

The relationship between habitual physical activity patterns of pregnant women and foetal growth parameters: a longitudinal study

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Dissertation submitted in fulfilment of the requirements for the degree
Magister Scientiae in *Biokinetics* at the Potchefstroom Campus of the
North-West University

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September 2014

ACKNOWLEDGEMENTS

“An unexamined life is not worth living.” - Socrates

First and foremost, I would like to thank the North-West University for providing the infrastructure in which I could complete my M.Sc. study. I would also like to convey my gratitude to the following people who supported and assisted me in the completion of this study:

- ❖ Prof. S.J. Moss, my project leader and supervisor, for her expert advice, time, effort, guidance and enthusiasm for the project.
- ❖ Mej. M. Stam for her assistance and guidance in the planning and conceptualisation of the project.
- ❖ Dr. Michiel de Boer for the assistance in the statistical data analyses and the interpretation of the results.
- ❖ Mej. M. Sparks for making countless bookings of the lab and ensuring an ideal testing environment.
- ❖ Carissa Nel for the language editing of this dissertation.
- ❖ Sister Lydia Masego, for the way in which she motivated participants to join and continue with the study.
- ❖ The staff of the clinic, thank you for the interest you've shown in the study.
- ❖ My family for their encouragement and support. Thank you for believing in me.
- ❖ Volunteers of the study, thank you for the commitment you have shown.
- ❖ The South African Sugar Association and NRF for their financial support towards this study.
- ❖ The South African Swiss Joint Programme for their financial support.

With sincere appreciation,

The author

March 2014

“Any opinion, findings and conclusions or recommendations expresses in this material are those of the authors(s) and therefore the NRF does not accept any liability in regard thereto”

SUMMARY

Regular physical activity during pregnancy provides both maternal and infant health benefits. The complexity of measuring physical activity during pregnancy hampers the determination of the optimal dose of habitual physical activity for pregnant women and has led to broad physical activity guidelines for pregnant women. Subjectively-determined physical activity levels by means of questionnaires may have contributed to these broad guidelines. However the ActiHeart®, a dual heart rate monitor and accelerometer, is an accurate and reliable measurement tool to determine physical activity levels during pregnancy. Maternal physical activity tends to decrease during pregnancy and may lead to various health risks, including excessive weight gain, risk for gestational diabetes, lower back pain and adverse foetal outcomes. Determining the influence of physical activity on foetal growth is confounded by various variables, therefore objectively-measured habitual physical activity is essential. This study aims to objectively determine habitual physical activity patterns of pregnant women and the relationship between habitual physical activity and foetal growth parameters.

In a longitudinal, observational, cohort study design, 60 pregnant women were measured at four stages in their pregnancy: the first trimester (9 – 12 weeks), second trimester (20 – 22 weeks), third trimester (28 – 32 weeks) and three months postpartum. Demographic information was collected by means of a questionnaire specifically compiled for this study, followed by anthropometric measurements (height and weight). Assessment of the participants resting blood pressure, heart rate (Microlife® Semi-Automatic blood pressure and heart rate monitor) and metabolic rate (Fitmate™, Cosmed) was obtained. Thereafter, a step-test was performed for individualised calibration of the ActiHeart® device for assessment of habitual physical activity patterns over a 7-day period. Foetal growth parameters that included birth weight (kg), birth length (cm), abdominal circumference (cm) and head circumference (cm), were collected from medical records and from the mother post-partum.

Habitual physical activity, presented as average Activity Energy Expenditure (AEE), physical Activity Level (PAL), activity counts and minutes spent in activity, declined from the first to the third trimester of pregnancy. The AEE during the first trimester averaged 803 ± 34 kCal/day and declined statistically significant to 592 ± 383 kCal/day in the third trimester. Minutes spent per week doing moderate activity declined from 103 ± 83 min/week in the first trimester to 55 ± 66

min/week in the third trimester. Average pregnancy AEE indicated a non-significant negative relationship with all foetal growth measurements - birth weight ($r = - 0.39, p = 0.45$), birth length ($r = - 0.16, p = 0.77$), Ponderal Index ($r = - 0.34, p = 0.51$) - and a non-significant positive relationship with head circumference at birth ($r = 0.14, p = 0.79$).

In conclusion, the objectively-determined, habitual physical activity levels of the participants did not meet the stated guidelines for pregnant women. During the progression of pregnancy, the activity levels declined significantly at the third trimester. The habitual activity levels indicate no effect on the foetal growth parameters.

Keywords:

physical activity, physical activity patterns, habitual physical activity, foetal growth, pregnancy

OPSOMMING

Gereelde fisieke aktiwiteit gedurende swangerskap hou gesondheidsvoordele vir beide die moeder, sowel as die baba in. Die kompleksiteit van fisieke aktiwiteit meting belemmer die bepaling van die optimale daaglikse fisieke aktiwiteit vir swanger vroue en het ook gelei tot die huidige bestaande, breë, algemene fisieke aktiwiteitsriglyne. Fisieke aktiwiteitsvlakke wat deur subjektiewe vraelyste bepaal is, het moontlik bygedra tot die bepaling van hierdie breë riglyne. Die ActiHeart®, 'n dubbelfunksieharttempomonitor en versnellingsmeter, is egter 'n akkurate en betroubare meetinstrument om fisieke aktiwiteitsvlakke gedurende swangerskap te bepaal. Swanger vroue se fisieke aktiwiteitsvlakke neem gewoonlik af gedurende swangerskap en kan lei tot 'n verskeidenheid gesondheidsrisiko's, insluitend uitermatige gewigstoename, risiko vir diabetes tydens swangerskap, lae-rugpyn en ander nadelige uitkomst vir die fetus. Die bepaling van die invloed van fisieke aktiwiteit op die groei van 'n fetus word deur verskeie veranderlikes gekompliseer, en daarom is 'n objektiewe meting van daaglikse fisieke aktiwiteit uiters belangrik. Hierdie studie het ten doel om die normale fisieke aktiwiteitspatrone van swanger vroue, asook die verwantskap tussen normale fisieke aktiwiteitsvlakke en fetale groei parameters, te bepaal.

'n Longitudinale, observasie-, portuurgroepstudie-ontwerp is toegepas, waartydens 60 vroue tydens vier fases van hulle swangerskap gemonitor is: die eerste trimester (9 – 12 weke), tweede trimester (20 – 22 weke), derde trimester (28 – 32 weke), en drie maande na geboorte. Demografiese inligting is deur middel van 'n vraelys wat spesifiek vir hierdie studie saamgestel is, ingesamel, en is met antropometriese metings (lengte en gewig) opgevolg. Deelnemers se rustende bloeddruk, harttempo (Microlife® Semi-outomatiese bloeddruk- en hartklopmonitor) en metabolisme tempo (Fitmate™, Cosmed) is verkry, en 'n opstap-toets is uitgevoer vir geïndividualiseerde kalibrasie van die ActiHeart®-toestel, om sodoende normale fisieke aktiwiteitspatrone gedurende 'n sewe-dae-periode te evalueer. Fetale groei parameters, insluitend gewig by geboorte (kg), lengte by geboorte (cm), maagomtrek (cm) en kopomtrek (cm), is uit mediese rekords van die moeders na afloop van geboorte verkry.

Daaglikse fisieke aktiwiteit, voorgestel as gemiddelde energie uitgawe (*AEE*), fisieke aktiwiteitsvlak (*PAL*), aktiwiteitstellers en minute wat aan fisieke aktiwiteit bestee is, het afgeneem vanaf die eerste- na die derde trimester van swangerskap. Die *AEE* gedurende die

eerste trimester was gemiddeld 803 ± 34 kCal/daaglik, en statisties betekenisvol verlaag tot 592 ± 383 kCal/daaglik gedurende die derde trimester. Minute wat aan matige fisieke aktiwiteit per week bestee is, het afgeneem van 103 ± 83 min/week gedurende die eerste trimester tot 55 ± 66 min/week in die derde trimester. Gemiddelde swangerskap-AEE het 'n nie-betekenisvolle negatiewe verhouding tussen alle fetale groei parameters getoon – gewig by geboorte ($r = -0.39$, $p = 0.45$), lengte by geboorte ($r = -0.16$, $p = 0.77$), Ponderale Indeks ($r = -0.34$, $p = 0.51$) – asook 'n nie-betekenisvolle positiewe verhouding met kopomtrek by geboorte ($r = 0.14$, $p = 0.79$).

Die gevolgtrekking word gemaak dat die objektief-bepaalde, daaglikse fisieke aktiwiteit van die deelnemers, nie met die bestaande riglyne vir swanger vroue ooreengestem het nie. Fisieke aktiwiteitsvlakke gedurende swangerskap het beduidend afgeneem teen die derde trimester. Die daaglikse fisieke aktiwiteitsvlakke het geen invloed op die fetale groei parameters getoon nie.

Sleutelwoorde:

fisieke aktiwiteit, fisieke aktiwiteitspatrone, daaglikse fisieke aktiwiteit, fetale groei, swangerskap

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LIST OF ABBREVIATIONS

A

ACOG	American College of Obstetricians and Gynaecologists
ACSM	American College of Sports Medicine
AEE	Active Energy Expenditure

B

BMI	Body Mass Index
-----	-----------------

C

cm	centimetre
----	------------

D

DIT	Diet-Induced Thermogenesis
-----	----------------------------

E

ECG	Electrocardiograph
-----	--------------------

G

g	gram
GPAQ	Global Physical Activity Questionnaire
GWG	Gestational Weight Gain

H

HAPPY	Habitual Activity Patterns during PregnancY
-------	---

I

IPAQ	International Physical Activity Questionnaire
------	---

K

kCal	kilocalories
kg	kilogram
kJ	kilojoule

M

m	meter
MET	Metabolic Equivalent of Task
Min	minutes

P

PA	Physical Activity
PAL	Physical Activity Level

PPAQ	Pregnancy Physical Activity Questionnaire
R	
R	Rand
RCOG	Royal College of Obstetricians and Gynaecologists
REE	Resting Energy Expenditure
RMR	Resting Metabolic Rate
RQ	Respiratory Quotient
S	
SD	Standard Deviation
SOGC	Society of Obstetricians and Gynaecologists of Canada
T	
TDEE	Total Daily Energy Expenditure
TEE	Total Energy Expenditure
U	
U.K.	United Kingdom
U.S.A.	United States of America
V	
VO ₂	Oxygen consumption
W	
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1. Introduction

1.2. Problem Statement

1.3. Aim and objectives of the study

1.4. Hypotheses of the study

1.5. Structure of the dissertation

1.1. Introduction

The benefits of physical activity (PA) on the lifecycle of the foetus are well recognised (Batista *et al.*, 2003:151; Downs *et al.*, 2012:496 Melzer *et al.*, 2010a:494). During pregnancy specifically, physical activity is recommended as evidence showing the benefits to both the mother and the foetus increases (Domingues *et al.*, 2012:S283). However, this information is not always inferred to the mother, and therefore some misconceptions regarding physical activity during pregnancy are nevertheless believed (Cioffi *et al.*, 2010:458; Duncombe *et al.*, 2007:431). Therefore, monitoring habitual, physical activity patterns during pregnancy is essential, providing a rationale for the first objective of this dissertation.

Early studies have associated physical activity to low birth weight (Kramer, 1987:696). While, more recent evidence fails to prove such an association and even concludes a protective effect of physical activity on foetal growth (Takito & Benício, 2010:100). Consequently, determining the relationship between foetal growth and habitual physical activity, the second objective of this dissertation is imperative as the information obtained may augment a healthy, active lifestyle during pregnancy.

The purpose of this chapter is to present the problem statement that has led to the research questions that are posed in this dissertation. The objectives and hypotheses set to answer the research questions are further described and finally, the structure of the dissertation is given.

1.2. Problem Statement

Pregnant women who participate in regular physical activity have a lower risk for foetal growth restriction than women leading a sedentary lifestyle (Juhl *et al.*, 2010:63e7). More women than before wish to continue exercising and be physically active during their pregnancy (Hausenblas *et al.*, 2011:315). Additionally, pregnant women leading a sedentary lifestyle wish to improve their overall health through regular physical activity (Davies *et al.*, 2003:332; Hausenblas *et al.*, 2011:315). Regardless of the physiological changes that they undergo during pregnancy, pregnant women benefit from physical activity as much as non-pregnant women (Melzer *et al.*, 2010a:493).

Maternal physical activity tends to decrease during pregnancy, because of the minor discomforts that are associated with pregnancy, such as leg cramps, swelling, fatigue, shortness of breath (Horns *et al.*, 1996:49) and difficulties in movement related to a larger body mass (Melzer *et al.*, 2010a:499). Occasionally, physical activity decreases, because of the perception that it may be damaging to the foetus (Cioffi *et al.*, 2010:458).

The American College of Obstetricians and Gynecology recommends that pregnant women should participate in 30 to 40 minutes of moderate-intensity physical activity on most, and preferably all days of the week during gestation for overall health benefits (ACSM, 2014:196; Artal & O'Toole, 2003:6). The benefits of PA during pregnancy are shorter time spent in labour and a lower incidence of caesarean sections, operative vaginal deliveries and acute foetal distress (Clapp, 1990:1779; Melzer *et al.*, 2010a:494). Benefits for the women include improved cardiovascular function (Melzer *et al.*, 2010a:494), limited pregnancy weight gain, decreased musculoskeletal discomfort (Pivarnik *et al.*, 2006:989), reduced incidence of muscle cramps and lower limb oedema (Arena & Maffulli, 2002:15), mood stability (Poudevigne & O'Conner, 2005:1374; Poudevigne & O'Conner, 2006:19), and attenuation of gestational diabetes mellitus and gestational hypertension (Artal & O'Toole, 2003:479). Foetal benefits include decreased gestational fat mass, improved stress tolerance and advanced neurobehavioral maturation (Clapp *et al.*, 1999:93; Melzer *et al.*, 2010a:494). Moreover, rigorous weight-bearing exercise regimens during pregnancy have been found to be associated with improved attentiveness and behavioural control in the immediate neonatal period, improved maintenance of the same morphometric profile (normal axial growth with reduced weight and fat mass) at age five, and are slightly ahead of controls at the same age with regard to neurodevelopment (Clapp, 2003:S80).

The majority of the documented studies in this area of pregnancy research have investigated the influence of exercise on foetal growth (Bell, 2002:32; Clapp *et al.*, 2000:1484; Clapp *et al.*, 2002:142; Clapp, 2006:527; Duncombe *et al.*, 2006:288; Penney, 2008:155) and not physical activity. However, studies reporting physical activity during pregnancy stated physical activity may increase (Hatch *et al.*, 1993:1105), decrease (Bell *et al.*, 1995:32; Clapp, 1990:1799; Clapp & Dickstein, 1984:556) or have no effect on birth-weight (Kardel & Kase, 1998:285; Rose *et al.*, 1991:1078; Sternfeld *et al.*, 1995:634). Decreases in birth-weight due to physical activity are attributed to differences in newborn fat mass (Melzer *et al.*, 2010a:502). Reasons for this variability may be that foetal growth and size at birth are dependent on the type, frequency, intensity and duration of the physical activity, as well as the point in the pregnancy at which the physical activity was performed (Clapp, 2003:S80). The overall term “foetal growth parameters” include: head- and abdominal circumference, femur length, ponderal index (weight in grams x100 divided by length in cubic centimetres), placental weight and estimated foetal weight (Juhl *et al.*, 2010:1e2).

In order to study the relationship between physical activity and foetal growth, both habitual physical activity and exercise should be included when researching this relationship. It is also important to include all three modes of physical activity as identified by Miles (2007:314), namely occupational household (e.g. housework), transport (e.g. walking to work) and leisure-time activities (e.g. dancing). Physical activity measurement techniques vary greatly and are not always reliable, especially over a longitudinal time of measurement (Brage *et al.*, 2005:562). Few studies have documented longitudinal changes in physical activity during all three trimesters (Barnes *et al.*, 1991:162; Lui *et al.*, 2010:237; Pereira *et al.*, 2007:312). One longitudinal study by Pereira *et al.* (2007:312) measured physical activity by means of a self-reported leisure-time questionnaire and found a decrease in moderate and vigorous physical activity during pregnancy. The accuracy of self-reporting questionnaires is influenced by the subjective nature of the phrase “intensity of physical activity” (Lee, 2011:116).

With these limitations in the literature, the question for this study remains: What are the objectively measured habitual physical activity patterns of pregnant women across all trimesters of pregnancy, and what is the relationship between the habitual, physical activity during pregnancy and foetal growth parameters?

The study will present objectively-determined habitual, physical activity patterns during pregnancy and the relationship that could exist between this kind of activity and foetal growth parameters. The information could be used by health practitioners to promote habitual, physical activity during pregnancy and to understand the factors that may contribute to inactivity, which may eventually result in long-term inactivity with detrimental effects on long-term health.

1.3. Aim and objectives

The research objectives of this study are to determine:

- Objectively, the habitual, physical activity patterns of pregnant women during all trimesters of pregnancy
- The relationship between habitual, physical activity of pregnant women and foetal growth parameters.

1.4. Hypotheses

This study assumes the following hypotheses:

- The objectively-determined habitual, physical activity patterns of pregnant women are lower than the prescribed American College of Sports Medicine guidelines and will decrease between the first and the third trimester of pregnancy.
- Habitual, physical activity patterns have a significant, inverse relationship to foetal growth parameters.

