fitness class or other exercise.**

Healthy women with uncomplicated pregnancies can integrate physical activity into their daily living and can participate without significant risks either to themselves or to their unborn child. Postulated benefits of such programs include improved aerobic and muscular fitness, promotion of appropriate weight gain, and facilitation of labour. Regular exercise may also help to prevent gestational glucose intolerance and pregnancy-induced hypertension.

The safety of prenatal exercise programs depends on an adequate level of maternal-fetal physiological reserve. PARmed-X for PREGNANCY is a convenient checklist and prescription for use by health care providers to evaluate pregnant patients who want to enter a prenatal fitness program and for ongoing medical surveillance of exercising pregnant patients.

Instructions for use of the 4-page PARmed-X for PREGNANCY are the following:

1. The patient should fill out the section on PATIENT INFORMATION and the PRE-EXERCISE HEALTH CHECKLIST (PART 1, 2, 3, and 4 on p. 1) and give the form to the health care provider monitoring her pregnancy.
2. The health care provider should check the information provided by the patient for accuracy and fill out SECTION C on CONTRAINDICATIONS (p. 2) based on current medical information.
3. If no exercise contraindications exist, the HEALTH EVALUATION FORM (p. 3) should be completed, signed by the health care provider, and given by the patient to her prenatal fitness professional.

In addition to prudent medical care, participation in appropriate types, intensities and amounts of exercise is recommended to increase the likelihood of a beneficial pregnancy outcome. PARmed-X for PREGNANCY provides recommendations for individualized exercise prescription (p. 3) and program safety (p. 4).

*NOTE: Sections A and B should be completed by the patient before the appointment with the health care provider.*

### A PATIENT INFORMATION

NAME _____

ADDRESS _____

TELEPHONE _____ BIRTHDATE _____ HEALTH INSURANCE No. _____

NAME OF PRENATAL FITNESS PROFESSIONAL _____ PRENATAL FITNESS PROFESSIONAL'S PHONE NUMBER _____

### B PRE-EXERCISE HEALTH CHECKLIST

#### PART 1: GENERAL HEALTH STATUS

In the past, have you experienced (check YES or NO):

| | YES | NO |
|---|---|---|
| 1. Miscarriage in an earlier pregnacy? | ❑ | ❑ |
| 2. Other pregnancy complications? | ❑ | ❑ |
| 3. I have completed a PAR-Q within the last 30 days. | ❑ | ❑ |

If you answered YES to question 1 or 2, please explain:

_____

Number of previous pregnancies? _____

#### PART 2: STATUS OF CURRENT PREGNANCY

Due Date: _____

During this pregnancy, have you experienced:

| | YES | NO |
|---|---|---|
| 1. Marked fatigue? | ❑ | ❑ |
| 2. Bleeding from the vagina ("spotting")? | ❑ | ❑ |
| 3. Unexplained faintness or dizziness? | ❑ | ❑ |
| 4. Unexplained abdominal pain? | ❑ | ❑ |
| 5. Sudden swelling of ankles, hands or face? | ❑ | ❑ |
| 6. Persistent headaches or problems with headaches? | ❑ | ❑ |
| 7. Swelling, pain or redness in the calf of one leg? | ❑ | ❑ |
| 8. Absence of fetal movement after 6th month? | ❑ | ❑ |
| 9. Failure to gain weight after 5th month? | ❑ | ❑ |

If you answered YES to any of the above questions, please explain:

_____

#### PART 3: ACTIVITY HABITS DURING THE PAST MONTH

1. List only regular fitness/recreational activities:

_____

_____

| INTENSITY | FREQUENCY (times/week) 1-2 | 2-4 | 4+ | TIME (minutes/day) <20 | 20-40 | 40+ |
|---|---|---|---|---|---|---|
| Heavy | ___ | ___ | ___ | ___ | ___ | ___ |
| Medium | ___ | ___ | ___ | ___ | ___ | ___ |
| Light | ___ | ___ | ___ | ___ | ___ | ___ |

2. Does your regular occupation (job/home) activity involve:

| | YES | NO |
|---|---|---|
| Heavy Lifting? | ❑ | ❑ |
| Frequent walking/stair climbing? | ❑ | ❑ |
| Occasional walking (>once/hr)? | ❑ | ❑ |
| Prolonged standing? | ❑ | ❑ |
| Mainly sitting? | ❑ | ❑ |
| Normal daily activity? | ❑ | ❑ |
| 3. Do you currently smoke tobacco?* | ❑ | ❑ |
| 4. Do you consume alcohol?* | ❑ | ❑ |

#### PART 4: PHYSICAL ACTIVITY INTENTIONS

What physical activity do you intend to do?

_____

Is this a change from what you currently do? ❑ YES ❑ NO

***NOTE: PREGNANT WOMEN ARE STRONGLY ADVISED NOT TO SMOKE OR CONSUME ALCOHOL DURING PREGNANCY AND DURING LACTATION.**



Supported by: Health Canada Santé Canada

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# PARmed-X for PREGNANCY PHYSICAL ACTIVITY READINESS MEDICAL EXAMINATION

## C CONTRAINDICATIONS TO EXERCISE: to be completed by your health care provider

### Absolute Contraindications

*Does the patient have:*

| | YES | NO |
|---|---|---|
| 1. Ruptured membranes, premature labour? | ❑ | ❑ |
| 2. Persistent second or third trimester bleeding/placenta previa? | ❑ | ❑ |
| 3. Pregnancy-induced hypertension or pre-eclampsia? | ❑ | ❑ |
| 4. Incompetent cervix? | ❑ | ❑ |
| 5. Evidence of intrauterine growth restriction? | ❑ | ❑ |
| 6. High-order pregnancy (e.g., triplets)? | ❑ | ❑ |
| 7. Uncontrolled Type I diabetes, hypertension or thyroid disease, other serious cardiovascular, respiratory or systemic disorder? | ❑ | ❑ |

### Relative Contraindications

*Does the patient have:*

| | YES | NO |
|---|---|---|
| 1. History of spontaneous abortion or premature labour in previous pregnancies? | ❑ | ❑ |
| 2. Mild/moderate cardiovascular or respiratory disease (e.g., chronic hypertension, asthma)? | ❑ | ❑ |
| 3. Anemia or iron deficiency? (Hb < 100 g/L)? | ❑ | ❑ |
| 4. Malnutrition or eating disorder (anorexia, bulimia)? | ❑ | ❑ |
| 5. Twin pregnancy after 28th week? | ❑ | ❑ |
| 6. Other significant medical condition? | ❑ | ❑ |

Please specify: _____

**NOTE:** Risk may exceed benefits of regular physical activity. The decision to be physically active or not should be made with qualified medical advice.