1.5. Structure of the dissertation

This study forms part of the larger **H**abitual **A**ctivity **P**atterns during **P**regnanc**Y** (HAPPY)-study, where the primary objective is to determine the habitual activity patterns of pregnant women. As indicated in the objectives, this study focuses on the habitual, activity patterns and their relationship with foetal growth measurements. Figure 1.1 illustrates the context of this study within the larger HAPPY-study, specifically where the objectives of this dissertation are included within the broader study.

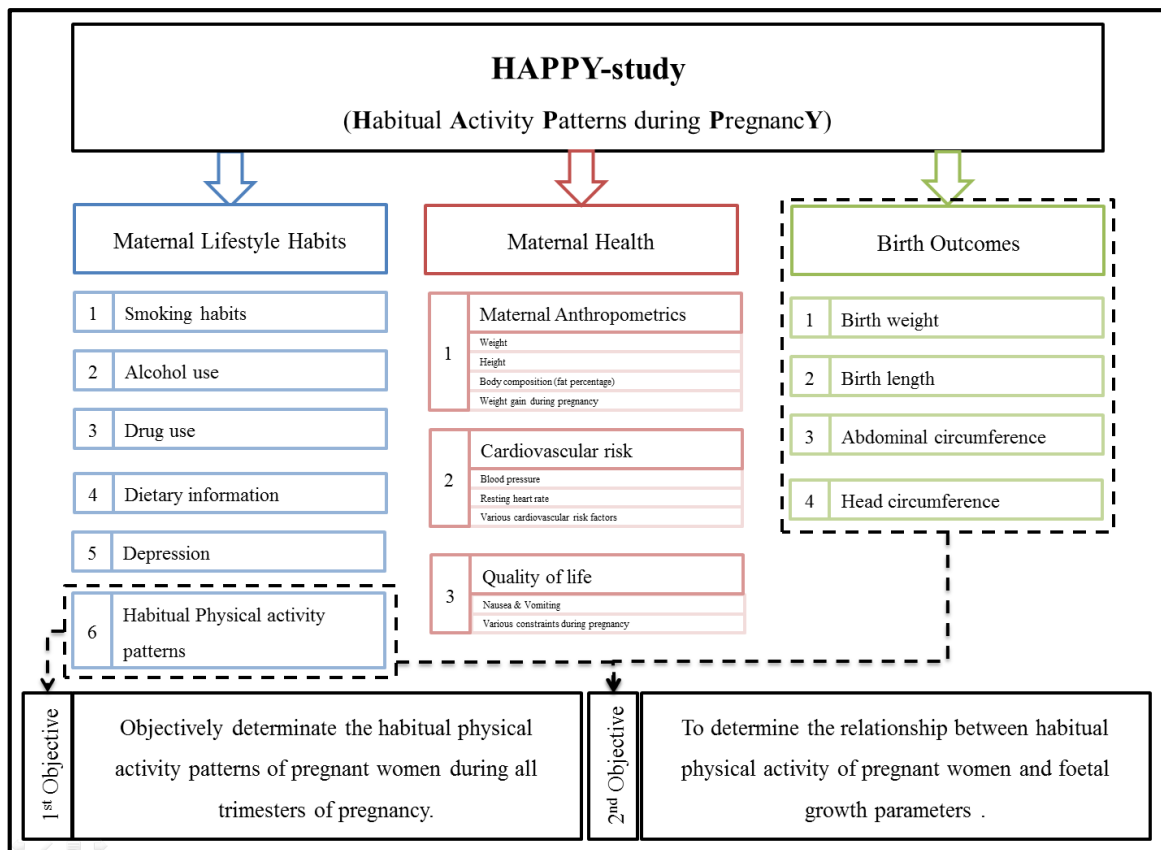


Figure 1.1: Context of the dissertation within the HAPPY-study

This dissertation is structured around five chapters. All referencing is presented at the end of the dissertation, in the adapted Harvard style as prescribed by the North-West University.

The dissertation consists of five main sections:

- Introduction (Chapter 1)
- Literature review: Habitual activity patterns during pregnancy and its relationship with foetal growth (Chapter 2)
- Research methods (Chapter 3)
- Results and discussion (Chapter 4)
- Summary, conclusion, limitations and recommendations (Chapter 5)

Chapter 1 introduces the topic of physical activity and foetal outcomes, the problem statement and the objectives and hypotheses of the study. After the introductory chapter, a literature review (Chapter 2) about the recent research regarding habitual, physical activity patterns during pregnancy and their influence on foetal growth parameters. The study design, research methods,

specifically the ActiHeart® device and various foetal growth parameters and birth outcomes, as well as the statistical analysis are discussed in detail in Chapter 3. The results are presented and discussed in Chapter 4, which investigates the outcome of this study, by firstly presenting the objectively-determined habitual, physical activity patterns during pregnancy and then citing their influence on various foetal growth parameters and birth outcomes. A general summary, conclusion, limitations and recommendations are presented in Chapter 5, after which the source references and appendices follow.

CHAPTER 2: LITERATURE REVIEW: THE RELATIONSHIP BETWEEN HABITUAL PHYSICAL ACTIVITY PATTERNS OF PREGNANT WOMEN AND FOETAL GROWTH PARAMETERS

2.1. Introduction

2.2. Physiological adaptations to pregnancy

2.3. Metabolic adaptations to pregnancy

2.4. Physical activity during pregnancy

2.5. Birth outcomes

2.6. Summary

2.1. Introduction

The literature regarding pregnancy provides sufficient, empirical evidence of maternal and infant health benefits in pregnant women who are physically active (Downs *et al.*, 2012:496). Regardless of the physiological changes women undergo during pregnancy, pregnant women benefit from physical activity just as much as non-pregnant women (Melzer *et al.*, 2010a:493). The complexity of assessing physical activity during pregnancy hampers the determination of the optimal dose of recreational physical activity for pregnant women (Chasan-Taber *et al.*, 2007:86) and has led to broad, physical activity guidelines being given for pregnant women. Concurrently, pregnancy is characterised by a reduction of physical activity (Evenson & Wen, 2011:41), resulting in discrepancies between physical activity during pregnancy and the guidelines set by various institutional and governmental entities (ACOG, 2002:79; ACSM, 2014:194; Barsky *et al.*, 2012:69; Davies *et al.*, 2003:335; Holan *et al.*, 2005:15; RCOG, 2006:2; Sports Medicine Australia, 2009:4; US Department of Health and Human Services, 2008:viii).

In this chapter, physiological adaptations to pregnancy are shortly reviewed as one needs to know the fundamental, physical adaptations that occur during pregnancy to understand the influence of physical activity on maternal- and foetal outcomes. Cardiovascular-, respiratory, musculoskeletal- and endocrine adaptations that occur during pregnancy are briefly explained in this chapter. Specifically, metabolic adaptations are addressed due to the importance of energy balance. The previously-mentioned physiological changes cause an increased demand for energy intake, while energy expenditure is also increased mainly due to an increased basal metabolic rate as body weight increases during pregnancy (Löf *et al.*, 2005:684; Melzer *et al.*, 2009:1188). Measurement of energy expenditure by means of the ActiHeart®, provides an objective measurement technique to quantify physical activity during pregnancy, and is therefore applied in this study. Due to the degree of difficulty measuring physical activity during pregnancy, specifically longitudinally, these patterns are poorly understood and concurrently reviewed. Physical activity tends to decrease when women are pregnant, although the literature provides a lot of evidence of the benefit of regular physical activity during pregnancy. This information is not always inferred to pregnant women and has led to a misconception that physical activity might be detrimental during pregnancy. The possible risk of physical activity is therefore discussed, as well as the guidelines for physical activity during pregnancy to ensure a beneficial and safe duration of the antenatal period. Finally, the influences of physical activity during pregnancy on birth outcomes are addressed because of the “theory of foetal origins” that states that the maternal environment influences foetal growth. Taking this theory into consideration, physical activity as lifestyle modification during pregnancy may provide benefits for foetal growth.

2.2. Physiological adaptations to pregnancy

The duration of a pregnancy averages 266 days (38 weeks) after ovulation, or 280 days (40 weeks) after the first day of the last menstrual cycle. This period equals 10 lunar months, or just over 9 calendar months (Blackburn, 2003:70). Physiological changes during pregnancy are divided into a series of stages and sub-stages and the entire process is then subdivided into three relatively equal trimesters (Kawaguchi & Pickering, 2010:40).

All maternal, physiological systems adapt to the demands of pregnancy, however, the quality, degree, and timing of the adaptation varies from one individual to the next and from one organ system to another (Heidemann & McClure, 2003:65; Norwitz *et al.*, 2005:338). The adaptations

are mostly mediated due to the effects of progesterone and oestrogen that are produced, predominantly by the ovary in the first 12 weeks of pregnancy and there-after produced by the placenta (Heidemann & McClure, 2003:65). These adaptations enable the foetus and placenta to grow and prepare the mother and baby for parturition (Carlin & Alfirevic, 2008:801; Heideman & McClure, 2003:65).

Physiological adaptations, as a result of pregnancy, represent a serious challenge to all body systems (Carlin & Alfirevic, 2008:801). While these adaptations do not pose major risks for healthy women, the normal physiological adaptations of pregnancy can place significant strain on already compromised systems (Carlin & Alfirevic, 2008:802).

2.2.1. Cardiovascular adaptations during pregnancy

Profound physiological adaptations occur in the cardiovascular system during pregnancy (Carlin & Alfirevic, 2008:802). Circulating blood volume increases in order to meet the demands of the developing foetus and placenta. During pregnancy there are major alterations in blood volume, constituents of cells and coagulation factors (Carlin & Alfirevic, 2008:802; Norwitz *et al.*, 2005:340). A substantial part of maternal weight gain during pregnancy results from fluid accumulation, specifically plasma volume (Norwitz *et al.*, 2005:339). This increase of plasma volume supplies the necessary nutrients to the uterus and the placenta and ensures the removal of waste products from them (Kawaguchi & Pickering, 2010:41). Overall blood pressure decreases as well, more specifically diastolic to a greater extent than systolic (Kawaguchi & Pickering, 2010:41), despite an increase in blood volume and cardiac output, due to a decrease in systemic and pulmonary vascular resistance (Capeless & Clapp, 1989:1449). Another change to the cardiovascular system includes an increase in cardiac output, the product of heart rate and stroke volume (Holschen, 2004:853; Kawaguchi & Pickering, 2010:41). Initially the increase in cardiac output is mediated by the increase in stroke volume. As the pregnancy progresses, an increase in heart rate becomes the dominant factor that affects cardiac output (Capeless & Clapp, 1989:1449).

2.2.2 Respiratory adaptations during pregnancy

Numerous changes occur in the maternal respiratory system during pregnancy to ensure sufficient oxygen to the placenta for increased foetal demands and for foetal physiology (Carlin

& Alfirevic, 2008:339; Heidemann & McClure, 2003:66; Norwitz *et al.*, 2005:339). The net physiologic change in the respiratory system is a lowering of the maternal PCO₂ to facilitate effective exchange of CO₂ from the foetus to the mother (Carlin & Alfirevic, 2008:804; Norwitz *et al.*, 2005:339). The oxyhaemoglobin dissociation curves of foetal haemoglobin and adult haemoglobin allow the foetus to extract oxygen effectively from the maternal circulation (Norwitz *et al.*, 2005:339). The effects are mediated by hormonal factors that influence the respiratory centre, specifically progesterone (Jensen *et al.*, 2007:1241). An increase in progesterone stimulates the respiratory centre to increase minute volume, lowers the threshold of carbon dioxide concentrations (Jensen *et al.*, 2007:1241) and may also decrease airway resistance, facilitating a greater airflow (Garcia-Rio *et al.*, 1996:450; Jensen *et al.*, 2005:1374).

2.2.3 Musculoskeletal adaptations during pregnancy

Hormonal changes, specifically, changes in progesterone and relaxin levels, lead to increased joint laxity and hyper-mobility (Calguneri *et al.*, 1982:126), which could potentially raise the risk of injury during exercise in pregnancy (RCOG, 2006:1). Increased body weight, as a result of foetal growth, increases the forces imposed on the joints such as the hips and knees (Artal & O'Toole, 2003:6). Since the abdomen expands anterior during foetal growth, the centre of gravity changes during pregnancy, resulting in postural adjustments, specifically an extension of the lumbar spine (Kawaguchi & Pickering, 2010:41) which realigns the body mass above the base of support (Whitcome *et al.*, 2007:1075). Elongation and decreased tone of the abdominal muscles may ensue, because of the prolonged maintenance of the abovementioned position (Kawaguchi & Pickering, 2010:41). The combination of weight gain, altered postural alignment, and ligamentous laxity causes changes in proprioception and postural balance in pregnant women (Wang & Apgar, 1998:1846-1847). These postural changes could also influence energy expenditure during pregnancy (McArdle, 2010:200).

2.2.4 Endocrine adaptations during pregnancy

Since the development of the foetal origin of disease in later life hypotheses (described later in this chapter) a lot of research focuses on the intra-uterine environment, specifically with regards to hormonal changes during gestation (Kuijper *et al.*, 2013:33). Both endogenous and maternal hormones influence the foetus (Kuijper *et al.*, 2013:34). Foetal development and sustained essential physiological functions of both mother and foetus are mediated by an increase in the

release of specific hormones (Lewis *et al.*, 2008:442) such as oestrogen, progesterone, human chorionic gonadotropin, prolactin, adrenocorticotrophic hormone, thyroid-stimulating hormone, cortisol and thyroid hormones (Wylie, 2005:39-40). The mass of cells that forms on the ovaries, the corpus luteum, is the main source of pregnancy-sustaining hormones during the first 6–8 weeks of gestation (Mittlemark *et al.*, 1991:69). As previously mentioned, the majority of hormonal changes in pregnancy are related to the activity of the placenta (Wylie, 2005:39). The placenta takes over the role of the corpus luteum later in the pregnancy. The changes of hormones during pregnancy and their effects include:

- Increased Oestrogen, which stimulates glandular tissue and ducts in the breast and increases prostaglandin and oxytocin production (Kuijper, 2013:37).
- Increased Progesterone, which mediates vital physiological function during pregnancy, including an increased mobility of the joints (Rode *et al.*, 2009:1181).
- Increased Relaxin, which functions synergistically with progesterone to decrease uterine activity during pregnancy and to suppress oxytocin release (Kawaguchi & Pickering, 2010:40). Relaxin also affects the connective tissue to increase the mobility of the joints, in a similar way as to progesterone (Aldabe, 2012:1770).
- Increased Cortisol secretion from the second trimester of pregnancy to meet the body's extra metabolic workload (Damjanovic, 2009:266).
- Increased Human chorionic gonadotropin levels, which are linked to changes in appetite, sleep patterns and food tolerance in the first trimester (Wylie, 2005:39).
- Increased Thyroid hormones, both T₃ and T₄, causing the basal metabolic rate to increase during pregnancy (Glinioer, 2004:134).

In summary the changes observed in the physiological systems during pregnancy (as seen in Figure 2.1) facilitate the adaptations observed in non-pregnant women who perform regular physical activity to a large degree.

2.3. Metabolic adaptations to pregnancy

2.3.1. Energy intake during pregnancy

The physiological changes that occur during pregnancy cause an increased demand for dietary energy as a result of increased oxygen consumption, respiration, circulation and renal function of the foetus during development (Chamberlain & Pipkin, 1998:163). From conception to birth, all

the growth of the foetus is possible because of the nutrients the mother consumes (Whitney & Rolfes, 2008:520). The nutrient needs during pregnancy and lactation are higher than any other time in a woman's life (Whitney & Rolfes, 2008:520). This high nutrient demand during pregnancy is met with an increased energy intake, as well as help from the mother's body that maximises absorption and minimises energy expenditure (Whitney & Rolfes, 2008:520).

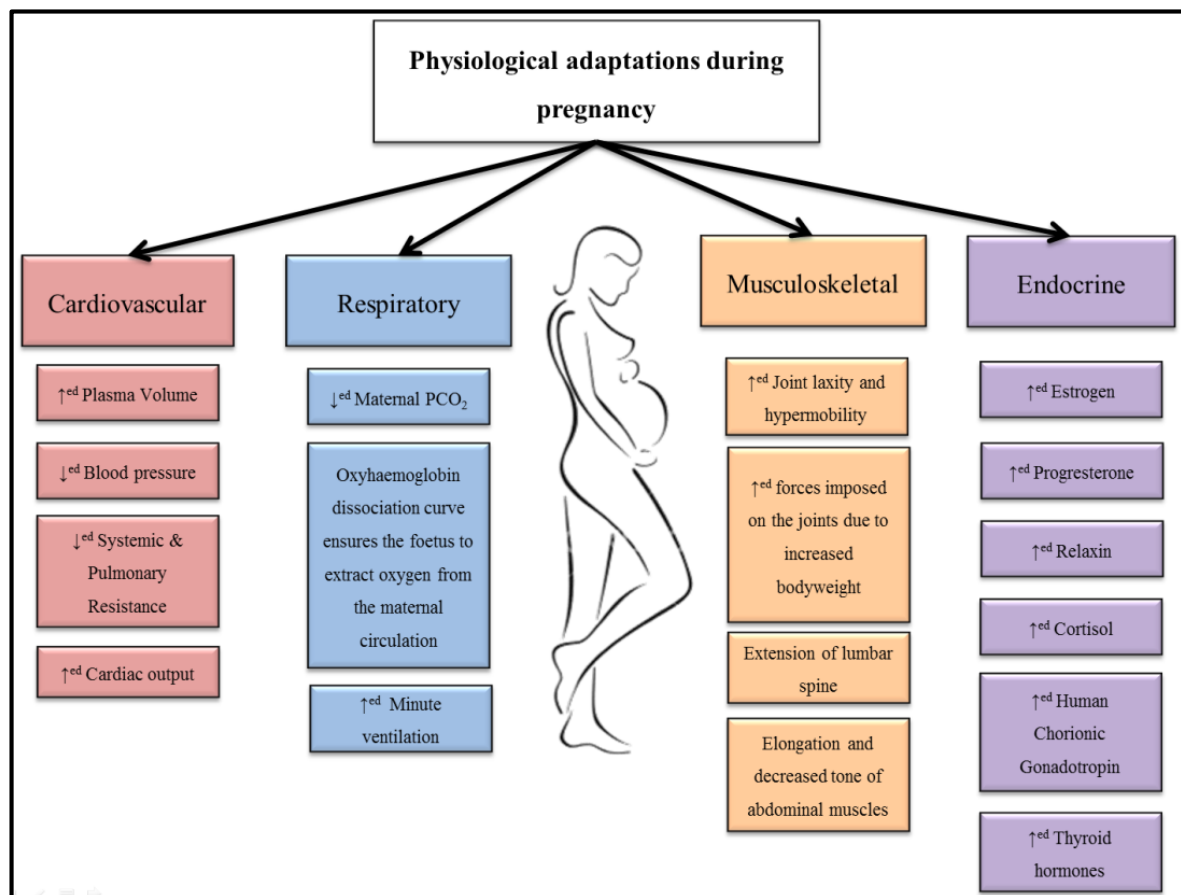


Figure 2.1: Summary of the physiological adaptations during pregnancy

The energy needs of pregnant women exceed those of non-pregnant women by an additional 340 kilocalories per day during the second trimester and extra 450 kilocalories per day during the third trimester (Whitney & Rolfes, 2008:520). The additional kilocalories represent 15 to 20 percent more food than before pregnancy for an average 2000-kcal daily intake. Ample carbohydrates are essential for fuel to the foetal brain, which ensures that the protein needed for growth is not catabolised and used to synthesise glucose (Jones *et al.*, 2010:126; Whitney & Rolfes, 2008:520). The extra energy demands of pregnancy can be met by an increase in food intake or by the mobilisation of energy fat stores of the mother, particularly those mothers with sufficient energy reserves (Melzer *et al.*, 2009:1189).

The additional energy requirements during pregnancy can be described as the energy needed for maternal tissue and foetal growth, as well as the energy required for the rise in basal metabolic rate and the changes in physical activity (Melzer *et al.*, 2009:118). Energy requirements during pregnancy remain controversial because of conflicting data on maternal fat deposition and putative reductions in the mother's physical activity as the pregnancy advances (Poppit *et al.*, 1993:363).

2.3.2. Energy expenditure during pregnancy

Total daily energy expenditure (TDEE) consists of three general factors: resting metabolic rate, thermogenic effect of feeding and physical activity (Manini, 2010:1). TDEE for the non-pregnant healthy woman is calculated as the energy expended from resting metabolic rate (60 – 75%), thermogenic effect of feeding (10%) and physical activity (25 – 30%). TDEE increases during pregnancy due to tissue growth, an elevated basal metabolic rate and the increased energy costs of moving a heavier body (Löf, 2011:1295).

Resting metabolic rate (RMR) accounts for all the metabolic activities in the human body (Manini, 2010:3). Human metabolism involves all the body's chemical reactions of bio molecules that cause anabolism and catabolism. RMR varies dramatically from person to person and vary for the same individual with a change in circumstances or physical condition (with pregnancy being an extreme physiological condition) (Manini, 2010:3). Pregnancy is a dynamic, anabolic state where the human body obtains energy for growth and maintenance (Mojtahedi *et al.*, 2002:1078).

The increased strain during pregnancy raises the RMR dramatically and demands extra energy (Butte *et al.*, 2004:1086; Löf *et al.*, 2005:684). This is calculated by Prentice *et al.* (1996:S82) as 20% in late pregnancy. Forty percent of this variability is explained by the percentage of total body fat before pregnancy and the gain in body weight during pregnancy (Löf *et al.*, 2005:684; Melzer *et al.*, 2009:1188). Body fat gain accounts for about $55.5\% \pm 20\%$ of total weight gain, during pregnancy (Okereke *et al.*, 2004:368). According to Löf *et al.* (2005:684) factors that are responsible for the variability in RMR response during pregnancy differ in the earlier and later trimesters of pregnancy. Most of the total body fat mass is deposited during the second trimester, with little change taking place in the first and third trimesters (Kopp-Hoolihan *et al.*, 1999:700). Chamberlain & Pipkin (1998:163) developed a theoretical model to estimate energy

requirements during pregnancy, assuming an average gestational weight gain (GWG) of 12.5 kg (≈ 0.925 kg protein, ≈ 3.8 kg fat, and ≈ 7.8 kg water), which is associated with an increase in RMR (Löf *et al.*, 2005:684).

The thermogenic effect of food is attributed to the digestion process and is proportional to the food energy that is consumed (Whitney & Rolfes, 2008:256). This diet-induced thermogenesis seems to be unaltered (Bronstein *et al.*, 1995:272; Nagy & King, 1984:1262; Piers *et al.*, 1995:511; Poppitt *et al.*, 1993:363; Prentice *et al.*, 1996:S107; Spaaij *et al.*, 1994:342) or even reduced (Contaldo *et al.*, 1987:302; Illingworth *et al.*, 1987:1575; Kopp-Hoolihan *et al.*, 1999:703) during pregnancy.

The most varying factor that determines total energy expenditure is physical activity and is dependent on the amount of muscle mass producing bodily movements and the intensity, duration, and frequency of muscular contractions (Caspersen *et al.*, 1985:127). The interaction between physical activity and energy metabolism is complex. For example, pregnant women may reduce physical activity energy expenditure by selecting less demanding activities or reducing the pace of activity, although the actual cost might be higher, because of moving a heavier body (Löf, 2011:1296). However, all pregnant women might not reduce their physical activity because of the knowledge of the health benefits of physical activity during pregnancy. Over the past 2 years, more studies have focused on the energy expenditure during pregnancy, especially in the wake of the rapid increase in obesity, globally. The total energy expenditure during pregnancy is controversial, mainly because of conflicting data on the extent of reduction in physical activity as pregnancy advances (Melzer *et al.*, 2009:1185) and the collection of physical activity information with self-report questionnaires.

The energy cost that is attributed to physical activity during pregnancy is generally lower (Butte *et al.*, 2004:1085; Clarke *et al.*, 2005:254; Lawrence & Whitehead, 1988:158; Löf & Forsum, 2006:301; Rousham *et al.*, 2006:398) and tends to decrease as pregnancy advances (Forsum *et al.*, 1992:341; Heini *et al.*, 1991:E15; Lawrence *et al.*, 1985:761; Singh *et al.*, 1989:327; Van Raaij *et al.*, 1987:953). Studies show that pregnant Scottish (Durnin *et al.*, 1987:898) and Dutch (Van Raaij *et al.* 1987:954) women had a slight decrease in absolute energy cost of physical activity, observed in activity diary studies, as their pregnancy advanced. The same results were found in British women by Prentice *et al.* (1996:S84) by means of an entire body calorimetry methodology. However, Melzer *et al.* (2009:1188) found this decrease in active energy

expenditure insignificant in pregnant women in Sweden and America (Melzer *et al.*, 2009:1189), but when expressed per unit of body weight to account for weight differences, this result became significant. Other studies from Sweden and the United Kingdom report similar decreases in active energy expenditure per kilogram in the pregnant compared to the non-pregnant state (Löf & Forsum, 2006:301; Prentice *et al.*, 1996:S107). Reasons for this decrease in physical activity are explained in the following section. However, physical activity cannot be observed in isolation when activity energy expenditure is discussed, because energy intake is also important in the energy balance. More details regarding behavioural changes in activity patterns are discussed in the following section.

To obtain relevant information with relation to dietary energy needs during pregnancy, studies should be carried out during free-living conditions using an appropriate methodology (Löf, 2011:1296). The correct measuring tool is essential to quantify physical activity during pregnancy.

2.4. Physical activity during pregnancy

2.4.1. Measurements

Critical appraisal of the physical activity during pregnancy and the influence of recreational or habitual physical activity on birth outcomes and maternal health are dependent on valid and reliable, objective measurements of physical activity (Chasan-Taber *et al.*, 2007:87). The relationship between physical activity and birth outcomes is likely to be modest, therefore it is essential to measure recreational, physical activity accurately to minimise the possibility that an effect is observed because of a measurement error (Chasan-Taber *et al.*, 2007:101).

A great variety of physical activity questionnaires have been developed and validated over the past 20 years. The accuracy of self-reporting questionnaires is influenced by the subjective nature of the term “intensity of physical activity” (Shephard, 2003:197). Physical activity questionnaires emphasise participation in moderate to vigorous sports, while not including household or childcare activity (Ainsworth *et al.*, 2000:S502). Indeed, women spend considerable time and energy in moderate-intensity activities related to household chores, their job and family care (Ainsworth *et al.*, 1993:13). Interestingly, the accuracy of short- and long-term recollections of physical activity patterns by pregnant women is not known (Poudevigne & O’Connor, 2006:21). According to Poudevigne and O’Connor (2006:21) there is a lack of

knowledge regarding how accurately women can recall their physical activity patterns during pregnancy.

Direct measurements of the metabolic cost of energy expenditure among pregnant women, as opposed to relying upon values collected among non-pregnant populations, will objectively define the intensity of recreational activity among pregnant women (Chasan-Taber *et al.*, 2007:103). For this purpose, double-labelled water and indirect calorimetry (Ainslie *et al.*, 2003:687; Speakman, 1998:933S) are used to measure physical activity, but because of these methods' costs, invasiveness and technical sophistication, their suitability for the general population decreases.

In large samples and population-based studies, questionnaires have been the instrument of choice. Herrmann *et al.* (2013:233) determined the validity of two questionnaires, namely the International Physical Activity Questionnaire (IPAQ) (Bauman & Sallis, 2008:544; Guthold *et al.*, 2008:487) and the Global Physical Activity Questionnaire version 2 (GPAQ) (Armstrong & Bull, 2006:67). The GPAQ shows short- and long-term-retest reliability and modest validity (Herrman *et al.*, 2013:233), although it has not been validated in the pregnant population. Specifically during pregnancy, four validated questionnaires are currently being used to determine physical activity (Aittasalo *et al.*, 2010:109; Chasan-Taber *et al.*, 2004:1755; Evenson & Wen, 2010:1-2; Schmidt *et al.*, 2006:43). A validated, self-administered questionnaire, the Pregnancy Physical Activity Questionnaire (PPAQ) has been used to assess the physical activity levels of pregnant women (Chasan-Taber *et al.*, 2004:1751). Categories in this questionnaire include: household/care giving, occupational, sport/exercise, transportation and inactivity (Cohen *et al.*, 2013:1001) and asks women to estimate the duration and frequency spent per activity during the previous month. The PPAQ provides an easy method of assessing physical activity patterns in women with uncomplicated pregnancies (Cohen *et al.*, 2013:1006).

Both accelerometers (Rousham *et al.*, 2006:394; Stein *et al.*, 2003:634) and heart rate monitors (Perkins *et al.*, 2007:81) have been used to measure daily physical activity accurately. However, when these devices are used separately, they have disadvantages (Barreira *et al.*, 2009:61). Temperature, humidity, fatigue and emotional stress can also influence heart rate (Eston *et al.*, 1998:362). Lost data from signal interruptions and delayed heart rate responses provide additional challenges (Janz, 2002:143; Strath *et al.*, 2000:S465). Accelerometers are not waterproof and cannot monitor activities in water (Barreira *et al.*, 2009:61). Also, static physical

activity, such as weight lifting, generates less body movement, but requires energy expenditure, which can be problematic when using accelerometers (Freedson & Miller, 2000:S21; Welk, 2002:125).

To continually measure free-living physical activity, a combination of the abovementioned accelerometers and heart rate monitors are used and could provide more accurate activity profiles by overcoming individual sources of error (Corder *et al.*, 2007:217; Freedson & Miller, 2000:S21; Sallis & Saelens, 2000:S1; Strath *et al.*, 2002:893-894; Treuth, 2002:213). One such device is the ActiHeart® (Barreira *et al.*, 2009:61), which was first used by Melzer *et al.* (2009:1189) to measure changes in resting and activity-related energy expenditure during pregnancy. The ActiHeart® is the only commercially-available device that combines acceleration and heart rate, therefore increasing the practical applicability to improve energy estimates compared to traditional acceleration devices (Spierer *et al.*, 2011:660). ActiHeart® is a waterproof, self-contained, logging device that allows physical activity to be measured synchronously with heart rate (Brage *et al.*, 2005:562). The device is worn on the chest and consists of two electrodes that are connected by a short lead and clip onto two standard electrocardiograph (ECG) pads. Free-living data, as assessed by the ActiHeart®, is essential to determine behavioural changes in activity patterns in pregnant women (Melzer *et al.*, 2009:1189). The ActiHeart® device has shown accurate estimates of energy expenditure versus indirect calorimetry over a wide range of activities (varying from sedentary behaviours to vigorous physical activity) in men and non-pregnant women, although it is not validated specifically for pregnant women (Melzer *et al.*, 2009:1189). Brage *et al.* (2006:561) conclude that the ActiHeart® is a reliable and valid tool for the measurement of movement and heart rate in humans at rest and during walking and running. Overall, the ActiHeart® is reliable in measuring and categorising intensities of physical activity (Barreira *et al.*, 2009:61) in addition to increased monitor-wear compliance in adolescents (Campbell *et al.*, 2012:599).

The complexity of assessing physical activity in general, and in particular, during pregnancy, a demanding period characterised by changing physiology, hampers the determination of the optimal dose of recreational physical activity for pregnant women (Chasan-Taber *et al.*, 2007:86). Because of the well-documented advantages of regular exercise in non-pregnant women, similar findings are expected during pregnancy. A lack of measuring instruments limits studies on the direct effect of exercise on the foetus. The results are that health professionals have been very conservative in the amount and intensity of exercise recommended to pregnant

women. These guidelines have therefore impacted directly on habitual activity patterns during pregnancy.

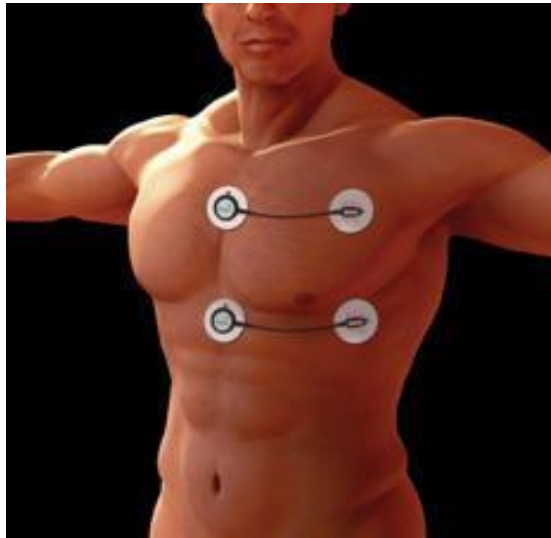


Figure 2.2: ActiHeart® device placement for the measurement of habitual activity energy expenditure

2.4.2. Physical activity patterns during pregnancy

The physical activity patterns of pregnant women are poorly understood (Poudevigne & O'Connor, 2006:21). Maternal physical activity tends to decrease during pregnancy, because of the minor discomforts that are associated with pregnancy, such as leg cramps, swelling, fatigue, shortness of breath (Horns *et al.*, 1996:49), difficulties in movement related to a larger body mass (Melzer *et al.*, 2010a:499) and, sometimes, because of the perception that physical activity may be damaging to the foetus (Cioffi *et al.*, 2010:458; Duncombe *et al.*, 2007:431).

Physical activity patterns vary across the duration of pregnancy and are generally at a lower level when compared to pre-pregnancy (Chasan-Taber *et al.*, 2007:87; Hinton & Olson, 2001:7). Prospective studies indicate that recreational, occupational, and overall physical activity declines during pregnancy (Clarke *et al.*, 2005:254; Rousham *et al.*, 2006:397). Physical activity is usually constrained in the first trimester because of nausea, vomiting and profound fatigue (Davies *et al.*, 2003:330; Poudevigne & O'Connor, 2006:27). These symptoms usually decrease in the second trimester. Physical limitations – like uterine enlargement and changes in weight distribution (Poudevigne & O'Connor, 2006:27) also lead to a decrease in physical activity in the third trimester (Davies *et al.*, 2003:330). Reductions in physical activity, especially in the third

trimester, might also be a method to meet the increased energy demands of pregnancy (Agarwal *et al.*, 2001:1019). Physical activity often decreases the most during the third trimester of pregnancy. This decrease in physical activity has sometimes been referred to as the “nesting effect”, as pregnant women prepare their home for the arrival of a new baby (Poudevigne & O’Connor, 2006:22).