PHYSICAL ACTIVITY RECOMMENDATION: ❑ Recommended/Approved ❑ Contraindicated

## Prescription for Aerobic Activity

***RATE OF PROGRESSION:*** The best time to progress is during the second trimester since risks and discomforts of pregnancy are lowest at that time. Aerobic exercise should be increased gradually during the second trimester from a minimum of 15 minutes per session, 3 times per week (at the appropriate target heart rate or RPE to a maximum of approximately 30 minutes per session, 4 times per week (at the appropriate target heart rate or RPE).

***WARM-UP/COOL-DOWN:*** Aerobic activity should be preceded by a brief (10-15 min.) warm-up and followed by a short (10-15 min.) cool-down. Low intensity calesthenics, stretching and relaxation exercises should be included in the warm-up/cool-down.

| F | I | T | T |
|---|---|---|---|
| **FREQUENCY** | **INTENSITY** | **TIME** | **TYPE** |
| Begin at 3 times per week and progress to four times per week | Exercise within an appropriate RPE range and/or target heart rate zone | Attempt 15 minutes, even if it means reducing the intensity. Rest intervals may be helpful | Non weight-bearing or low-impact endurance exercise using large muscle groups (e.g., walking, stationary cycling, swimming, aquatic exercises, low impact aerobics) |

***"TALK TEST"*** - A final check to avoid overexertion is to use the "talk test". The exercise intensity is excessive if you cannot carry on a verbal conversation while exercising.

***PRESCRIPTION/MONITORING OF INTENSITY:*** The best way to prescribe and monitor exercise is by combining the heart rate and rating of perceived exertion (RPE) methods.

### TARGET HEART RATE ZONES

The heart rate zones shown below are appropriate for most pregnant women. Work during the lower end of the HR range at the start of a new exercise program and in late pregnancy.

| Age | Heart Rate Range |
|---|---|
| < 20 | 140-155 |
| 20-29 | 135-150 |
| 30-39 | 130-145 |

### RATING OF PERCEIVED EXERTION (RPE)

Check the accuracy of your heart rate target zone by comparing it to the scale below. A range of about 12-14 (somewhat hard) is appropriate for most pregnant women.

| | |
|---|---|
| 6 | |
| 7 | Very, very light |
| 8 | |
| 9 | Somewhat light |
| 10 | |
| 11 | Fairly light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Very, very hard |
| 20 | |

The original PARmed-X for PREGNANCY was developed by L.A. Wolfe, Ph.D., Queen's University. The muscular conditioning component was developed by M.F. Mottola, Ph.D., University of Western Ontario. The document has been revised based on advice from an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill, with additonal input from Drs. Wolfe and Mottola, and Gregory A.L. Davies, M.D.,FRCS(C) Department of Obstetrics and Gynaecology, Queen's University, 2002.



Disponible en français sous le titre «Examination medicale sur l'aptitude à l'activité physique pour les femmes enceintes (X-AAP pour les femmes enceintes)»

Additional copies of the PARmed-X for PREGNANCY, the PARmed-X and/or the PAR-Q can be downloaded from: http://www.csep.ca/forms.asp.
For more information contact the:

Canadian Society for Exercise Physiology
185 Somerset St. West, Suite 202, Ottawa, Ontario CANADA K2P 0J2
tel.: 1-877-651-3755 FAX (613) 234-3565 www.csep.ca

# PARmed-X for PREGNANCY

**PHYSICAL ACTIVITY READINESS MEDICAL EXAMINATION**

## Prescription for Muscular Conditioning

**It is important to condition all major muscle groups during both prenatal and postnatal periods.**

WARM-UPS & COOL DOWN:
*Range of Motion:* neck, shoulder girdle, back, arms, hips, knees, ankles, etc.

*Static Stretching:* all major muscle groups

**(DO NOT OVER STRETCH!)**

### EXAMPLES OF MUSCULAR STRENGTHENING EXERCISES

| CATEGORY | PURPOSE | EXAMPLE |
|---|---|---|
| Upper back | Promotion of good posture | Shoulder shrugs, shoulder blade pinch |
| Lower back | Promotion of good posture | Modified standing opposite leg & arm lifts |
| Abdomen | Promotion of good posture, prevent low-back pain, prevent diastasis recti, strengthen muscles of labour | Abdominal tightening, abdominal curl-ups, head raises lying on side or standing position |
| Pelvic floor ("Kegels") | Promotion of good bladder control, prevention of urinary incontinence | "Wave", "elevator" |
| Upper body | Improve muscular support for breasts | Shoulder rotations, modified push-ups against a wall |
| Buttocks, lower limbs | Facilitation of weight-bearing, prevention of varicose veins | Buttocks squeeze,standing leg lifts, heel raises |

### PRECAUTIONS FOR MUSCULAR CONDITIONING DURING PREGNANCY

| VARIABLE | EFFECTS OF PREGNANCY | EXERCISE MODIFICATIONS |
|---|---|---|
| Body Position | • in the supine position (lying on the back), the enlarged uterus may either decrease the flow of blood returning from the lower half of the body as it presses on a major vein (inferior vena cava) or it may decrease flow to a major artery (abdominal aorta) | • past 4 months of gestation, exercises normally done in the supine position should be altered<br>• such exercises should be done side lying or standing |
| Joint Laxity | • ligaments become relaxed due to increasing hormone levels<br>• joints may be prone to injury | • avoid rapid changes in direction and bouncing during exercises<br>• stretching should be performed with controlled movements |
| Abdominal Muscles | • presence of a rippling (bulging) of connective tissue along the midline of the pregnant abdomen (diastasis recti) may be seen during abdominal exercise | • abdominal exercises are not recommended if diastasis recti develops |
| Posture | • increasing weight of enlarged breasts and uterus may cause a forward shift in the centre of gravity and may increase the arch in the lower back<br>• this may also cause shoulders to slump forward | • emphasis on correct posture and neutral pelvic alignment. Neutral pelvic alignment is found by bending the knees, feet shoulder width apart, and aligning the pelvis between accentuated lordosis and the posterior pelvic tilt position. |
| Precautions for Resistance Exercise | • emphasis must be placed on continuous breathing throughout exercise<br>• exhale on exertion, inhale on relaxation using high repetitions and low weights<br>• Valsalva Manoevre (holding breath while working against a resistance) causes a change in blood pressure and therefore should be avoided<br>• avoid exercise in supine position past 4 months gestation | |

## PARmed-X for Pregnancy - Health Evaluation Form

**(to be completed by patient and given to the prenatal fitness professional after obtaining medical clearance to exercise)**

I, _____ PLEASE PRINT (patient's name), have discussed my plans to participate in physical activity during my current pregnancy with my health care provider and I have obtained his/her approval to begin participation.

Signed: _____ Date: _____
(patient's signature)

Name of health care provider: _____

Address: _____

_____

Telephone: _____

*HEALTH CARE PROVIDER'S COMMENTS:*

_____

_____

_____

_____
(health care provider's signature)

3

## 10.5 Appendix 5 - Advertising materials


Want to know more about how your body and baby respond to exercise during pregnancy?
ACU
A team of ACU researchers are currently investigating the effect that exercise during pregnancy has on your blood vessels, blood pressure and your baby's heart rate.
What's involved?
You would perform three free exercise sessions at the ACU Health Clinic in Banyo each week throughout pregnancy.
Your heart rate, blood pressure, arterial stiffness and baby's heart rate will be monitored before, during and after the session to see how these things respond to exercise.
If you would like more information, please email courtney.giles@myacu.edu.au or scan the QR code!
Scan me

## 10.6 Appendix 6 - Informed consent form Study 4

CONSENT FORM

TITLE OF PROJECT: Feasibility, safety and efficacy of completing vigorous intensity interval training during pregnancy

PRINCIPAL INVESTIGATOR/SUPERVISOR: Dr Rich Johnston

STUDENT RESEARCHER: Miss Courtney Giles

I ..... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this exercise trial in which results will be digitally recorded, realising that I can withdraw my consent at any time without adverse consequences. I understand that my data will be stored electronically on a password secured hard drive for up to 5 years. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT:

SIGNATURE ..... DATE .....

SIGNATURE OF PRINCIPAL INVESTIGATOR (or SUPERVISOR): .....
DATE: ……

SIGNATURE OF STUDENT RESEARCHER: .....

## 10.7 Appendix 7 - Participant information letter Study 4

AUSTRALIAN CATHOLIC UNIVERSITY

# PARTICIPANT INFORMATION LETTER

**PROJECT TITLE:** **Feasibility, safety and efficacy of completing vigorous intensity interval training during pregnancy**

**PRINCIPAL INVESTIGATOR:** **Dr Rich Johnston**
**STUDENT RESEARCHER:** **Miss Courtney Giles**
**STUDENT'S DEGREE:** **PhD**

Dear Participant,

You are invited to participate in the research project described below.

***What is the project about?***
In this study we will be looking at the effects of exercise during each trimester of pregnancy on blood pressure and blood vessels, as well as foetal heart rate. More specifically we want to see if exercising at a higher intensity may be more beneficial to vascular function during pregnancy. During pregnancy adaptations occur to the circulatory system to support the growing foetus. Sometimes these changes can result in negative health outcomes for the mother and the baby, e.g. gestational hypertension and pre-eclampsia. Exercise during pregnancy has been shown to have a range of benefits, including reducing blood pressure and the risk of pre-eclampsia. Higher intensity exercise has been shown to have more benefits on blood pressure in non-pregnant populations, however research on the effects during pregnancy is currently lacking.

***Who is undertaking the project?***
This project is being conducted by Miss Courtney Giles and will form the basis for the degree of Miss Giles at Australian Catholic University under the supervision of Dr Rich Johnston, Associate Professor Michael Baker, Dr Kassia Beetham and Dr Jemima Spathis. Miss Giles is an Accredited Exercise Physiologist, currently completing a Doctor of Philosophy at ACU with a particular interest in women's health and pregnancy. Dr Rich Johnston is an experienced researcher whose expertise is in applied sport science. Associate Professor Baker's clinical and teaching career has focused on the integration of exercise, medicine and behavioural change to improve quality of life, particularly among those with chronic illness. Dr Beetham and Dr Spathis are both Accredited Exercise Physiologists, with research experience in pregnancy as well as chronic disease and sport.

***Are there any risks associated with participating in this project?***
As with any form of exercise, there exists the remote possibility during exercise of adverse events including, but not limited to, musculoskeletal injury, and abnormal cardiovascular responses. Research has shown that exercising at the intensity required in this study during healthy pregnancy

does not show any negative outcomes for the foetus. The accredited exercise physiologists running the exercise sessions are CPR and first aid trained. Every effort will be made by the researchers and exercise physiologists to mitigate these risks through pre-exercise screening, a familiarisation session with the equipment and appropriate monitoring of physiological measures during the exercise sessions (heart rate, blood pressure, rating of perceived exertion [RPE]).