Psychological changes, such as a declining body image and depression may make physical activity less attractive during pregnancy (Bungum *et al.*, 2000:262). In contrast to this, some of the barriers to physical activity during pregnancy, such as depression and fatigue, can be attenuated by regular exercise (Poudevigne & O’Connor, 2006:21). Exercise intensity decreases as many women cease vigorous sport activities when pregnant (Hegaard *et al.*, 2011:807; Mottola & Campbell, 2003:650; Pereira *et al.*, 2007:318). Evidence indicates that pregnant women’s primary mode of physical activity is low-intensity walking (Albright *et al.*, 2005:106; Evenson *et al.*, 2004:403). There is a shift in the nature of activities to activities that are less vigorous, more comfortable or perceived as safer, like walking and swimming and less bicycling (Da Costa *et al.*, 2003:111; Hatch *et al.*, 1997:531; Poudevigne & O’Connor, 2006:22). Work-related physical activity also decreases as pregnancy proceeds (Poudevigne & O’Connor, 2006:27).

A study done by Löf (2011:1300) found that pregnant women, compared with non-pregnant controls, spend less time (1.5h/24h) standing, being moderately active and more time (1.5h/24h) being sedentary. Additionally, active energy expenditure decreased by 18% (Löf, 2011:1330). The physical activity level (PAL) was also significantly lower than the corresponding value for non-pregnant controls (Löf, 2011:1300). However, as stated by Prentice *et al.* (1996:108), the use of PAL on pregnant women is not advisable, because even if active energy expenditure (total energy expenditure - basal metabolic rate) is unchanged, PAL will still decrease as basal metabolic rate increases during pregnancy. These findings correspond with an American study that confirmed a decrease in active energy expenditure by 13% because of activity records (Butte *et al.*, 2004:1085). However, another study done on healthy Swedish women, no major effect of pregnancy on activity patterns or on active energy expenditure was found (Löf & Forsum, 2006:301).

While all of the abovementioned factors contribute to the decreased pattern of physical activity during pregnancy, the strongest predictor of physical activity during pregnancy is the level of

physical activity during the year prior to pregnancy (Ning *et al.*, 2003:385; Zhang & Savits, 1996:58). If pregnant women were active as teenagers, they were 13 times more likely to engage in high-intensity physical activity during pregnancy as compared to sedentary teens (Ning *et al.*, 2003:385). Highly active women may be more aware of the health benefits of exercise and may have more confidence in their ability to choose an appropriate mode and intensity of exercise (Poudevigne & O'Connor, 2006:27). As with women who were sedentary before pregnancy, some started becoming physically active when they became pregnant according to a few studies (Domingues & Barros, 2007:180; Hegaard *et al.*, 2011:811; Hinton & Olson, 2001:127; Zhang & Savitz, 1996:58). This indicates that these women consider their pregnancy to be a chance to change their lifestyle (Hegaard *et al.*, 2011:811). Few studies document longitudinal changes in physical activity during all three trimesters (Barnes *et al.*, 1991:162; Lui *et al.*, 2010:237; Pereira *et al.*, 2007:312).

Very limited research exists pertaining to the physical activity patterns of South-African women (Brunette *et al.*, 2012:133). A single study researching physical activity during pregnancy in a South-African population, Brunette *et al.* (2012:139), found no change in physical activity level as pregnancy progressed from the second- to the third trimester. This contradicts previously-mentioned studies that found a decline in physical activity as pregnancy progressed. This contradiction can be explained by the fact that the patients in the study were recruited from a gynaecologist who advocated exercise during pregnancy (Brunette *et al.*, 2012:140).

Hegaard *et al.* (2011:809) found women with a higher BMI (more than 25 kg/m²) decreased their physical activity during pregnancy more than pregnant women with a normal weight (BMI 18.5 - 24.99 kg/m²). Changes in physical activity during pregnancy is extremely detrimental, because this decrease results in an even higher risk of gestational diabetes, pre-eclampsia or preterm delivery than in women who continued their normal level of physical activity (Dempsey *et al.*, 2004:668, Juhl *et al.*, 2008:63e7, Sørensen *et al.*, 2003:1273)

The most extreme type of physical inactivity is bed rest, which is recommended by obstetrics and gynaecology physicians in 20% of all pregnancies (Poudevigne & O'Connor, 2006:20). Bed rest is recommended in the hope of preventing or treating a wide variety of conditions, including spontaneous abortion, preterm labour, foetal growth retardation, oedema, and pre-eclampsia (Goldenberg *et al.*, 1994:131). Little evidence exists regarding the effectiveness of bed rest on the treatment of these conditions (Crowther & Han, 2010:CD000110). The adverse effects of bed

rest may be even more detrimental than the conditions it is meant to prevent or treat, for instance decreased sex steroids, insulin resistance, systemic inflammation, mood disturbances and even progressive bone and muscle loss compromising the ability to perform tasks of daily living (Biolo *et al.*, 2003:31). Additionally, Poudevigne and O'Connor (2006:27) state that a combination of biological, psychological, social and environmental factors interacts to contribute to changes in physical activity during pregnancy.

Physical activity in the postpartum period is usually decreased, because of the added fatigue of delivery and newborn-care (Davies *et al.*, 2003:333). However, less is known about physical activity during the postpartum period and in the change in activity from pregnancy to postpartum (Borodulin *et al.*, 2009:32). According to Pereira *et al.* (2007:315) walking as a physical activity modality might remain unchanged from pre-pregnancy to postpartum. Usually care-giving physical activity in the postpartum period constitutes the largest proportion of total physical activity (Borodulin *et al.*, 2009:38).

In summary, a reduction of physical activity during pregnancy augments the need to promote regular physical activity of pregnant women as a necessary part of their lifestyle due to the minimal risk and numerous short- and long-term benefits for both the mother and the baby. Education about the benefits of regular, physical activity during pregnancy must be included in the planning and implementation of health promotion programmes by medical personnel and physical education staff (Szumilewicz *et al.*, 2013:387).

2.4.3. Benefits of regular physical activity during pregnancy

Physical activity is a major determinant of life-long health (Aaron *et al.*, 2005:36; Wahlqvist, 2005:62) and has been associated with reduced morbidity and mortality (Helmrich *et al.*, 1991:147; Kushi *et al.*, 1989:1292; Sandvik *et al.*, 1993:537) by serving as a primary preventive behaviour for several chronic health conditions including coronary heart disease (Hu *et al.*, 2005:804; Lee *et al.*, 1999:379; Paisley *et al.*, 2003:325), cancer (Paisley *et al.*, 2003:325), type-2 diabetes (Burchfiel *et al.*, 1995:360; Sigal *et al.*, 2006:1433), stroke (Ellekjær *et al.*, 2000:16), metabolic syndrome (Laaksonen *et al.*, 2003:2162) and osteoporosis (Warburton *et al.*, 2006:801).

Maternal benefits of physical activity appear to be both physical and psychological in nature (RCOG, 2006:2). Physical benefits during pregnancy include shorter labour and a lower incidence of operative abdominal and vaginal deliveries and acute foetal distress (Clapp, 1990:1779; Melzer *et al.*, 2010a:494; Paisley *et al.*, 2003:325; Sternfeld, 1997:33; Wolfe *et al.*, 1989:273). Benefits for pregnant women also include improved cardiovascular function (Melzer *et al.*, 2010a:494), reduced incidence of muscle cramps and lower limb oedema (Arena & Maffulli, 2002:14; Wallace *et al.*, 1986:225), and attenuation of gestational diabetes mellitus (Bung *et al.*, 1991:182; Bung & Artal, 1996:328) and gestational hypertension (Artal & O'Toole, 2003:479).

Physical activity does not only have physical benefits, but also improves psychological health and provides well-being benefits (Borg-Stein *et al.*, 2005:180; Da Costa *et al.*, 2003:111; Hutchinson, 2011:17). An increased level of physical activity is known to have a protective effect against insomnia, stress, anxiety and depression (Adams *et al.*, 2007:71; Clapp *et al.*, 1992:S294; Kritz-Silverstein *et al.*, 2001:602; Strawbridge *et al.*, 2002:332), relieve job strain (Yang *et al.*, 2010:374) and provide mood stability (Poudevigne & O'Conner, 2006:19; Poudevigne & O'Conner, 2005:1374) as well as increased perceived levels of energy during the day (Mottola, 2002:362). These benefits carry over to the postpartum period (Mottola, 2002:362) and does not compromise infant breast milk acceptance of infant growth (Carey & Quinn, 2001:44).

Kalisiak and Spitznagle, (2009:265) reviewed clinically-controlled trials that demonstrate that there is a moderate amount of evidence proving that exercise during pregnancy in healthy females has positive effects on both the mother and the foetus. While many studies conclude a positive relationship between physical activity and pregnancy outcome, determining physical activity remains difficult. Therefore, accurate and objective methods to measure levels of physical activity are important when defining an appropriate relationship between physical activity and health (Spierer *et al.*, 2011:659).

2.4.4. Risks associated with physical activity during pregnancy

Physical activity was discouraged until the early 20th century on the basis of theoretical concerns about exercise-induced injury and adverse foetal and maternal outcomes (Clapp *et al.*, 1992:S294; Mittlemark *et al.*, 1991:203). These concerns were based on the potentially

detrimental effects of exercising on the mother and the foetus, secondary to increases in maternal body temperature, circulating stress hormones, caloric expenditure, decreased blood flow and biomechanical stress (Clapp, 2000:273; Shangold, 1989:1676) as seen in Figure 2.3.

Biological mechanisms that might contribute to reduced birth weight and length of gestation were theorised by Luke and Papiernik (1997:127). They suggest that these effects are mediated by the sympathetic nervous system and may also be associated with the release of prostaglandins into the maternal circulation. Physical strain may lead to the release of catecholamines, which may increase maternal blood pressure and uterine contractility and decrease placental function (Mozurkewich *et al.*, 2000:632).

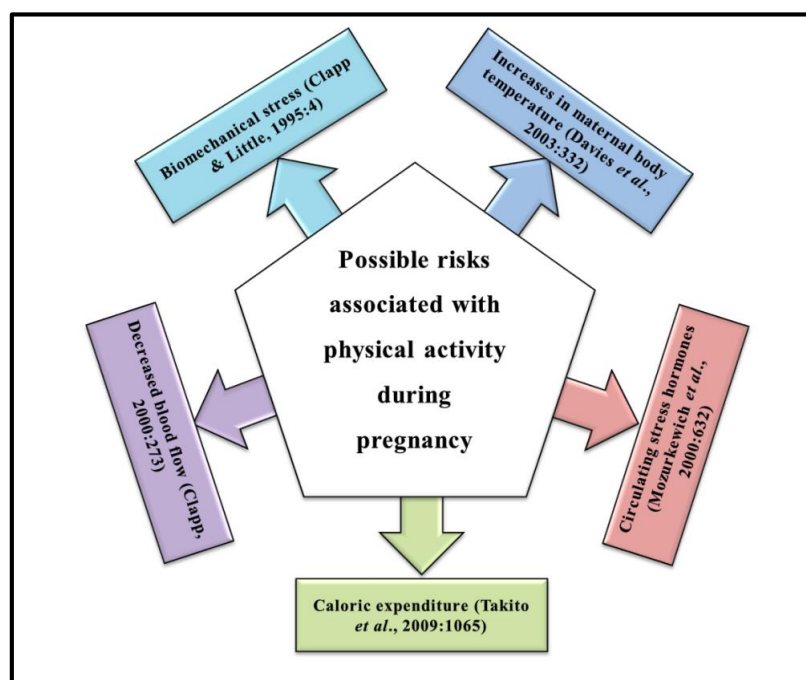


Figure 2.3: Possible risks associated with physical activity during pregnancy

Another concern of physical training while pregnant is the subsequent teratogenic effect of hyperthermia in the first trimester (Barsky *et al.*, 2012:70; Edwards, 1986:563; Milunsky *et al.*, 1992:884). However, this has not been shown to occur in studies of exercising women (Davies *et al.*, 2003:332), because an increase in minute ventilation and skin blood flow augment heat dissipation and somewhat inhibit the potential hyperthermic effects of exercise (Stevenson, 1997:109). Even so, exercising while pregnant should preferably take place in a well-ventilated and temperature-controlled environment (Barsky *et al.*, 2012:70).

The theoretical risk of foetal hypoxia is another concern for the exercising pregnant woman. It was once believed that the demands of exercising muscles divert blood flow from the

uteroplacental unit (RCOG, 2006:2). However, compensatory changes with exercise, such as raised maternal haematocrit and oxygen extraction, appear to prevent the impairment of foetal oxygenation (Sternfeld, 1997:33; Takito *et al.*, 2009:1065). Takito *et al.* (2009:1060) found that maintaining specific standing postures for a prolonged period could potentially reduce uteroplacental blood flow and lead to decreased foetal growth. Decreased visceral blood flow is suggested to cause potential adverse outcomes, such as congenital malformation, growth retardation, premature labour, brain damage, difficult labours, haemorrhage and maternal musculoskeletal injury (Clapp, 2000:273).

Takito *et al.*, (2009:1065) identified energy expenditure to potentially be associated with low birth weight, preterm birth and intrauterine growth restriction under the supposition that higher caloric expenditures could withhold energy from the foetus. The risk of maternal musculoskeletal injury due to changes in posture and centre of gravity or fetoplacental injury caused by blunt trauma or stress effects from sudden motions is also a concern (Clapp & Little, 1995:4).

Recommendations of physical activity during pregnancy before the 20th century were overly conservative (Clapp, 1989:1453; Clapp *et al.*, 1999:91; Clapp *et al.*, 1998:594; Hall & Kaufmann, 1987:1199; Hatch *et al.*, 1993:1105; Kardel & Kase, 1998:280; Klebanoff *et al.*, 1990:1450; Kulpa *et al.*, 1987:1395; O'Neill, 1996:32; Sternfeld *et al.*, 1995:634). Recently, the guidelines evolved as more reliable research emerged (Kawaguchi & Pickering, 2010:39). The American College of Obstetricians and Gynaecologists found no scientific support that normal pregnant women should limit their exposure to physical activity based on the risks to the foetus and/or mother. However, some studies found that higher daily physical activity is inversely associated with foetal growth (Magann *et al.*, 2002:470) and birth weight (Rao *et al.*, 2003:539).

Campbell and Mottola (2001:405) found that excessive physical exercise, at a frequency greater than five days a week, resulted in a low birth weight. However, their results also showed an equally harmful effect on foetal growth in the group of women who exercised less than two times per week. Magann *et al.* (1996:187) supported the abovementioned results and found that less energy expenditure, at work and during leisure-time, was associated with an increased risk of preterm birth and low birth weight (< 10th and < 3rd percentile).

The risk-benefit balance of physical activity during pregnancy needs to be assessed. During pregnancy, the risk of a sedentary lifestyle may be more detrimental than an active one (Barsky *et al.*, 2012:70), since a sedentary lifestyle includes loss of muscular and cardiovascular fitness, excessive weight gain, raised risk of gestational diabetes or pre-eclampsia, development of varicose veins and an increased risk of physical complaints such as dyspnoea, lower back pain and poor psychological adjustment (Bung *et al.*, 1991:182; Sørensen *et al.*, 2003:1273; Wolfe & Mottola, 2000:205). According to Takito *et al.* (2009:1059), both excessive and insufficient physical activity impact negatively on pregnancy outcomes. Physical activity, done at an appropriate level for the physical condition of the woman, is beneficial to foetal growth, with the extremes being inactivity/sedentarism and a prolonged duration of vigorous intensities, which are potentially harmful to the supply of oxygen for adequate foetal growth (Takito *et al.*, 2009:1066). However, women with complicated pregnancies have been discouraged from participating in exercise activities for fear of impacting the underlying disorder or maternal or foetal outcomes (Davies *et al.*, 2003:330). Some publications indicate that high levels of strenuous, high-intensity activity may result in pre-term labour in susceptible individuals as well as babies with a low birth weight (Bell, 2002:35; Derbyshire *et al.*, 2008:20; Riemann & Kanstrup Hansen, 2000:14-15).

Absolute contra-indications to exercise in pregnancy include hemodynamically significant heart disease, restrictive lung disease, incompetent lung disease, multiple gestation at risk for premature labour ($\geq$ triplets), persistent second- or third-trimester bleeding, placenta praevia after 25 weeks' gestation, ruptured membranes, preterm labour, pre-eclampsia, uncontrolled type-1 diabetes and thyroid disease or other serious systemic disorders like chronic bronchitis and uncontrolled seizures (Davies *et al.*, 2003:334). Relative contra-indications to exercise include anaemia (defined by the World Health Organization as < 19 g/dL in pregnant women), unevaluated maternal cardiac arrhythmia, extreme morbid obesity, extreme underweight (BMI <12), intra-uterine growth restriction in current pregnancy, poorly controlled hypertension and orthopaedic limitations, such as degenerative joint disease and joint instabilities (Davies *et al.*, 2003:334).

However, pregnant women should be advised that adverse pregnancy or neonatal outcomes are not increased for exercising pregnant women (Artal, 1992:363; Barsky *et al.*, 2012:69; Bell & O'Neill, 1994:85; Dewey & McCrory, 1994:4446S; Jarski & Tripett, 1990:185; Lokey *et al.*, 1991:1234; Schick-Boschetto & Rose, 1991:10; Snyder, 1990:50) and maternal and infant health

can even be enhanced (Artal, 1992:363; Clapp, 1991:9; Clapp *et al.*, 1992:S294; Hutch & Erkkola, 1990:208; McMurray *et al.*, 1993:1305; Revelli, 1992:355; Warren, 1991:131). Table 2.1 provides evidence regarding the effects of physical activity on foetal growth and birth outcomes.

2.2.2. Guidelines for physical activity during pregnancy

The American College of Obstetricians and Gynecologists (ACOG, 2002:79) recommend that healthy pregnant women exercise at moderate intensity for at least 30 minutes, most days of the week (Artal & O'Toole, 2003:9), while the American College of Sports Medicine (ACSM, 2014:194) encourages an accumulation of 30 minutes or more of moderate physical activity per day on most, if not all, days of the week. Yet, another recommendation set forth by the US Department of Health and Human Service states in the document: “2008 Physical Activity Guidelines for Americans” that pregnant women should engage in a minimum of 150 minutes of moderate-intensity aerobic activity a week, even if they were not physically active prior to pregnancy (US Department of Health and Human Services, 2008:viii). Recommendations in Australia (Sports Medicine Australia, 2009:4), Canada (Davies *et al.*, 2003:335), the United Kingdom (RCOG, 2006:2) and Norway (Holan *et al.*, 2005:15) are similar to the abovementioned American Guidelines (Szumilewicz *et al.*, 2013:380). A recent South African Position Statement (Barsky *et al.*, 2012:69) supports the guidelines set out by the American College of Obstetricians and Gynecologists (ACOG, 2002:80), the Society of Obstetricians and Gynaecologists of Canada (SOGC) and the Canadian Society of Exercise Physiology (Davies *et al.*, 2003:335), but focuses on exercise and does not give guidelines regarding general physical activity during pregnancy.

The question remains whether pregnant women adhere to these guidelines. Due to the uncertainty regarding the benefits and risks of exercise during pregnancy (Price *et al.*, 2012:2263), the adherence of pregnant women to exercise is not reflective of the recommended ACOG guidelines (Evenson *et al.*, 2004:404, Macera *et al.*, 2001:A17, Rousham *et al.*, 2006:396). Additionally, pregnant women often receive mixed messages from friends, family, and even their doctors about exercise during pregnancy (Price *et al.*, 2012:2268). While scientific data supports the safety of exercise during pregnancy, this knowledge is not always inferred to pregnant women. According to Price *et al.* (2012:2268) exercise must be prescribed to pregnant women in a similar way as the prescription of medicine. In addition, more reliable

quantitative-determined data is warranted to provide an evidence-based exercise regimen for pregnant women (Price *et al.*, 2012:2263).

2.5. Birth outcomes

2.5.1. Foetal growth parameters and confounders thereof

Monitoring the growth of the foetus is a major purpose of antenatal care (Hall *et al.*, 1980:78). The overall term “foetal growth parameters include”: head- and abdominal circumference, femur length, ponderal index (weight in grams x100 divided by length in cubic centimetres), placental weight and expected birth weight (Juhl *et al.*, 2010:1e2). While birth weight is a crude measurement of foetal growth, the measurement of head size and length at birth gives an insight into the timing of growth retardation during intrauterine life (Barker *et al.*, 1993:423).

2.5.2. Birth weight

Although birth weight is not the most objective measurement of foetal growth, it is important with regards to public health (Chasan-Taber *et al.*, 2007:87). Birth weight is an amalgam of multiple determinants and is a proxy for the many different processes that occur in the months preceding delivery (Oken & Gillman, 2003:501). Birth weight is associated with a broad range of short and long-term maternal complications (e.g. pre-eclampsia, premature labour), foetal complications (e.g. stillbirth, malformations), neonatal complications (e.g. respiratory distress, infant mortality) and long-term complications (e.g. behavioural disorders, cerebral palsy) (Martin *et al.*, 2005:1; Massett *et al.*, 2003:125).

Foetuses delivered with a lower birth weight than expected might become healthy, thriving infants, while others are small, because their growth in utero was impaired and have an increased risk for perinatal morbidity and mortality (Gardosi *et al.*, 1998:529; Lobos *et al.*, 2005:331). Cut-off for small-for-gestational-age is a birth weight below the 10th percentile (Breeze & Lees, 2007:383-384). Low birth weight and foetal growth impairment may be multi-factorial in origin, therefore it is vital to have knowledge of possible associations between specific risk factors, pre- and postnatal growth patterns and specific adult health parameters like smoking and physical activity habits (Vielwerth *et al.*, 2007:492).

Table 2.1: Mapping the evidence: Physical activity and foetal growth (Randomised Controlled Trials)

Author	Year	Title	Study Design	Method	Foetal Growth	Outcome
Alderman, B.W., Zhao, H., Holt, V.L., Watts, D.H. & Beresford, A.A.	1998	Maternal Physical Activity in Pregnancy and Infant Size for Gestational Age	Control: Women recruited for an epidemiological investigation of risk factors for craniosynostosis. Experimental: Mothers were identified by random sampling of Colorado live births records for 1979 to 1988 matched to birth defect registry cases on month and year of birth.	By means of interviews that comprised an adaptation of the CARDIA PAH, which classifies activities into 13 groups based on intensity.	Birth weight was abstracted from birth records. Gestational age was reviewed from medical records of the neonatal exam, interview data from the mother, and birth records.	Maternal physical activity decreased the risk of large for gestational age infants.
Bell, R. & Palma, S.	2000	Antenatal exercise and birth weight	Experimental: Continued strenuous exercise ≥ 5 times per week from 24 weeks Control: Strenuous exercise reduced to ≤ 3 times per week from 24 weeks	Exercise diaries, provided details of the baby, labour and delivery.	Birth weight and birth rate.	Increased mean birth weight.
Clapp, J.F., Kim, H., Burciu, B. & Lopez, B.	2000	Beginning regular exercise in early pregnancy: effect on fetoplacental growth	Experimental: 20 minutes of aerobic exercise, 3-4 times per week, beginning at 8-9 weeks and continuing until delivery Control: No aerobic exercise	Respiratory calorimetry.	Gestational weight gain, mid-trimester placental growth rate, placental volume, birth weight, length, ponderal index, head circumference, preterm birth, infant lean mass, fat mass, % fat.	Significant, balanced increase in fetoplacental growth in normal pregnancy.
Clapp, J.F., Kim, H., Burciu, B., Schmidt, S. Petry, K. & Lopez, B.	2002	Continuing regular exercise during pregnancy: effect of exercise volume on fetoplacental growth.	Experimental: 60 minutes weight-bearing exercise, 5 days per week from 8 – 20 weeks, then reduced to 20 minutes, 5 times per week from 24 weeks to delivery ('Hi-Lo' group) opposite pattern ('Lo-Hi' group) Control: Intermediate intensity, constant pattern (40 minutes, 5 days per week, from 8 weeks to delivery).	Respiratory calorimetry.	Placental growth rate, birth weight and placental volume at term.	Reduced fetoplacental growth. Proportionally greater increase in fat mass than in lean body mass.
Haakstad, L.A.H. & Bø, K.	2011	Exercise in pregnant women and birth weight: a randomized controlled trial	Experimental group: Nulliparous pregnant women (N = 52) were encouraged to participate in supervised aerobic dance and strength training for 60 minutes, twice per week for a minimum of 12 weeks, with an additional 30 minutes of self-imposed physical activity on the non-supervised week-days. Control group: (N = 53) Was neither encouraged to, nor discouraged from, exercising.	Questionnaire measured physical activity and sedentary behaviour.	Labour and delivery records (infant birth weight, length, head circumference, gestational age at time of delivery and Apgar scores at 1 and 5 min after birth).	Aerobic-dance exercise appeared to be safe and was not associated with any reduction in newborn birth weight, preterm birth rate or neonatal well-being.
Marquez-Sterling, S., Perry, A.C., Kaplan, T.A., Halberstein, R.A. & Signorile, J.F.	2000	Physical and psychological changes with vigorous exercise in sedentary primigravidae.	Experimental: 1 hour aerobic exercise, 3 times per week, for 15 weeks Control: No aerobic exercise during pregnancy	Questionnaires.	Physical fitness, gestational weight gain, birth weight, 5-minute Apgar score, caesarean section and body image.	Low birth weight in experimental group.
Prevedel, T., Calderon, I., Abadde, J. Borges, V. Rudge, M.	2003	Maternal and perinatal effects of hydrotherapy in pregnancy	Experimental: Aerobic (swimming exercise for 1 hour, 3 times per week, for 10 weeks. Control: normal activity without aerobic exercise.	Maximal oxygen consumption, stroke volume and cardiac output.	Physical fitness, no data reported on pregnancy outcomes. Foetal heart rate before and after exercise (acute exercise effect) not included in review.	Hydrotherapy adequately assisted metabolic and cardiovascular maternal adaptation to pregnancy and did not cause prematurity or weight loss in newborns.

Over the last decade, a new paradigm evolved from the notion that environmental factors in early life and in utero can have profound influences on lifelong health (Oken & Gillman, 2003:496). Reduced foetal growth might also be the origin of cardiovascular disease later in life through programming in foetal life and infancy (Barker *et al.*, 1993:426).

2.5.3. Theory of foetal origins

Time in the womb can be seen as a critical window during which maturation must be achieved, because failure of maturation is to some extent irrecoverable (Barker *et al.*, 1993:423). The maternal environment influences these critical stages of early life and leads to long term changes in the body's structure, physiology, or metabolism - this is called programming (Lucas, 1994:288; Lucas, 1991:38). Relationships between foetal experiences and later risk for adult chronic disease, including cardiovascular disease and its risk factors, cancer, osteoporosis, diabetes, neuropsychiatric outcomes and respiratory diseases, have been demonstrated by a large number of studies (Ekbom *et al.*, 1996:340; Innes *et al.*, 2000:1126; Karter *et al.*, 1999:938; Shaheen *et al.*, 1999:401). The abovementioned relationship, the foetal origins hypothesis, was first proposed by the British epidemiologist David Barker as the "thrifty gene hypothesis" (Barker, 1995:171). The foetal origin hypothesis was developed by linking records of births in the early 20th century with health in later life from the Hertfordshire records (Barker, 1995:171; Barker *et al.*, 1993:422; Barker, Winter, *et al.*, 1989:577; Barker, Osmond, *et al.*, 1989:564; Gupta & Gupta, 1996:241; Hales *et al.*, 1991:1019; Law & Shiell, 1996:935; McKeigue *et al.*, 1991:382; Stien *et al.*, 1996:348; Yajnik *et al.*, 1995:330).

The theory of foetal origins suggests that associations with body size at birth underestimate the influence of intrauterine development to later disease. Prevention of coronary heart disease and non-insulin dependent diabetes may be related to the choices of the mother. Therefore, chronic disorders that manifest later in life may be related to: poverty (malnourished mothers give birth to malnourished infants with low birth weight) and prosperity (exposure of an infant with low body weight phenotype to a high caloric diet) (Nair *et al.*, 2009:S49). In this way, both a low and high birth weight is associated with negative outcomes in later life, showing a U-shaped relationship as observed by Rich-Edwards *et al.* (1999:282). Newborns that are small-for-gestational-age tend to preserve body fat at the expense of lean body mass (Hediger *et al.*, 1998:E66), whereas large newborns may also have relatively increased body fat. Hammami *et al.* (2001:821), suggest that associations between foetal growth and later adiposity are complex. The findings that a low and high

birth weight is a strong predictor of diabetes and cardiovascular disease in later life has led to continuing debate about the significance of nature and nurture (Vaessen *et al.*, 2002:1036).

2.5.4. Environmental pollution

Environmental air pollution has been shown to have associations with a low birth weight and its determinants: preterm delivery and intrauterine growth restriction (Bobak, 2000:176; Dejmek *et al.*, 1999:475; Ha *et al.*, 2001:646; Maisonet *et al.*, 2001:351; Ritz & Yu, 1999:22; Ritz *et al.*, 2000:510; Wang *et al.*, 1997:520; Xu *et al.*, 1995:414). Exposure to an air pollutant like carbon monoxide, could lead to decreased oxygen delivery to tissues, including the foetus (Maisonet *et al.*, 2004:107). Inhaling air pollution particles may lead to increased blood viscosity, which may have an adverse effect on placental function, thereby restricting foetal growth (Ha *et al.*, 2001:643). However, the effect of air pollution on foetal growth is smaller than the effect of high risk behaviours (Maisonet *et al.*, 2004:114).

2.5.5. Lifestyle

Tobacco smoking, alcohol consumption and illicit drug abuse are increasing among women of childbearing age (De Santis *et al.*, 2011:106). Intrauterine growth restriction and low birth weight are the most consistent effect of these high risk behaviours (De Santis *et al.*, 2011:106).

Maternal smoking during pregnancy is an extremely important, modifiable risk factor that is associated with adverse perinatal outcomes (Jauniaux & Greenough, 2007:697; Pollack *et al.*, 2000:398; Samper *et al.*, 2012:141), such as intrauterine growth retardation (Figueras *et al.*, 2008:171; Samper *et al.*, 2012:141), low birth weight (Barker *et al.*, 1995:317; Bernstein *et al.*, 2005:986; Källen, 2001:329; Horta *et al.*, 1997:141), preterm and very preterm delivery (Fantuzzi *et al.*, 2007:195), ectopic pregnancy (Dekeyser-Boccara & Milliez, 2005:S119), placental pathologies (Jauniaux & Burton, 2007:700) and a significant higher risk of perinatal and infant mortality (Cnattingius & Lambe, 2002:293; Kyrklund-Blomberg *et al.*, 2001:292; Mitchell & Milerad, 2006:82; Wisborg *et al.*, 2001:322). Specifically, smoking has negative effects on multiple foetal growth parameters including body weight, femur length, limb length, total length, head circumference, chest circumference and abdominal circumference (Andersson & Arner, 2001:1225; Bernstein *et al.*, 2000:863; Cliver *et al.*, 1995:625; Reeves & Bernstein, 2008:721). According to

Hernández-Martínez *et al.* (2012:403) maternal smoking during pregnancy is also related to cognitive, emotional, temperamental and behavioural problems throughout the child's life.

The effects of smoking could be mediated by the direct toxic effect on the foetus, leading to metabolic alterations, as well as by mechanisms resulting in decreased oxygen delivery (Samper *et al.*, 2012:141). Cigarette smoke contains more than 2500 chemicals and some of these are harmful to the developing foetus and cause adverse pregnancy outcomes (Bruchova *et al.*, 2010:186; Zhang & Ratcliffe, 1993:209). Carbon monoxide readily crosses the placental barrier by passive diffusion, causing a 4-fold increase in the level of carboxyhemoglobin in umbilical cord blood, which inhibits the release of oxygen into foetal tissues (Eskenazi *et al.*, 1995:398; Hansen *et al.*, 1992:51; Jauniaux *et al.*, 1999:25; Luck *et al.*, 1985:384). This chronic hypoxia alters the physiological development of organs and tissues (Bruchova *et al.* 2010:187; Lichtensteiger *et al.*, 1988:137). Therefore, cigarette smoking during pregnancy is a strong dose-dependent risk factor for smallness-for-gestational age (Rasmussen & Irgens, 2006:6; Windham *et al.*, 2000:430). Second-hand smoke showed a similar relationship according to Horta *et al.* (1997:148).

Cigarette smoking may confound the relationship between birth weight and later body size (Oken & Gillman, 2003:497). Multiple studies have demonstrated a clear inverse relationship between maternal smoking and childhood weight (Morley *et al.*, 1995:123; Williams & Poulton, 1999:900), although Power & Jefferis (2002:418) suggest an increased risk of obesity later in life among offspring of mothers who smoked during pregnancy. Samper *et al.* (2012:145) analysed body composition and found that lean body mass was more affected than body fat and proportional body distribution of subcutaneous fat was not affected in infants from mothers who smoked while pregnant.

Alcohol consumption during pregnancy has been associated with various pregnancy complications such as miscarriage (Maconochie *et al.*, 2007:171), stillbirth (Burd *et al.*, 2007:371) and other multiple birth defects (Barr *et al.*, 2006:1061; Lazzaroni *et al.*, 1993:605; Little & Wendt, 1991:1887; O'Leary *et al.*, 2009:398; Warren & Foundin, 2001:158) such as foetal alcohol syndrome (Chiriboga, 2003:268; Sokol *et al.*, 2003:2996) and an increased risk of low birth weight (Henderson, Gray, *et al.*, 2007:247; Henderson, Kesmodel, *et al.*, 2007:1069).

Drug abuse during pregnancy may lead to complications for the foetus, the newborn, and later during childhood (De Santis *et al.*, 2011:106). Cannabis, cocaine and heroin specifically have been studied in relation to their effects on foetal growth (De Santis *et al.*, 2011:107; Hayatbakhsh *et al.*, 2010:182)

and findings have proposed that cannabis abuse during pregnancy decreases foetal growth, but this has not been confirmed in follow-up studies (Hatch & Bracken, 1986:986; Fried *et al.*, 1984:23; Hingson *et al.*, 1982:545; Zuckerman *et al.*, 1989:762). Poor pregnancy outcomes, including premature birth and abnormalities of behavioural testing in the offspring have been associated with cocaine use during pregnancy (De Santis *et al.*, 2011:106). Associations with heroin use during pregnancy and an increased incidence of pregnancy complications, including premature delivery, premature rupture of the membranes, intrauterine foetal growth retardation and perinatal mortality have also been confirmed (De Santis *et al.*, 2011:107).