***What will I be asked to do?***

- This study will involve filling out written questionnaires. The questionnaires will ask general questions about you (age, education, post code, marital status etc.), your pregnancy and your physical activity levels.
- You will also be asked to wear an Oura ring for 7 days during the study which will continuously monitor your heart rate. The Oura ring is a small ring shaped device that will be fitted to your index finger. You will be required to take the ring off for showering but asked to wear it at all other times when possible for the 7 days. The researchers will review the data from the Oura Ring following the 7 day period and contact your doctor/obstetrician if there are any abnormalities found.
- Participation in the study will involve three-four monitored exercise sessions over three-four weeks in each trimester at the ACU Health Clinic during your pregnancy
    - Prior to exercising resting measures will be taken including heart rate, foetal heart rate, blood pressure, and arterial stiffness. These will be measured throughout the exercise session using a heart rate monitor, a foetal doppler, a blood pressure cuff and a device to measure arterial stiffness (which works similar to a blood pressure cuff that will go around your leg).
    - You will be asked to remain in a seated position for 10 minutes following the bout of exercise so that we can look at the response to heart rate, blood pressure and arterial stiffness following exercise.

***How much time will the project take?***

The questionnaires will take approximately 10-15 minutes to complete each. You will be required to visit the ACU Health Clinic for three-four monitored exercise sessions in each trimester which run for approximately 30 minutes. You will be asked to arrive 10 minutes before and stay for 10 minutes following the session to allow time for resting and post exercise measures to be taken.

***What are the benefits of the research project?***

Regular exercise performed throughout pregnancy has been shown to have a range of benefits including but not limited to decreased risk of gestational diabetes, high blood pressure, caesarean section, excessive weight gain throughout pregnancy, urinary incontinence and depression. Participation in this study may not provide any immediate benefits, however acute bouts of exercise have been shown to produce a post exercise hypotensive response - this means a reduction in blood pressure following exercise. The results of this study may help to inform exercise guidelines for women during pregnancy to ensure they get the most benefits from exercising as possible.

***Can I withdraw from the study?***

Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences

***Will anyone else know the results of the project?***
The results of the study will be published in a high-quality scientific journal, with only aggregated non-identifiable data published.

***Will I be able to find out the results of the project?***
If you wish to view the results of the study a summary of the results can be emailed to the participants following completion of the study and compared to aggregate data. A copy of the published journal article will also be made available to participants who wish to read it.

***What will happen to any data collected about me?***
All electronic data will be stored on a password protected hard drive. Any paper files collected will be stored within a locked filing cabinet, within a locked office in building 211 on the ACU Banyo Campus. All data will be stored for a period of up to 5 years at which point it will be destroyed.

***How do I know if I am eligible for the study?***
We are recruiting 18- to 40-year old women who are currently pregnant and have either no diagnosed conditions, or have been diagnosed with gestational hypertension, gestational diabetes, chronic hypertension, BMI >25 kg/m$^2$, or who have been diagnosed with gestational hypertension or pre-eclampsia in previous pregnancies. You will be required to undertake a screening session with an exercise physiologist at ACU which will ensure that it is safe for you to partake in these sessions. All levels of fitness and current physical activity levels are eligible for participation.

***Who do I contact if I have questions about the project?***
Please contact Courtney Giles or Dr Rich Johnston via phone or email if you have any questions about the project.
E: Courtney.giles@myacu.edu.au
E: Richard.johnston@acu.edu.au
P: (07) 3623 7726

***What if I have a complaint or any concerns?***
The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (review number 2020-103H). If you have any complaints or concerns about the conduct of the project, you may write to the Manager of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph.: 02 9739 2519
Fax: 02 9739 2870
Email: resethics.manager@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

***I want to participate! How do I sign up?***

Please contact Courtney Giles or Dr Rich Johnston and an informed consent form will be emailed to you, please sign both copies of the form and return via email.

Yours sincerely,
Courtney Giles


## 10.8 Appendix 8 - Informed consent form Study 5

CONSENT FORM

TITLE OF PROJECT: The effects of three different training modalities and intensities on arterial stiffness and blood pressure completed weekly throughout pregnancy: A longitudinal randomised cross-over trial

PRINCIPAL INVESTIGATOR/SUPERVISOR: Dr Rich Johnston

STUDENT RESEARCHER: Miss Courtney Giles

I ..... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this exercise trial in which results will be digitally recorded, realising that I can withdraw my consent at any time without adverse consequences. I understand that my data will be stored electronically on a password secured hard drive for up to 5 years. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT:

SIGNATURE ..... DATE .....

SIGNATURE OF PRINCIPAL INVESTIGATOR (or SUPERVISOR): .....
DATE: ……

SIGNATURE OF STUDENT RESEARCHER: .....

## 10.9 Appendix 9 - Participant information letter Study 5


# PARTICIPANT INFORMATION LETTER

**PROJECT TITLE:** **The effects of three different training modalities and intensities on arterial stiffness and blood pressure completed weekly throughout pregnancy: A longitudinal randomised cross-over trial**

**PRINCIPAL INVESTIGATOR:** **Dr Rich Johnston**
**STUDENT RESEARCHER:** **Miss Courtney Giles**
**STUDENT'S DEGREE:** **PhD**

Dear Participant,

You are invited to participate in the research project described below.

***What is the project about?***
In this study we will be looking at the effects of vigorous intensity exercise during each trimester of pregnancy on blood pressure and blood vessels, as well as foetal heart rate. More specifically we want to see if exercising at a higher intensity may be more beneficial to vascular function during pregnancy. During pregnancy adaptations occur to the circulatory system to support the growing foetus. Sometimes these changes can result in negative health outcomes for the mother and the baby, e.g. gestational hypertension and pre-eclampsia. Exercise during pregnancy has been shown to have a range of benefits, including reducing blood pressure and the risk of pre-eclampsia. Higher intensity exercise has been shown to have more benefits on blood pressure in non-pregnant populations, however research on the effects during pregnancy is currently lacking.