Another confounder between birth weight and later adiposity may be social and economic factors (Oken & Gillman, 2003:497). Vagero *et al.* (1999:452) found that babies born to women with a lower social status had lower birth weights. As such, neighbourhood factors that have been associated with an increased risk for a low birth weight include a negative perception of the neighbourhood (Collins *et al.*, 1998:289), an average income (Fang *et al.*, 1999:1; O'Campo *et al.*, 1997:1115), economic hardship, low housing costs (Roberts, 1997:599) and interestingly neighbourhood crime rates (Collins & David, 1997:184). How these factors relate to birth weight remains speculation, but there have been explanations that focus on the stress-related, hormonal factors and birth outcomes through biological mechanisms (Copper *et al.*, 1996:1290; Hickey *et al.*, 1995:417; Hoffman & Hatch, 1996:380; Sandman *et al.*, 1997:273; Wadhwa *et al.*, 1996:442), whereas others researched the association with maternal health behaviours, such as smoking (LeClere & Wilson, 1997:7-8; Wakefield *et al.*, 1993:1428; Walsh, 1994:1059). Although environmental factors play an important role in determining foetal growth, genetics must also be considered.

2.5.6. Genetics

Both genetic and environmental factors are important determinants of foetal growth (Hattersley & Tooke, 1999:1789; Knight *et al.*, 2005:824; Vaessen *et al.*, 2002:1036). As stated by Tower and Baker (2006:99) the growth potential of any foetus is likely to be genetically-determined. As an example, Knight *et al.* (2005:830) found that paternal height is an important, independent determinant of foetal linear growth. Knight *et al.* (2005:24) concludes that skeletal size is regulated by genetic information, while the adiposity of the newborn is reflected by the maternal intrauterine environment. Another example is that offspring birth weight has a strong association with parental adiposity (Guillaume *et al.*, 1995:S5 & Okun *et al.*, 1997:285). Therefore, the associations with

maternal and paternal birth weight with offspring birth weight suggest genetic or intergenerational environmental influences (Magnus *et al.*, 2001:876; Oken & Gillman, 2003:497; Skjaerven *et al.*, 1997:1378).

Foetal growth restriction is a complex trait for which no single susceptibility gene can be identified (Tower & Baker, 2006:99). There are between 100 and 200 imprinted genes and there is increasing evidence that many are involved in pre- and post-natal growth (Preece & Moore, 2000:274). When the normal imprint is disrupted, malformations in the development of the foetus occur (Preece & Moore, 2000:274). Vaessen *et al.* (2002:1036) postulate that the Insulin-Growth-Factor-I (IGF-I) gene imprint disruption may lead to low circulating IGF-I concentrations, reduced height in adulthood, diminished insulin secreting capacity, and a high risk of type-2 diabetes and myocardial infarction. Although genetically established expression of IGF-I and insulin are important determinants of growth during the foetal period, they do not play a major role in the regulation of bodyweight in postnatal life (Vaessen *et al.*, 2002:1037). Additionally, the postnatal environment that includes adverse eating and activity habits shared by family members may also lead to a higher birth weight and higher adiposity later in life. Other genetic and environmental factors such as diet and physical activity have more relevant effects on the regulation of weight (Vaessen *et al.*, 2002:1037).

2.5.7. Labour

Natural birth seems to be the best conclusion of the pregnancy for both the mother and the baby (Odent, 2001:S40) and should therefore be seen as a major goal for all pregnant women (Szumilewicz *et al.*, 2013:380). Other methods of childbirth, including a caesarean section, should only be used when justified by the circumstances (Szumilewicz *et al.*, 2013:380). From a public health perspective there is concern regarding the increased rate of caesarean sections during the last decade, because this procedure is not risk-free (Bovbjerg & Siega-Riz, 2009:200). One possible explanation for this recent rise in caesarean sections includes a rise in maternal obesity (Chu *et al.*, 2008:1450). However, this rise cannot be attributed entirely to a worsening of maternal or foetal risk factors (Bailit *et al.*, 2004:803; Declercq *et al.*, 2006:870; Kabir *et al.*, 2004:16). Therefore, caesarean sections may be not justified medically, exposing women and babies to surgical risks without proved benefit (Baicker *et al.*, 2006:w364; Shearer, 1993:1223). Reducing rates of caesarean sections should be a public health priority (Bovbjerg & Siega-Riz, 2009:201).

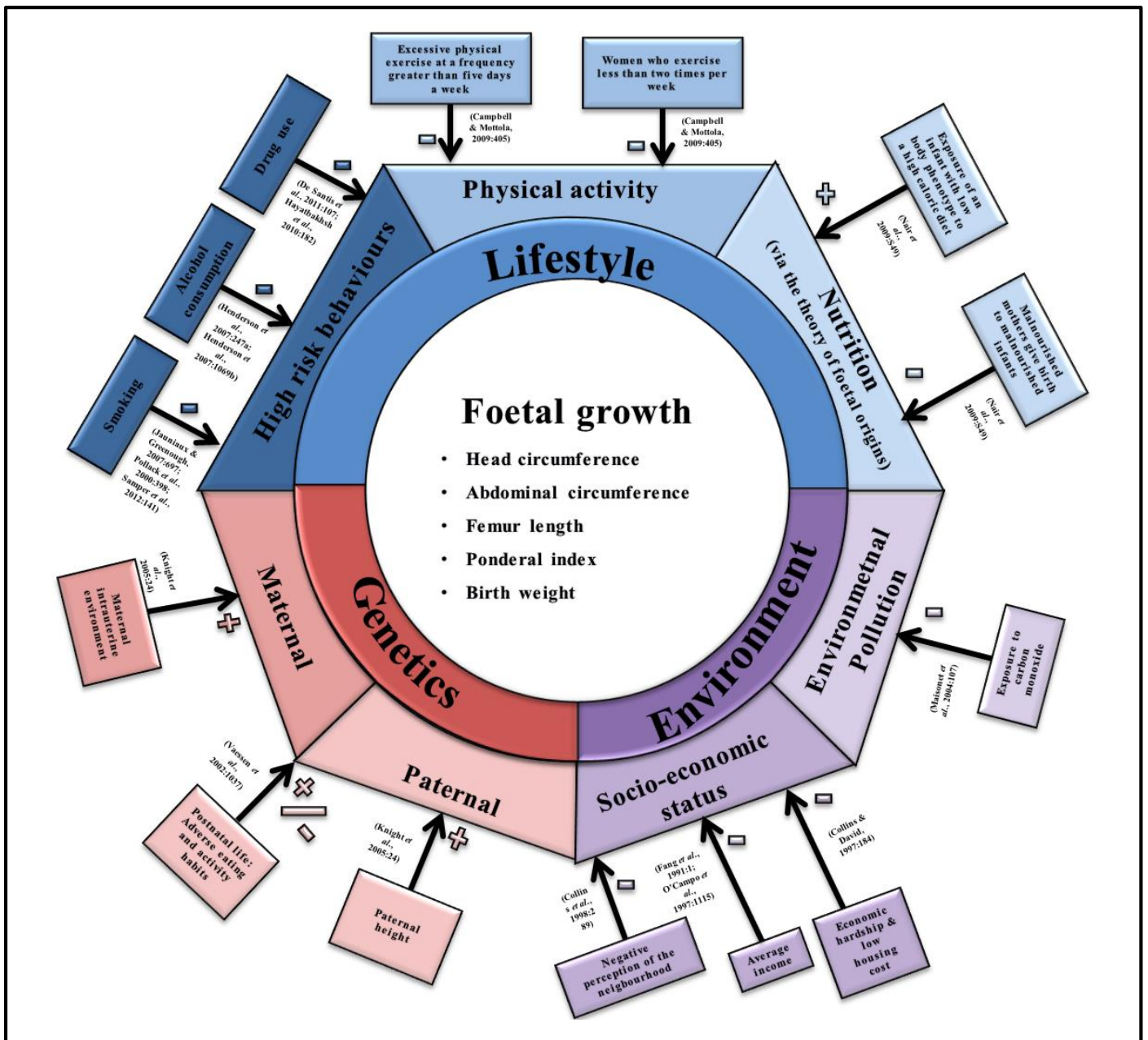


Figure 2.4: Multifactorial influences on foetal growth

In recent years, prenatal physical activity has increasingly been recommended to promote natural birth (Bungum *et al.*, 2000:258; Clapp, 1990:1799; Hall & Kaufmann, 1987:1199; Melzer *et al.*, 2010b:266e4; Szumilewicz *et al.*, 2013:380). Regular physical activity during pregnancy may have other beneficial effects on multiple aspects of the course and outcome of labour and delivery (Szumilewicz *et al.*, 2013:387) including a shorter delivery (Beckmann & Beckmann, 1990:704; Clapp, 1990:1799; Valgesoo & Linkberg 1997:101; Ghodsi *et al.*, 2012:444; Wong & McKenzie, 1987:441), less frequent need for anaesthesia (Clapp, 1990:1799; Baciuk *et al.*, 2008:20), a lower rate of induction of labour (Beckmann & Beckmann, 1990:704; Clapp, 1990:1799), amniotomy

(Clapp, 1990:1799), episiotomy and perineum lacerations (Clapp, 1990:1799; Valgesoo & Linkberg 1997:101; Salvesen & Mørkved, 2004:379) and improved neonatal outcome directly after birth (Clapp, 1990:1799). Based on these findings, it is clear that physical activity during pregnancy has physiological benefits on labour. However, as stated by Guskowska (2011:114) pregnant women often experience fear about labour and delivery, which is undoubtedly detrimental. Physical activity might produce anti-anxiety effects that will help to reduce labour anxiety (Guskowska, 2011:114).

To conclude, Ghodsi *et al.* (2012:441-442) state that physical activity can result in shorter labour, fewer medical interventions, less exhaustion during labour and might also reduce the fear associated with giving birth. Encouraging pregnant women to be physically active could represent a low-cost, low-risk approach to reduce the number of caesarean deliveries (Bovbjerg & Siega-Riz, 2009:201).

2.5.8. Body composition of the baby and in later life

Early environmental influences, as early as in the womb, have long term effects on body composition and musculoskeletal development as evidenced by the prevalence of obesity, sarcopenia and osteoporosis in later life (Sayer & Cooper, 2005:741). This phenomenon is explained by means of foetal programming as previously mentioned, and more specifically, to the body composition of the baby, referred to as developmental plasticity (Sayer & Cooper, 2005:735). Developmental plasticity is defined as the ability of a single genotype to produce more than one alternative form of structure, physiological state or behaviour in response to early environmental conditions (Sayer & Cooper, 2005:735).

During embryonic life, bone and muscle develop from the mesoderm layer, differentiating into dermatomes containing bone and muscle cell precursors in the first trimester (Sayer & Cooper, 2005:735). Muscle development starts between 6 and 8 weeks of gestation and progresses until about 18 weeks (Barbet *et al.*, 1991:3). Adipose cell formation is determined much later, the critical period varying from 30 weeks of gestation to the first year of postnatal life (Brook, 1972:624). These major phases of the developing of muscle and fat are important, because of the high vulnerability of foetal programming occurring during this period of rapid cell division, the so called ‘critical periods’ (McCance & Widdowson, 1974:7).

A low birth weight has implications in fat, muscle and bone distribution in later life (Sayer & Cooper, 2005:739). An association between low birth weight and increased adult central distribution

of fat exist and has been evident in a couple of studies (Law *et al.*, 1992:184; Rogers, 2003:775; Sayer & Cooper, 2005:739). Reduced muscle mass and strength have also been implicated due to a small size at birth (Sayer & Cooper, 2005:738). These abovementioned effects are mediated by mechanisms that include a direct effect on cell number, altered stem cell function and resetting of regulatory hormonal axis (Sayer & Cooper, 2005:741).

Overall, evidence indicates that a higher birth weight is associated with increased risk of adiposity in childhood and adulthood, as reflected by BMI (Oken & Gillman, 2003:498). According to findings from Silverman *et al.* (1991:121) increased adiposity was apparent at birth and progressively after the age of 4 years, but not at ages 1 to 3 years. Numerous studies have found direct associations between a higher birth weight and a higher adult body mass index (Fall *et al.*, 1995:431; Gale *et al.*, 2001:271; Parsons *et al.*, 2001:1335; Parsons *et al.*, 1999:S30; Rich-Edwards *et al.*, 1999:280; Rich-Edwards *et al.*, 1997:397-398; Sørensen *et al.*, 1997:1137; Williams & Poulton, 1999:900). Specifically, the magnitude ranges from 0.5 to 0.7 kg/m² for each 1-kg increment in birth weight (Loos *et al.*, 2001:1543; Sørensen *et al.*, 1997:1137).

2.5.9. Weight gain

Women often express concern about the weight gain during pregnancy; however it is important to remember that during pregnancy, all women gain weight due to foetal and maternal health. This weight gain also corresponds directly with foetal birth weight, which is a strong precursor of the health and development of the infant (Kramer, 1987:664). However, desirable weight gain also depends on body mass index (BMI) before pregnancy. Siega-Riz *et al.*, (2009:339.e3) recommend gestational weight gain ranges for women on the basis of body mass index as outlined in Table 3. The recommended ranges are derived from the observed weight gains of women delivering full-term, healthy infants without complications (Butte *et al.*, 2004:1078). The total amount of weight gained in normal-term pregnancies varies considerably between women (Löf *et al.*, 2005:678). Studies show that about one third of mothers in the United States gain more or less the recommended weight, however, there is a lack in current research regarding the effects of physical activity on weight gain during pregnancy in the South African context (Brunette *et al.*, 2012:133). One cross-sectional South African study found physically active pregnant women tend to gain less weight than relatively inactive pregnant women (Brunette *et al.*, 2012:140).

Table 2.2: Recommended gestational weight gain ranges for women on the basis of body mass index (Siega-Riz *et al.* 2009:339.e3)

Body mass classification	Body mass index (kg/m ²)	Recommended weight gain range (kg)
Low	< 19.8	12.5 – 18
Normal	19.8 – 26.0	11.5 – 16
Overweight	26.0 – 29.0	7.0 – 11.5
Obese	≥ 29.0	6

Weight gain during pregnancy is an important factor to consider to determine long-term obesity (Rooney & Schauburger, 2002:251) and predict other health risks such as pre-eclampsia and adverse birth outcomes (Cedergren, 2006:269). Women are usually very self-conscious or concerned about weight gain during pregnancy (Devine *et al.*, 2000:568). Brunette *et al.* (2012:141) conclude that leading a moderately active lifestyle during pregnancy can have definite weight-control benefits, therefore women should be advised to be physically active during their pregnancies to reap the benefits and possibly to prevent the development of post-natal obesity. On the other hand, adopting a sedentary lifestyle, a common trend among pregnant women, results in women gaining weight above the recommended weight gain ranges (American Pregnancy Association, 2008).

2.6. Summary

Early environmental influences, as early as in the womb, have long term effects on an individual's health. The maternal environment influences critical stages of early life and leads to long term changes in the body's structure, physiology, and metabolism. A healthy lifestyle during pregnancy, which includes regular physical activity, no smoking and alcohol consumption, is essential. The physical and psychological benefits of regular physical activity during pregnancy are plentiful. Regular physical activity not only provides maternal benefits (decreased gestational weight gain, reduced risk of gestational diabetes and pre-eclampsia) but also foetal benefits (decreased risk for small- or large-for-gestational-age) and improved birth outcomes (lower incidence of operative abdominal and vaginal deliveries and a shorter labour period).

Physical activity tends to decrease as pregnancy progresses despite these known benefits. Although scientific data supports the safety of physical activity during pregnancy, this knowledge is not always inferred to pregnant women. The lack of objective and quantitative research regarding physical

activity and pregnancy might have led to these uncertainties. Determining physical activity during pregnancy remains problematic due to methodological difficulties. However, the ActiHeart® is a valid and reliable tool for the measurement of physical activity. Free-living data, as assessed by the ActiHeart®, is essential to determine behavioural changes in activity patterns during pregnancy. Accurately determining physical activity will minimise possible inaccuracies of subjectively determined habitual activity patterns by means of questionnaires and could provide better insights into the effect of these patterns on foetal growth.

Determining the influence of habitual physical activity on foetal growth is difficult. Multiple determinants influence foetal growth and these factors have thoroughly been researched. One exception is the influence of habitual physical activity on foetal growth, possibly because of a relatively small relationship. Regular physical activities tend to decrease the risk of small- and large-for-gestational-age.

Various institutional and governmental entities have set guidelines specifically for physical activity during pregnancy, but few women follow these guidelines, because of uncertainty of the benefits and risks associated with physical activity during pregnancy. These guidelines are not based on longitudinal studies on pregnant women and might be unnecessarily conservative. Future research needs to be aimed at objectively determining the habitual physical activity patterns during pregnancy, as well as guiding governmental organisations to set specific physical activity guidelines and educating women about these guidelines. In addition, the safety of regular physical activity during pregnancy must also be addressed with doctors and health workers.