***Who is undertaking the project?***
This project is being conducted by Miss Courtney Giles and will form the basis for the degree of Miss Giles at Australian Catholic University under the supervision of Dr Rich Johnston, Associate Professor Michael Baker, Dr Kassia Beetham and Dr Jemima Spathis. Miss Giles is an Accredited Exercise Physiologist, currently completing a Doctor of Philosophy at ACU with a particular interest in women's health and pregnancy. Dr Rich Johnston is an experienced researcher whose expertise is in applied sport science. Associate Professor Baker's clinical and teaching career has focused on the integration of exercise, medicine and behavioural change to improve quality of life, particularly among those with chronic illness. Dr Beetham and Dr Spathis are both Accredited Exercise Physiologists, with research experience in pregnancy as well as chronic disease and sport.

***Are there any risks associated with participating in this project?***

As with any form of exercise, there exists the remote possibility during exercise of adverse events including, but not limited to, musculoskeletal injury, and abnormal cardiovascular responses. Research has shown that exercising at the intensity required in this study during healthy pregnancy does not show any negative outcomes for the foetus. The accredited exercise physiologists running the exercise sessions are CPR and first aid trained. Every effort will be made by the researchers and exercise physiologists to mitigate these risks through pre-exercise screening, a familiarisation session with the equipment and appropriate monitoring of physiological measures during the exercise sessions (heart rate, blood pressure, rating of perceived exertion [RPE]).

***What will I be asked to do?***

- This study will involve filling out written questionnaires. The questionnaires will ask general questions about you (age, education, post code, marital status etc.), your pregnancy and your physical activity levels.
- You will also be asked to wear an Oura ring for 7 days during the study which will continuously monitor your heart rate. The Oura ring is a small ring shaped device that will be fitted to your index finger. You will be required to take the ring off for showering but asked to wear it at all other times when possible for the 7 days. The researchers will review the data from the Oura Ring following the 7 day period and inform you if any abnormalities have been found. You will be encouraged to discuss these with your GP if so.
- Participation in the study will involve 3 monitored exercise sessions each week at the ACU Health Clinic during your pregnancy
    - Prior to exercising resting measures will be taken including heart rate, foetal heart rate, blood pressure, and arterial stiffness. These will be measured throughout the exercise session using a heart rate monitor, a foetal doppler, a blood pressure cuff and a device to measure arterial stiffness (which works similar to a blood pressure cuff that will go around your leg).
    - You will be asked to remain in a seated position for 10 minutes following the bout of exercise so that we can look at the response to heart rate, blood pressure and arterial stiffness following exercise.

***How much time will the project take?***

The questionnaires will take approximately 10-15 minutes to complete each. You will be required to visit the ACU Health Clinic for three monitored exercise sessions each week which run for approximately 30 minutes. You will be asked to arrive 10 minutes before and stay for 10 minutes following the class to allow time for resting and post exercise measures to be taken.

***What are the benefits of the research project?***

Regular exercise performed throughout pregnancy has been shown to have a range of benefits including but not limited to decreased risk of gestational diabetes, high blood pressure, caesarean section, excessive weight gain throughout pregnancy, urinary incontinence and depression. Participation in this study may not provide any immediate benefits, however acute bouts of exercise have been shown to produce a post exercise hypotensive response - this means a reduction in blood pressure following exercise. The results of this study may help to inform exercise guidelines for women during pregnancy to ensure they get the most benefits from exercising as possible.

***Can I withdraw from the study?***
Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences

***Will anyone else know the results of the project?***
The results of the study will be published in a high-quality scientific journal, with only aggregated non-identifiable data published.

***Will I be able to find out the results of the project?***
If you wish to view the results of the study a summary of the results can be emailed to the participants following completion of the study and compared to aggregate data. A copy of the published journal article will also be made available to participants who wish to read it.

***What will happen to any data collected about me?***
All electronic data will be stored on a password protected hard drive. Any paper files collected will be stored within a locked filing cabinet, within a locked office in building 211 on the ACU Banyo Campus. All data will be stored for a period of up to 5 years at which point it will be destroyed.

***How do I know if I am eligible for the study?***
We are recruiting 18 to 40 year-old women who are currently pregnant, with no diagnosed pre-existing or pregnancy related health conditions. You will be required to undertake a screening session with an exercise physiologist at ACU which will ensure that it is safe for you to partake in these sessions. All levels of fitness and current physical activity levels are eligible for participation.

***Who do I contact if I have questions about the project?***
Please contact Courtney Giles or Dr Rich Johnston via phone or email if you have any questions about the project.
E: Courtney.giles@myacu.edu.au
E: Richard.johnston@acu.edu.au
P: (07) 3623 7726

***What if I have a complaint or any concerns?***
The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (review number 2020-103H). If you have any complaints or concerns about the conduct of the project, you may write to the Manager of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph.: 02 9739 2519
Fax: 02 9739 2870
Email: resethics.manager@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

***I want to participate! How do I sign up?***

Please contact Courtney Giles or Dr Rich Johnston and an informed consent form will be emailed to you, please sign both copies of the form and return via email.

Yours sincerely,
Courtney Giles


## 10.10 Appendix 10 - Borg RPE scale

| Rating | Perceived Exertion |
|---|---|
| 6 | No exertion |
| 7 | Extremely light |
| 8 | |
| 9 | Very light |
| 10 | |
| 11 | Light |
| 12 | |
| 13 | Somewhat hard |
| 14 | |
| 15 | Hard |
| 16 | |
| 17 | Very hard |
| 18 | |
| 19 | Extremely hard |
| 20 | Maximal exertion |

## 10.11 Appendix 11 - Pre-enrolment questionnaire


This questionnaire will take approximately 5 minutes to complete and covers topics including your health, intentions for birth and physical activity interests.

→


Name

DOB

What is your due date?

How many weeks pregnant are you?

How tall are you (in cm)?

What was your pre-pregnancy weight (in Kg, if known)?

What is your ethnicity?

Were you born in Australia?

- ◯ Yes
- ◯ No

Is this your first pregnancy?