CHAPTER 3: METHODS

3.1. Introduction

3.2. Empirical investigation

3.3. Procedure

3.4. Statistical analysis

3.1. Introduction

Literature regarding pregnancy and physical activity provides sufficient empirical evidence of maternal and infant health benefits (Downs *et al.*, 2012:496). However, the complexity of assessing physical activity during pregnancy hampers the determination of the optimal dose of habitual, physical activity for pregnant women (Chasan-Taber *et al.*, 2007:86) and has led to broad guidelines for physical activity during pregnancy. The research objectives of this study are to determine longitudinally the habitual, physical activity patterns of pregnant women during all trimesters of pregnancy, as well as the relationship between habitual physical activity of pregnant women and foetal growth parameters.

Multiple studies make use of questionnaires to determine the physical activity patterns of pregnant women (Chasan-Taber *et al.*, 2011:S231; Cohen *et al.*, 2013:1001; Haakstad *et al.*, 2012:2; Hegaard *et al.*, 2011:806; Marshall, Bland, *et al.*, 2013:363; Marshall, Bridget, *et al.*, 2013:50; Power *et al.*, 2013:A1133). The most frequently used questionnaires in these studies include The Pregnancy Physical Activity Questionnaire (PPAQ) and the more general questionnaire for all ages, races and gender: the International Physical Activity Questionnaire (IPAQ). Another validated, twelve-page questionnaire for pregnant women is the Physical Activity Pregnancy Questionnaire (PAOQ) used in the study of Power *et al.* (2013:A1133).

Critical appraisal of the influence of habitual, physical activity on foetal growth can only be done by means of a valid and reliable measurement of physical activity (Chasan-Taber *et al.*, 2007:87). Free-living data is assessed by the Actiheart® and is essential when determining behavioural changes in activity patterns during pregnancy (Melzer *et al.*, 2009:1189). This free-living data is used in the

study, specifically to determine the first objective: to determine, objectively, the habitual, physical activity patterns of pregnant women during all trimesters of pregnancy.

The second objective of the study is to determine the relationship between habitual, physical activity and foetal growth. Foetal growth parameters are represented by the head circumference, abdominal circumference, femur length, biparietal diameter and ponderal index of the new-born. These measurements are obtained via ultrasounds measured by the consulting gynaecologists of the participants. Birth outcomes, extracted from medical records, are also used and include date of birth, birth-weight, birth-length, abdominal circumference and mode of delivery.

3.2. Empirical investigation

3.2.1. Research design

The purpose of the study is to determine the longitudinal patterns of physical activity across pregnancy. A longitudinal observational cohort study was performed. According to Ployhart & Vandenberg (2010:97), longitudinal research emphasises the study of change and contains a minimum of three repeated observations on at least one of the substantive constructs of interest. Women in their first trimester of pregnancy were observed during their entire pregnancy until three months postpartum and measurements were taken at four stages/measurement points. These stages were: pre-pregnancy, first trimester (9-12 weeks), second trimester (20-22 weeks), third trimester (28-32 weeks) and three months postpartum. Figure 3.1 illustrates the progress of the study and the measurement times. These measurements were aligned with the recommended sonar measurements that are performed during routine-visits to the gynaecologist. The measurements that were done at the clinic coincided with the compulsory visits the pregnant participants had at the Promosa-Clinic to monitor their pregnancy.

3.2.2. Participants

The study recruited 60 pregnant women by means of advertisements placed in the local press and the consulting rooms of local gynaecologists, as well as at a local health clinic in Potchefstroom, North West Province, South Africa.

The following criteria were used for inclusion:

- Healthy, pregnant women from any ethnic background.
- Over 18 years of age, but younger than 40 years.
- First trimester of pregnancy (< 12 weeks of gestation).

Participants were excluded from the study if they met any of the following criteria:

- Mentally impaired or physical limitations.
- Orthopaedic limitations to perform the tests.

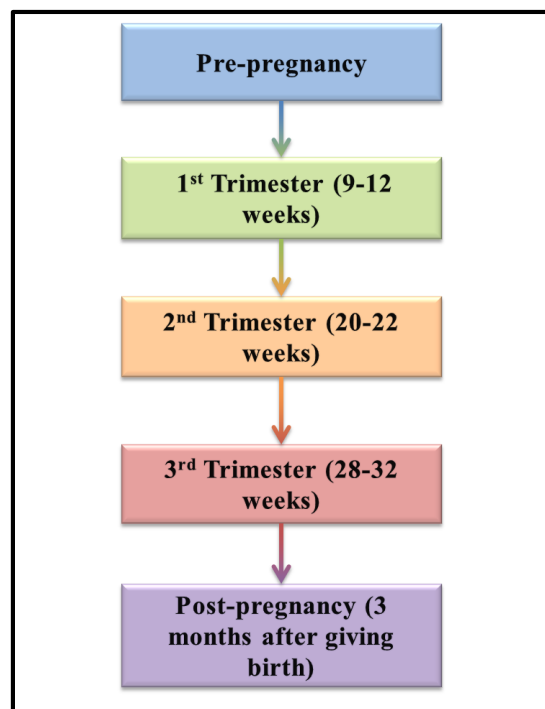


Figure 3.1: Course of the study and measurement times

3.2.3. Ethical issues

Participants indicating interest in the study were asked to give their informed consent to participate in the study by completing a consent form (see Appendix A). Consent to access their medical records with regards to the foetal growth parameters and birth outcomes were also obtained in order to follow the foetal growth during pregnancy longitudinally in relation to habitual, physical activity.

Ethical approval was obtained from the Ethics Committee of the North-West University (NWU-00044-10-A1).

Ethical issues that arose during the study included language differences, where some participants' home language was neither Afrikaans nor English, the languages the researcher speaks. This issue was mainly confronted in the local health clinic in Potchefstroom, where the test subjects' home language varied between Tswana, Sotho and Setswana. In these cases a translator (appointed in the clinic) translated the questions of the researcher to the participants. Another issue that arose was that some of the pregnant women felt uncomfortable to be measured by a man and would have preferred to be measured by a woman.

3.2.4. Materials and methods

For the determination of the first objective of the study, the dependent variable: habitual physical activity was measured by means of the ActiHeart®. More specifically, active energy expenditure during all three trimesters was measured (the independent variable). The second objective of the study, determining the influence of physical activity (dependent variable) on foetal growth (independent variable) was assessed by means of head circumference (cm), abdominal circumference (cm), femur length (cm), biparietal diameter and birth weight (kg). Possible confounders for foetal growth include high risk behaviours (smoking, alcohol usage and drug abuse), pre-pregnancy weight of the mother (kg), socio-economic status and energy intake of the mother (kJ). These confounders will be assessed by the questionnaire that was specifically developed for this study (Appendix B).

3.2.4.1. Demographic information

During the first measurement, a demographic questionnaire was administered to obtain information with regards to the participants' age, home language, ethnicity, marital status, employment status, education level and average household income per annum. This questionnaire was compiled specifically for this study and can be viewed in the Appendix B.

3.2.4.2. Pregnancy-related information

A questionnaire (Appendix B) was administered to collect pregnancy-related data, which includes the following: pre-pregnancy weight (kg), weeks of pregnancy, type of pregnancy (single, twin or

triplets), expected date of birth, number of previous pregnancies and number of live births. The questionnaire also collected data regarding medicine use, smoking habits, alcohol consumption and drug use in the previous three months (yes/no). Risk factors for cardiovascular disease and genetic abnormalities were also determined. A health screen was performed with regards to risk factors for activity during pregnancy and cardiovascular disease as indicated by the American College of Sports Medicine (ACSM, 2014:195).

Medical records yielded information on potential risk factors such as diagnosed gestational diabetes mellitus (yes/no), gestational hypertension (yes/no) and pre-eclampsia (yes/no). At every measurement interval, data was collected on current medicine use (yes/no), smoking (yes/no) and current alcohol consumption (glasses/day).

3.2.4.3. Anthropometric measurements

At all measurement points, anthropometric measurement of height (to the nearest 0.1 cm) by means of a stadiometer, weight (to the nearest 0.1 kg) by means of an electronic scale (Beurer, Germany), waist and hip circumferences (to the nearest 0.1 cm) were measured using the standard procedures according to the standards for anthropometric assessment described by the International Society for the Advancement of Kinanthropometry (Stewart *et al.*, 2011:8-9). Weight and height were used to calculate body mass index, by dividing weight (kg) by height squared (m^2).

3.2.4.4. Blood pressure and resting heart rate

Subjects were requested to lie on their left lateral position in order to measure their resting blood pressure and resting heart rate. This position was used from the first measurement point, as the enlarged uterus often causes supine hypotension in pregnant women lying flat on their backs. Blood pressure, as well as resting heart rate was measured by the Microlife® Semi-Automatic blood pressure monitor (Microlife BP A80, Switzerland). Two measurements were taken 5 minutes apart after a 5-minute resting period and were reported in millimetre mercury (mmHg).

3.2.4.5. Resting metabolic rate

Resting metabolic rate was determined by means of a gas exchange analysis with the Fitmate™ (Cosmed, Italy) as seen in Figure 3.2. Participants were requested to breathe through an anti-bacterial

filter for 16 minutes after a 10 minute resting period. Subjects were requested to remain awake and breathe normally for the duration of the testing period. During this time, the inspired oxygen was quantified to determine resting metabolic rate. The FitMate™ measures ventilation by means of a turbine flow meter and analyses the fraction of oxygen in expired gases through a galvanic fuel cell oxygen sensor (Nieman *et al.*, 2006:2). Standard metabolic formulas are used to calculate oxygen uptake, while energy expenditure (measured in kcal/day) is calculated using a fixed respiratory quotient (RQ) of 0.85 (Nieman *et al.*, 2006:4). The first minute is discarded as it is considered the stabilisation period for breathing. Participants were requested not to perform any exercises during the 24 hours preceding the resting metabolic rate measurement and they were also requested to fast for at least 10 hours prior to the measurement. A calibration of the FitMate™ was done before each participant was subjected to a measurement. Nieman *et al.* (2006:6) conclude that the FitMate™ gives reproducible and accurate oxygen consumption and RMR measurements for a wide range of adults.



Figure 3.2: Cosmed Fitmate™ (Cosmed, Italy)

3.2.4.6. Habitual physical activity measurements

Habitual, physical activity was determined by means of objective assessment. Currently the only reliable and valid instrument is the ActiHeart® device (Figure 3.3). This device combines accelerometry (movement counts) and heart rate response in one device in order to give an objective measurement of activity energy expenditure. The Actiheart® is a waterproof, self-contained logging device that allows physical activity to be measured synchronously with heart rate (Brage *et al.*, 2005:562). The Actiheart® reports simulated heart rate within 1 beat per minute above 30 beats per

minute, which is comparable to heart rate monitors (Brage *et al.*, 2005:567; Boudet & Chamoux, 2000:379). The device is worn on the chest and consists of two electrodes (connected by a short lead) that clip onto two standard electrocardiograph (ECG) pads. The reliability and validity of the product for recording activity, heart rate and energy expenditure has been scientifically validated (Brage *et al.*, 2005:561). Specifically with regards to pregnancy, Melzer *et al.* (2012:e9) conclude that the Actiheart® is a valid method for estimating physical activity in pregnant women.



Figure 3.3: The ActiHeart®

At every measurement interval in the study, habitual physical activity was measured for a seven day period, using the Actiheart®. The following parameters were extracted from the data: Activity Energy Expenditure (AEE), Physical Activity Level (PAL), Diet-Induced Thermogenic energy expenditure (DIT) and Total Energy Expenditure (TEE). Activity-, Diet-Induced Thermogenic- and Total Energy Expenditure are expressed in J/kg/min. Reliable estimates of AEE by means of the Actiheart® were confirmed by Melzer *et al.* (2012:e7) for walking, cycling and stepping, specifically during pregnancy. These activities reflect common activities engaged during pregnancy. PAL is calculated by dividing Total Energy Expenditure (TEE) through Resting Energy Expenditure (REE). However, as stated by Prentice *et al.* (1996:108), the use of PAL on pregnant women is not advisable, since even if Active Energy Expenditure (Total energy expenditure – Basal metabolic rate) is unchanged, PAL will still decrease as basal metabolic rate increases during pregnancy. Additionally, Brage *et al.* (2005:568) found that the PAL models of the Actiheart® are reasonably precise with R^2 values that exceeded 0.84.

Additional data downloaded from the ActiHeart® includes sleeping heart rate (beats/min), mean heart rate (beats/min), movement counts (counts/min), lost minutes (min) and time spent in a specific

metabolic equivalent of task category (MET). The combination of movement counts and heart rate measurements is shown to be accurate in the classification of physical activity rather than the individual measures (Barreira *et al.*, 2009:67). Movement counts can be grouped into three categories, namely: low activity (< 1952 counts/min), moderate activity (1952-6893 counts/min) and vigorous activity (≥ 6893 counts per minute) (Freedson *et al.*, 1998:779; Hendelman *et al.*, 2000:S445). Barreira *et al.* (2009:69) indicate that these counts/min is more accurate at low or moderate intensities. Considering that pregnant women mostly participate in low- and moderate physical activity, the ActiHeart® is a valuable tool in identifying these types of activities during pregnancy. Time spent in a specific metabolic equivalent of task was divided into the following categories: sedentary activity (MET < 1.5), light activity (1.5 – 2.9), moderate activity (3.0 – 5.9) and vigorous activity (MET ≥ 6.0) in accordance with the ACSM (2014:3).

Another important measurement that was downloaded from the ActiHeart® is the number of days the ActiHeart® was worn. Although the test subjects were encouraged to wear the ActiHeart® monitor for seven consecutive days, not all of the women adhered to this recommendation. The data of the days the women did not wear the ActiHeart® was trimmed and only the days on which measurements were taken were taken into account.

In order for the ActiHeart® to calculate the most accurate Activity Energy Expenditure, a resting metabolic rate was determined and an eight-minute step test with a ramp protocol on a step box (21.5 cm in height) was conducted. The resting metabolic rate measurement and the step test were administered at every measurement interval. This individual calibration step test develops a heart rate, a VO_2 regression line, specifically for the pregnant women and takes into account the physiological changes that the women experience during pregnancy (Melzer, 2012:e9).

Before the measurements, the ECG pads were placed on the chest, as indicated in Figure 3, to form an arc across the heart. A fifteen-minute period was given to determine a good signal to ensure an accurate measurement of the heart rate for the following seven consecutive days. If a good signal was established, the eight-minute calibration step test with the Actiheart® for AEE calculation was done. Participants were able to stop at any time during the step test if they experienced any discomfort or fatigue. A two minute period of quiet sitting was required after the step test to determine the recovery heart rates.

Once the step test information was downloaded using the accompanying software, the Actiheart® was set to the “Advanced Energy Expenditure” mode. Participants then wore the device for seven consecutive days. The Actiheart® was programmed to measure energy expenditure using 30-second epochs (counts per minute), allowing measurements notations of 5 to 20 days. A 15-second epoch, as stated by Melzer *et al.* (2012:e9), would have given a more precise AEE measurement, but the time of recording would have been too short due to a shorter battery life. Women were advised to take the monitor off when they were bathing or showering and to put it on again immediately afterwards. The device was removed after seven days and the data was downloaded using the accompanying software (Version 2.132, Cambridge Neurotechnology Ltd, Cambridge, UK).

3.2.4.7. Outcome: Foetal growth parameters

During routine visits to the gynaecologists and the clinic that were scheduled within the same week as the testing protocol, foetal growth was measured by the gynaecologists using ultrasound and by the clinic using symphysis fundal height. Estimated foetal weight (g) was then calculated. The head circumference, abdominal circumference, femur length and biparietal diameter (all measured in cm), were measured. From this data, the Ponderal Index (kg/m³) was calculated (Nguyen & Wilcox, 2005:1020).

3.2.4.8. Birth outcomes of the baby

The following birth outcomes from the medical records were used: gender (male/female, date of birth, birth weight (kg), birth length (cm), abdominal circumference (cm), mode of delivery (natural/caesarean section) and duration of delivery (hours).

These abovementioned variables were used to determine the ponderal index by means of the following calculation:

$$\text{Ponderal index} = \frac{\text{Birth weight (kg)}}{\text{Birth length}^3 \text{ (cm)}}$$

3.2.5. Procedure

All participants in the study were requested to complete an informed consent form after the study protocol was explained to them. As soon as the participants' demographic information was collected,

the anthropometric and body composition measurements were taken. The participants were then requested to lie on their left lateral position in order to measure their resting blood pressure and their resting heart rate followed by the resting metabolic rate. After the resting measurements were taken, the ECG electrodes were attached; the Actiheart® was programmed on the “step-test” conformation and attached to the ECG electrodes. The participants completed the step-test and the data was downloaded immediately. The Actiheart® was then programmed to measure habitual activity for 7 consecutive days and the electrodes were reattached to the participants. Finally, the participants completed the quantitative food frequency questionnaire. The abovementioned procedure was repeated for each measurement period as indicated in Figure 3.1. After the women had given birth, the babies’ birth outcomes were collected telephonically from the mothers.

3.3. Statistical analysis of data

The descriptive statistics of the baseline characteristics were determined, reporting means and standard deviations. Additionally, descriptive statistics were also performed on various anthropometric- and cardiovascular determinants of health values and were calculated in each of the trimesters and three months postpartum.

Determination of the first objective of this study was done by means of a Mixed Model Analysis where the means of the dependent variable, Active Energy Expenditure (kCal), was analysed from pre-pregnancy to 3 months postpartum. The significance of change between active energy expenditure from pre-pregnancy to 3 months postpartum was determined by setting the p-value lower than 0.05 to be significant.