- ◯ Yes
- ◯ No
- ◯ Prefer not to say

How many times have you been pregnant?

Do you have any children? (including non-biological children)

- ◯ No
- ◯ Yes (how many?)

What is your postcode?

What is the highest level of education that you have completed?

- ◯ Year 11 or below
- ◯ Year 12
- ◯ Certificate III/IV
- ◯ Advanced Diploma/Diploma
- ◯ Bachelor Degree
- ◯ Graduate Diploma and Graduate Certificate
- ◯ Masters
- ◯ PhD
- ◯ Other (Please specify)

What is your marital status?

- ◯ Single
- ◯ Married/Domestic Partnership
- ◯ Divorced
- ◯ Widowed
- ◯ Seperated
- ◯ Prefer not to say

What is your employment status?

- ○ Full time employment
- ○ Part time employment
- ○ Unemployed
- ○ Looking for work
- ○ Student
- ○ Other (Please specify)

Which type of care are you receiving during your pregnancy?

- ○ Routine Care
- ○ Obstetric Care
- ○ Midwifery Group Practice
- ○ GP Shared Care
- ○ Private Midwifery Care
- ○ Maternity Navigator
- ○ Other (Please Specify)

Which type of delivery are you planning to have?

- ○ Vaginal
- ○ Cesarean Section
- ○ Have not yet planned/Prefer not to say

Where are you planning to deliver?

→

In an average day how many steps would you do?

- ○ <5000
- ○ 5001-10000
- ○ 10001-15000
- ○ 15001-20000
- ○ >20000

Do you use any of the following physical activity trackers?

- [ ] Smart watch
- [ ] Smart phone
- [ ] Pedometer
- [ ] Other (please specify)
- [ ] None

Do you enjoy exercise/physical activity?

- ○ Yes
- ○ Sometimes
- ○ No

On a scale of 1-10 how important would you say that regular exercise is to you?

| Not at all important | | Slightly important | | Moderately important | | | Very important | | Extremely important |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Click to write Choice 1

On a scale of 1-10 how motivated are you to exercise?

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|

Click to write Choice 1

Were you given any advice by your doctor on how much or how hard you should be exercising during pregnancy?

- ○ No
- ○ Yes (Please describe the advice if you can recall it)

Which type/s of exercise do you most prefer?

- [ ] Walking/running/treadmill
- [ ] Resistance/strength training
- [ ] Reformer Pilates
- [ ] Mat Pilates
- [ ] Swimming
- [ ] Yoga
- [ ] Other (Please Specify)

Have you ever been diagnosed with high blood pressure?

- ○ Yes
- ○ No
- ○ Unsure

Do you have a family history of high blood pressure?

- ○ Yes (please state which relative/s)
- ○ No
- ○ Unsure

During this pregnancy have you been diagnosed with any of the following?

- [ ] High blood pressure
- [ ] Gestational diabetes
- [ ] Pre-eclampsia
- [ ] None of the above

During any previous pregnancies have you been diagnosed with any of the following?

- [ ] High blood pressure
- [ ] Gestational diabetes
- [ ] Pre-eclampsia
- [ ] None of the above
- [ ] This is my first pregnancy

We thank you for your time spent taking this survey.
Your response has been recorded.

## 10.12 Appendix 12 - Post delivery questionnaire


This survey will take you approximately 5 minutes to complete and will provide us with information on your birth experience, foetal outcomes and your opinion on the exercise you completed as part of this study. If you don't feel comfortable answering any of the questions or are unsure of the answer feel free to leave the question blank.

If you are unsure of any answers you may be able to find them in your baby's Personal Health Record (little red book).

→

Name

Type of Delivery

Where did you deliver?

Duration of labour (in hours)

Gestational age at delivery (in weeks)

Did you experience any of the following?

- [ ] Labour that did not progress
- [ ] Perineal tears
- [ ] Shoulder dystocia
- [ ] Problems with the umbilical cord
- [ ] Foetal distress
- [ ] Perinatal asphyxia (lack of oxygen to the foetus)
- [ ] Excessive bleeding
- [ ] Breech birth
- [ ] Placenta previa
- [ ] Preterm labour
- [ ] Miscarriage
- [ ] Still birth
- [ ] None of the above
- [ ] Other complications (please specify)

- [ ] Prefer not to say

Were any of the following medical interventions implemented during your labour/delivery?

- [ ] Forceps
- [ ] Vacuum
- [ ] Episiotomy
- [ ] Induction
- [ ] Epidural
- [ ] None of the above
- [ ] Other (please specify)

- [ ] Prefer not to say

Time spent in hospital following delivery

Were you diagnosed with any of the following during pregnancy?

- [ ] Gestational Hypertension (high blood pressure)
- [ ] Pre eclampsia
- [ ] Gestational Diabetes
- [ ] None of the above
- [ ] Other (Please Specify)

Baby's DOB

Baby's sex

- ◯ Female
- ◯ Male
- ◯ Prefer not to say

Birth weight (in Kg)

Birth length (in cm)

Head circumference (in cm)

Apgar Score 1 minute (if known)

Apgar Score 5 minutes (if known)

Of the three types of exercise performed in this study (treadmill/bike, resistance training, reformer), please rank in order from your most preferred to least preferred.

Treadmill/Bike

Resistance

Reformer Pilates

Please rate how enjoyable you found each type of exercise? (0 = least enjoyable, 10 = most enjoyable)

0 1 2 3 4 5 6 7 8 9 10

Treadmill/Bike

Resistance Training

Reformer Pilates

Please rate how motivated you felt to perform each type of exercise (0 least motivation, 10 = highest motivation)

0 1 2 3 4 5 6 7 8 9 10

Treadmill/Bike

Resistance Training

Reformer Pilates

We thank you for your time spent taking this survey.
Your response has been recorded.

## 10.13 Appendix 13 - Systematic review search strategy

| DATABASE | POPULATION | | INTERVENTION | | OUTCOME |
|---|---|---|---|---|---|
| CINAHL | Key Words:<br>pregnan* OR gestation* OR "expect* mother" OR "expect* woman*" OR "expect* women*" OR prenatal OR "prenatal care" OR antenatal OR perinatal OR peri-natal OR pre-natal OR peripartum OR peri-partum<br>Headings:<br>(MH "Pregnancy Trimesters") OR (MH "Pregnancy") OR (MH "Pregnancy Trimester, Third") OR (MH "Pregnancy Trimester, Second") OR (MH "Pregnancy Trimester, First") OR (MH "Expectant Mothers") OR (MH "Prenatal Care") OR (MH "Perinatal Care") | AND | Key Words:<br>exercise* OR exercising OR "physical activity" OR "physical activit*" OR "physical exert*" OR "physical fitness" OR "fitness train*" OR running OR sport* OR "physical train*" OR "exercis* therap*" OR "aerobic exercise*" OR conditioning OR "physical conditioning" OR "resistance train*" OR "strength train*" OR "resistance exercis*" OR "weight train*" OR "weight lift*" OR "power train" OR "powerlift*"<br>Headings:<br>(MH "Exercise") OR (MH "Therapeutic Exercise") OR (MH "Exercise Intensity") OR (MH "Plyometrics") OR (MH "Aerobic Exercises") OR (MH "Leisure Activities") OR (MH "Physical Activity") OR (MH "Physical Fitness") OR (MH "Sports") OR (MH "Resistance Training") OR (MH "Weight lifting") OR (MH "Muscle Strengthening") | AND | Key Words:<br>MAP OR "mean arterial pressure" OR "blood pressure" OR BP OR "vascular *function" OR hypertensi* OR hypotensi* OR "high blood pressure" OR haemodynamic* OR hemodynamic* OR "cardiovascular function" OR vascular OR "central blood pressure" OR "aortic blood pressure"<br>Headings:<br>(MH "Blood Pressure") OR (MH "Hypertension") OR (MH "Hypotension") OR (MH "Arterial Pressure") OR (MH "Systolic Pressure") OR (MH "Hemodynamics") |

| | | | | | |
|---|---|---|---|---|---|
| MEDLINE | Key Words:<br>pregnan* OR gestation* OR "expect* mother" OR "expect* woman*" OR "expect* women*" OR prenatal OR "prenatal care" OR antenatal OR perinatal OR peri-natal OR pre-natal OR peripartum OR peri-partum<br>MeSH:<br>(MH "Pregnant Women") OR (MH "Pregnancy") OR (MH "Pregnancy Trimesters") OR (MH "Pregnancy Trimester, First") OR (MH "Pregnancy Trimester, Second") OR (MH "Pregnancy Trimester, Third") OR (MH "Prenatal Care") OR (MH "Perinatal Care") OR (MH "Peripartum Period") | | Key Words:<br>exercise* OR exercising OR "physical activity" OR "physical activities" OR "physical exert*" OR "physical fitness" OR "fitness train*" OR running OR sport* OR "physical train*" OR "exercis* therap*" OR "aerobic exercise*" OR conditioning OR "physical conditioning" OR "resistance train*" OR "strength train*" OR "resistance exercis*" OR "weight train*" OR "weight lift*" OR "power train" OR "powerlift*"<br>MeSH:<br>(MH "Exercise") OR (MH "Plyometric Exercise") OR (MH "Exercise Therapy") OR (MH "Circuit-Based Exercise") OR (MH "High-Intensity Interval Training") OR (MH "Physical Conditioning, Human") OR (MH "Running") OR (MH "Leisure Activities") OR (MH "Physical Exertion") OR (MH "Physical Fitness") OR (MH "Cardiorespiratory Fitness") OR (MH "Sports") OR (MH "Resistance Training") OR | | Key Words:<br>MAP OR "mean arterial pressure" OR "blood pressure" OR BP OR "vascular *function" OR hypertensi* OR hypotensi* OR "high blood pressure" OR haemodynamic* OR hemodynamic* OR "cardiovascular function" OR vascular OR "central blood pressure" OR "aortic blood pressure"<br>Headings:<br>(MH "Blood Pressure") OR (MH "Arterial Pressure") OR (MH "Hypertension") OR (MH "Hypotension") OR (MH "Hemodynamics") |

| | | | | | |
|---|---|---|---|---|---|
| | | | (MH "Weight Lifting") OR (MH "Muscle Strengthening") | | |
| EMBASE | Key Words:<br>pregnan* OR gestation* OR "expect* mother" OR "expect* woman*" OR "expect* women*" OR prenatal OR "prenatal care" OR antenatal OR perinatal OR peri-natal OR pre-natal OR peripartum OR peri-partum<br>Emtree:<br>'pregnant woman'/exp OR 'pregnancy'/exp OR 'first trimester pregnancy'/exp OR 'second trimester pregnancy'/exp OR 'third trimester pregnancy'/exp OR 'expectant mother'/exp OR 'prenatal care'/exp | | Key Words:<br>exercise* OR exercising OR 'physical activity' OR 'physical activities' OR 'physical exert*' OR 'physical fitness' OR 'fitness train*' OR running OR sport* OR 'physical train*' OR 'exercis* therap*' OR 'aerobic exercise*' OR conditioning OR 'physical conditioning' OR 'resistance train*' OR 'strength train*' OR 'resistance exercis*' OR 'weight train*' OR 'weight lift*' OR 'power train' OR 'powerlift*'<br>Emtree:<br>'exercise'/exp OR 'aerobic exercise'/exp OR 'circuit training'/exp OR 'exercise intensity'/exp OR 'high intensity interval training'/exp OR 'plyometrics'/exp OR 'dynamic exercise'/exp OR 'physical activity'/exp OR 'cycling'/exp OR 'running'/exp OR 'fitness'/exp OR 'kinesiotherapy'/exp OR 'movement therapy'/exp OR 'muscle training'/exp OR | | Key Words:<br>MAP OR 'mean arterial pressure' OR 'blood pressure' OR BP OR 'vascular *function' OR hypertensi* OR hypotensi* OR 'high blood pressure' OR haemodynamic* OR hemodynamic* OR 'cardiovascular function' OR vascular OR 'central blood pressure' OR 'aortic blood pressure'<br>Emtree:<br>'blood pressure'/exp OR 'arterial pressure'/exp OR 'hemodynamics'/exp OR 'mean arterial pressure'/exp OR 'cardiovascular function'/exp |

| | | | | | |
|---|---|---|---|---|---|
| | | | 'sport'/exp OR 'resistance training'/exp | | |
| WEB OF SCIENCE | Key Words:<br>pregnan* OR gestation* OR "expect* mother" OR "expect* woman*" OR "expect* women*" OR prenatal OR "prenatal care" OR antenatal OR perinatal OR peri-natal OR pre-natal OR peripartum OR peri-partum | | Key Words:<br>exercise* OR exercising OR "physical activity" OR "physical activities" OR "physical exert*" OR "physical fitness" OR "fitness train*" OR running OR sport* OR "physical train*" OR "exercis* therap*" OR "aerobic exercise*" OR conditioning OR "physical conditioning" OR “resistance train*” OR “strength train*” OR “resistance exercis*” OR “weight train*” OR “weight lift*” OR “power train” OR “powerlift*” | | Key Words:<br>MAP OR "mean arterial pressure" OR "blood pressure" OR BP OR "vascular *function" OR hypertensi* OR hypotensi* OR "high blood pressure" OR haemodynamic* OR hemodynamic* OR "cardiovascular function" OR vascular OR "central blood pressure" OR "aortic blood pressure" |
| PUBMED | Key Words:<br>pregnan* OR gestation* OR "expect* mother" OR "expect* woman*" OR "expect* women*" OR prenatal OR "prenatal care" OR antenatal OR perinatal OR peri-natal OR pre-natal OR peripartum OR peri-partum<br>MeSH:<br>"Pregnant Women"[Mesh] OR "Pregnancy"[Mesh] OR "Pregnancy Trimesters"[Mesh] | | Key Words:<br>exercise* OR exercising OR "physical activity" OR "physical activities" OR "physical exert*" OR "physical fitness" OR "fitness train*" OR running OR sport* OR "physical train*" OR "exercis* therap*" OR "aerobic exercise*" OR conditioning OR "physical conditioning" OR “resistance train*” OR “strength train*” OR “resistance exercis*” OR “weight train*” OR “weight | | Key Words:<br>MAP OR "mean arterial pressure" OR "blood pressure" OR BP OR "vascular *function" OR hypertensi* OR hypotensi* OR "high blood pressure" OR haemodynamic* OR hemodynamic* OR "cardiovascular function" OR vascular OR "central blood pressure" OR "aortic blood pressure"<br>MeSH: |

| | | | | | |
|---|---|---|---|---|---|
| | OR "Pregnancy Trimester, Third"[Mesh] OR "Pregnancy Trimester, Second"[Mesh] OR "Pregnancy Trimester, First"[Mesh] OR "Prenatal Care"[Mesh] OR "Peripartum Period"[Mesh] OR "Perinatal Care"[Mesh] | | lift*" OR "power train" OR "powerlift*"<br>MeSH:<br>"Exercise"[Mesh] OR "Exercise Therapy"[Mesh] OR "High-Intensity Interval Training"[Mesh] OR "Physical Exertion"[Mesh] OR "Physical Fitness"[Mesh] OR "Running"[Mesh] OR "Sports"[Mesh] OR "Physical Conditioning, Human"[Mesh] OR "Plyometric Exercise"[Mesh] OR "Circuit-Based Exercise"[Mesh] OR "Leisure Activities"[Mesh] OR "Resistance Training"[Mesh] OR "Exercise Movement Techniques"[Mesh] | | "Blood Pressure"[Mesh] OR "Arterial Pressure"[Mesh] OR "Hypotension"[Mesh] OR "Hypertension"[Mesh] OR "Hemodynamics"[Mesh] |
| COCHRANE | Key Words:<br>pregnan* OR gestation* OR "expect* mother" OR "expect* woman*" OR "expect* women*" OR prenatal OR "prenatal care" OR antenatal OR perinatal OR peri-natal OR pre-natal OR peripartum OR peri-partum<br>MeSH: | | Key Words:<br>exercise* OR exercising OR "physical activity" OR "physical activities" OR "physical exert*" OR "physical fitness" OR "fitness train*" OR running OR sport* OR "physical train*" OR "exercis* therap*" OR "aerobic exercise*" OR conditioning OR "physical conditioning" OR "resistance train*" OR "strength | | Key Words:<br>MAP OR "mean arterial pressure" OR "blood pressure" OR BP OR "vascular *function" OR hypertensi* OR hypotensi* OR "high blood pressure" OR haemodynamic* OR hemodynamic* OR "cardiovascular function" OR vascular OR "central blood |

| | | | | | |
|---|---|---|---|---|---|
| | (Pregnant Women) OR (Pregnancy) OR (Pregnancy Trimesters) OR (Pregnancy Trimester, First) OR (Pregnancy Trimester, Second) OR (Pregnancy Trimester, Third) OR (Prenatal Care) | | train*" OR "resistance exercis*" OR "weight train*" OR "weight lift*" OR "power train" OR "powerlift*"<br>MeSH:<br>(Exercise) OR (Exercise Therapy) OR (Plyometric Exercise) OR (Circuit-Based Exercise) OR (High-Intensity Interval Training) OR (Physical Conditioning, Human) OR (Running) OR (Leisure Activities) OR (Physical Exertion) OR (Physical Fitness) OR (Cardiorespiratory Fitness) OR (Sports) OR (Resistance Training) OR (Weight Lifting) | | pressure" OR "aortic blood pressure"<br>MeSH:<br>(Blood Pressure) OR (Arterial Pressure) OR (Hypotension) OR (Hypertension) OR (Hemodynamics) |