The second objective was statistically analysed by means of a partial correlation (2 tailed) test between the mean of Active Energy Expenditure (kCal) in all three trimesters with relation to birth weight (kg), birth length (cm) and head circumference at birth (cm), controlling for gestational age at birth (weeks). Statistical analysis was performed with the SPSS version 21.0 statistical software package.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

4.2. Results

4.3. Discussion

4.4. Summary

4.1. Introduction

There is a lack in objectively-determined, habitual activity patterns of pregnant women from pre-pregnancy to postpartum and the influence of such activity on foetal growth. The objective of this chapter is, therefore, to report and discuss the results of objectively-determined habitual activity patterns of pregnant women across all trimesters of pregnancy. Furthermore, the results of the relationship between physical activity and foetal growth are presented and discussed in the context of multiple variables that influence the relationship.

The results of a section of data from the longitudinal observational cohort study design is presented from the larger **H**abitual **A**ctivity **P**atterns during **P**regnanc**Y** (HAPPY)-study (Figure 4.1). For the HAPPY-study, women in their first trimester of pregnancy were followed for lifestyle risk factors of cardiovascular disease during their entire pregnancy and three months postpartum.

In this chapter, the results are presented in the following way: Firstly, an overview of the recruitment and drop-out rates of the participants and the various baseline characteristics and their changes during the total pregnancy are presented per trimester and postpartum. Secondly, the results of the physical activity patterns and related measurements of the participants are presented. Finally, the relationship between the physical activity levels and birth outcomes are presented.

4.2. Results

4.2.1. Participants

Recruitment for the study started in 2011 when women who were planning on becoming pregnant within the following year, or who were pregnant at least less than 12 weeks, were requested to

participate in the HAPPY-study. The recruitment of participants was performed through the local newspaper, a local health clinic and from the consultation rooms of the local gynaecologists of Potchefstroom. Six women, who were not pregnant, signed informed consent forms for inclusion in the study and were measured before they became pregnant. Although these women planned to become pregnant in the following months, four of these women did not conceive, therefore only two pregnant women continued with the study.

Thirty-three participants were recruited in their first trimester, thirteen of these participants dropped out of the study due to various reasons, including, but not limited to miscarriages ($N = 2$), relocation ($N = 3$), and lost to follow-up in the study. In the second trimester, nineteen women were recruited, while twenty-seven women dropped out, mainly due to not following-up with the study or not returning for a follow-up during their routine check-up. Four participants were recruited in their third trimester, while nine participants dropped out. The overview of the recruitment and dropout rates of the participants are illustrated in Figure 4.1. The study continues to this day, therefore the figure below is a representation of the results of the participants to date, since there are still participants that are due to give birth in the near future.

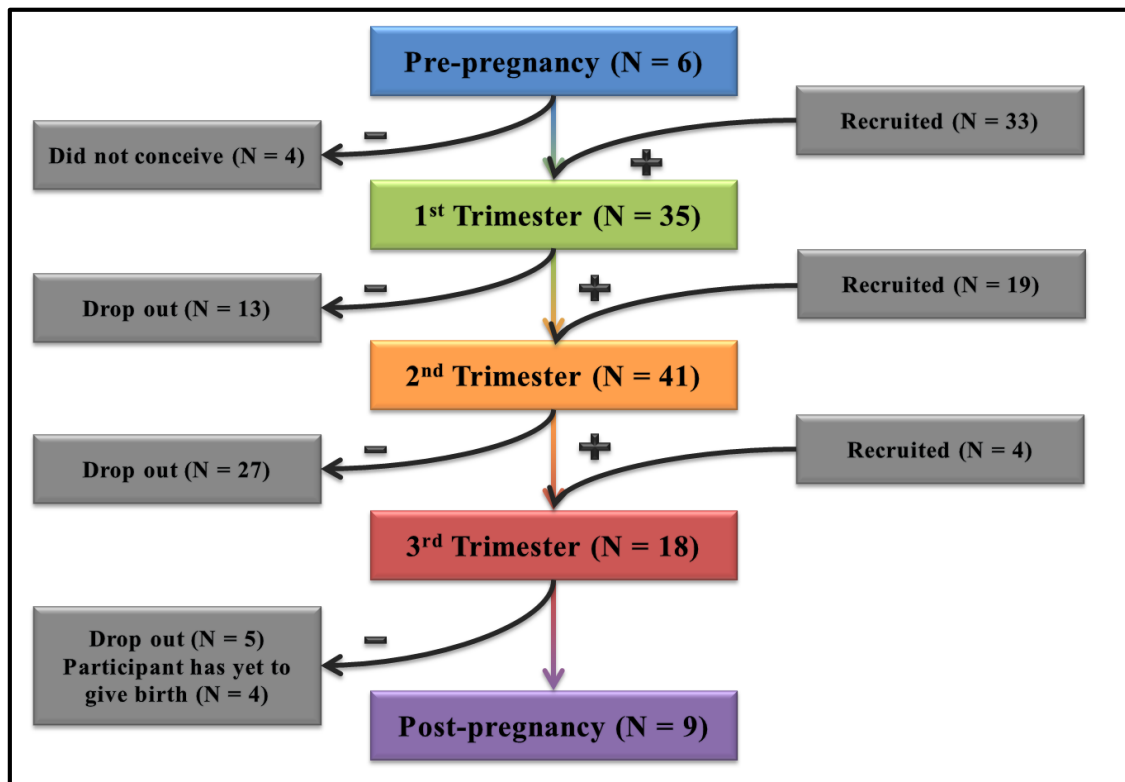


Figure 4.1: Overview of the recruitment and drop-out rates of subjects

4.2.2. Demographic information at enrolment

The subjects' demographic information included the following facts. For twenty six of the participants, this was their first pregnancy (37.7%). Twenty nine of the participants (42%) participated in the study during their second pregnancy, while twelve subjects (17.4%) were in their third pregnancy. A description of the baseline characteristics of the participants is given in Table 4.1. Most of the subjects did not have a previous miscarriage (N = 57, 82.6%), although 10 subjects had one miscarriage (14.5%) and two subjects (2.9%) had two miscarriages before participating in the HAPPY-study.

The mean age of all the subjects was 28 ± 5 years, with a minimum age of 19 and a maximum age of 38 years. The mean of the self-reported pre-pregnancy weight of thirty-five participants (N=35) was 63.03 ± 13.17 kg, with a minimum of 35 kg and a maximum of 94 kg. Not all of the patients reported their pre-pregnancy weight. Forty of the sixty-nine participants (58%) were not married, while 29 participants (42%) were married.

The ethnicity of the participants (Figure 4.2) is nearly equally distributed with about one third representation of each major ethnic group in South Africa. Of the participants, 36,7% are Caucasian, 33,3% are black and 29% are coloured as seen in Figure 4.2. Most of the participants' (N = 41) home language is Afrikaans, (59.4%), with only two participants being English-speaking (2.9%), 17 participants Tswana-speaking (24.6%), and nine participants spoke other languages (13%) such as Xhosa or Zulu.

The mean household income per annum (Rand-value) of all the participants (Figure 4.3) indicates that most of the participants (52.2%) are of the low socioeconomic status (< R 100 000 mean household income per annum), while 27.5% (N = 19) of all the participants are of middle socio-economic status (R 100 000 – R 300 000 mean household income per annum) and 20.3% (> R 300 000 mean household income per annum) are of a high socio-economic status.

Table 4.1: Demographic information of the participants

Variables	N	Mean	SD.
Age (years)	69	28	5
Pre-pregnancy weight (kg)	35	63.06	13.17
	n	Percentage (%)	
Marital status			
Unmarried	40	58.0	
Married	29	42.0	
Number of children at home (n)			
None (%)	26	37.7	
One (%)	29	42.0	
Two (%)	12	17.4	
Three (%)	2	2.9	
Number of previous miscarriages (n)			
None (%)	57	82.6	
One (%)	10	14.5	
Two (%)	2	2.9	
Ethnicity			
White (%)	26	37.7	
Black (%)	23	33.3	
Coloured (%)	20	29.0	
Home language			
Afrikaans (%)	41	59.4	
English (%)	2	2.9	
Tswana (%)	17	24.6	
Other (%)	9	13.0	
Socio-economic status			
Low (< R 100 000)	36	52.5	
Middle (R 100 000 – R 300 000)	19	27.5	
High (> R 300 000)	14	20.3	

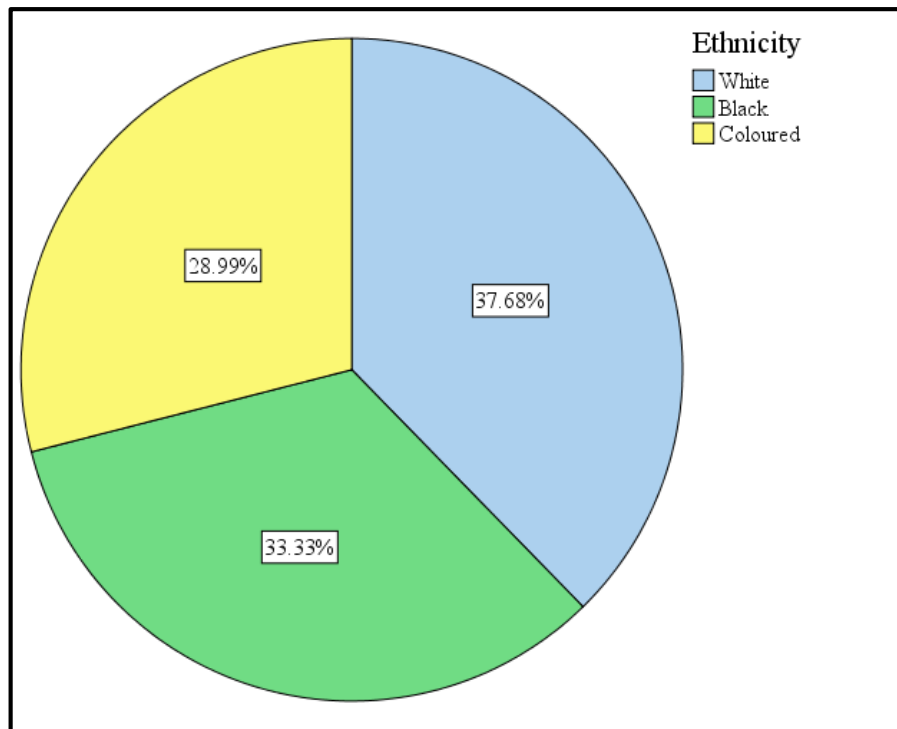


Figure 4.2: Distribution of representation of the ethnic groups participating in the HAPPY-study

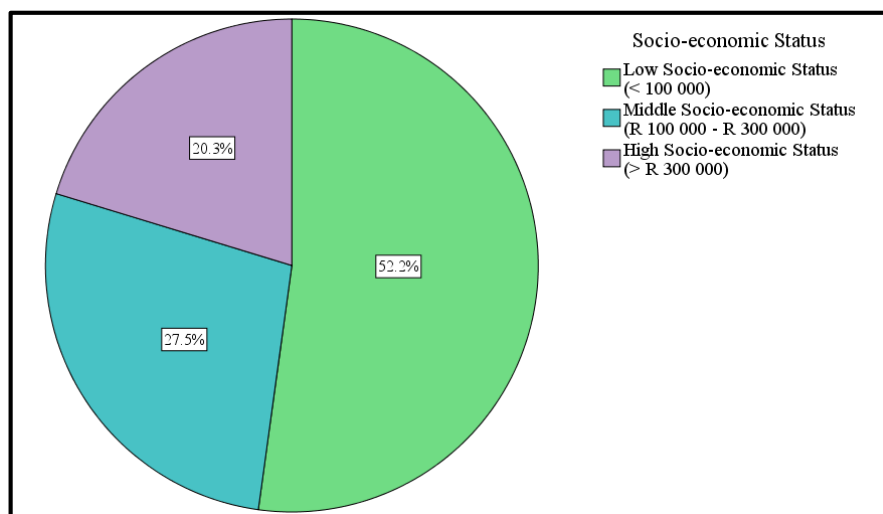


Figure 4.3: Socio-economic status distribution categorised by household income per annum

4.2.3. Maternal anthropometric, lifestyle and biological variables during pregnancy

As the purpose of the study is to determine changes across the period of the entire pregnancy, the results of the variables are presented as reported for each of the trimesters and post-partum. Various changes in descriptive results from pre-pregnancy to three months postpartum are illustrated in Table 4.2. Special emphasis is placed on maternal weight gain during the trimesters, as well as maternal

weight retention, as illustrated in Figure 4.4 and Figure 4.5. To be comprehensive, cardiovascular changes as well as lifestyle habits are also noted in Table 4.2. None of the subjects used drugs, while only one subject smoked during the first and second trimester. Two of the subjects consumed alcohol during their first and second trimester.

Table 4.2 shows the means and standard deviations of anthropometric measurements from pre-pregnancy to three months postpartum. Weight (kg) and Body Mass Index ($\text{BMI} = \text{kg}/\text{m}^2$) increased from the first to the third trimester, and declined from the third trimester to three months postpartum, as expected. A similar trend was observed in the waist- and hip circumferences (cm). Fat percentage (determined by skinfolds) also increased as the pregnancies progressed and decreased three months postpartum. Weight and BMI decreased from pre-pregnancy to the first trimester of pregnancy. However, the mean of reported pre-pregnancy weight was determined as 63.06 ± 13.17 kg ($N = 35$). Weight, BMI, Waist circumference, Waist-to-Hip Ratio and fat percentage did not reach pre-pregnancy values after three months post-partum. Figure 4.4 illustrates the progressive increase of weight from pre-pregnancy (reported) to postpartum (measured).

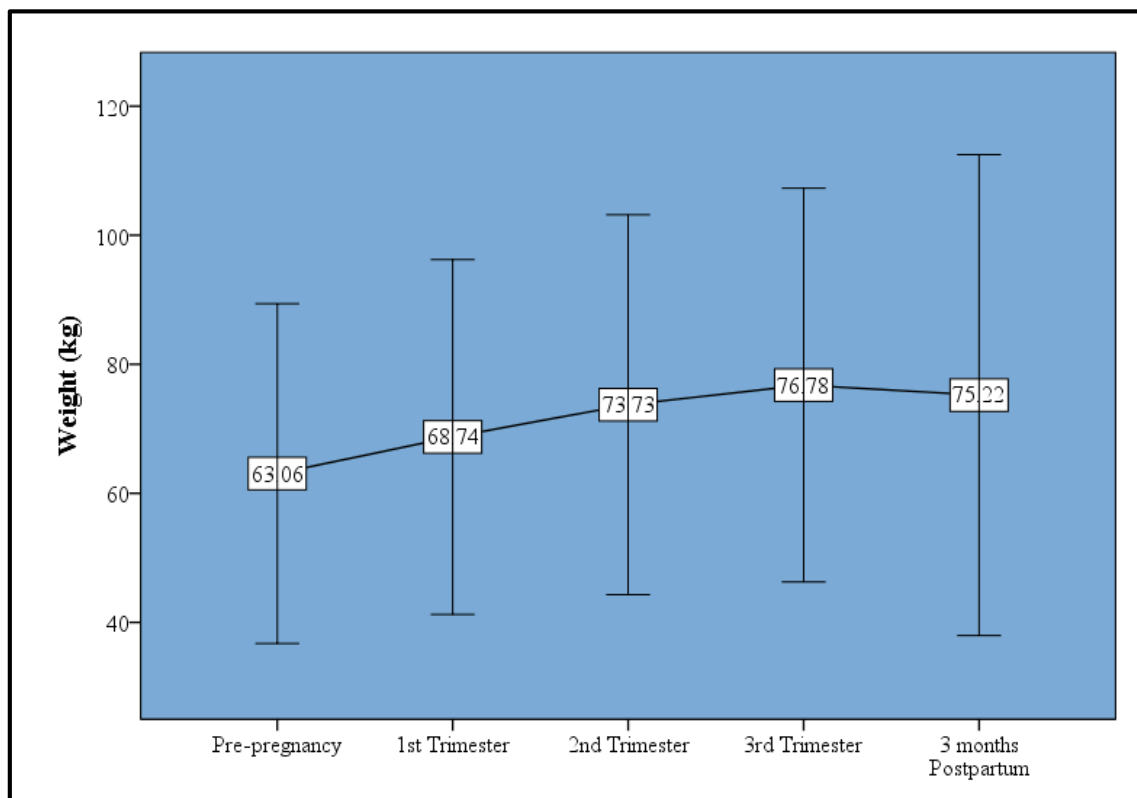


Figure 4.4: Weight gain (kg) from pre-pregnancy (reported) to post-partum with standard deviations

Changes in weight during pregnancy and as pregnancy progresses as well as weight loss three months postpartum are shown in Figure 4.5. The mean weight gain from pre-pregnancy to first trimester was 4.50 kg. The weight increase from the first to the second trimester was similar to the weight that increased from pre-pregnancy to the first trimester. Weight gain from the second to the third trimester was slightly smaller (0.43 kg) than the previous trend with a 4.07 kg increase. The mean weight loss from after the third trimester to three months postpartum was 5.86 kg. This means that the total weight retention from pre-pregnancy to three months postpartum was 7.21 kg.

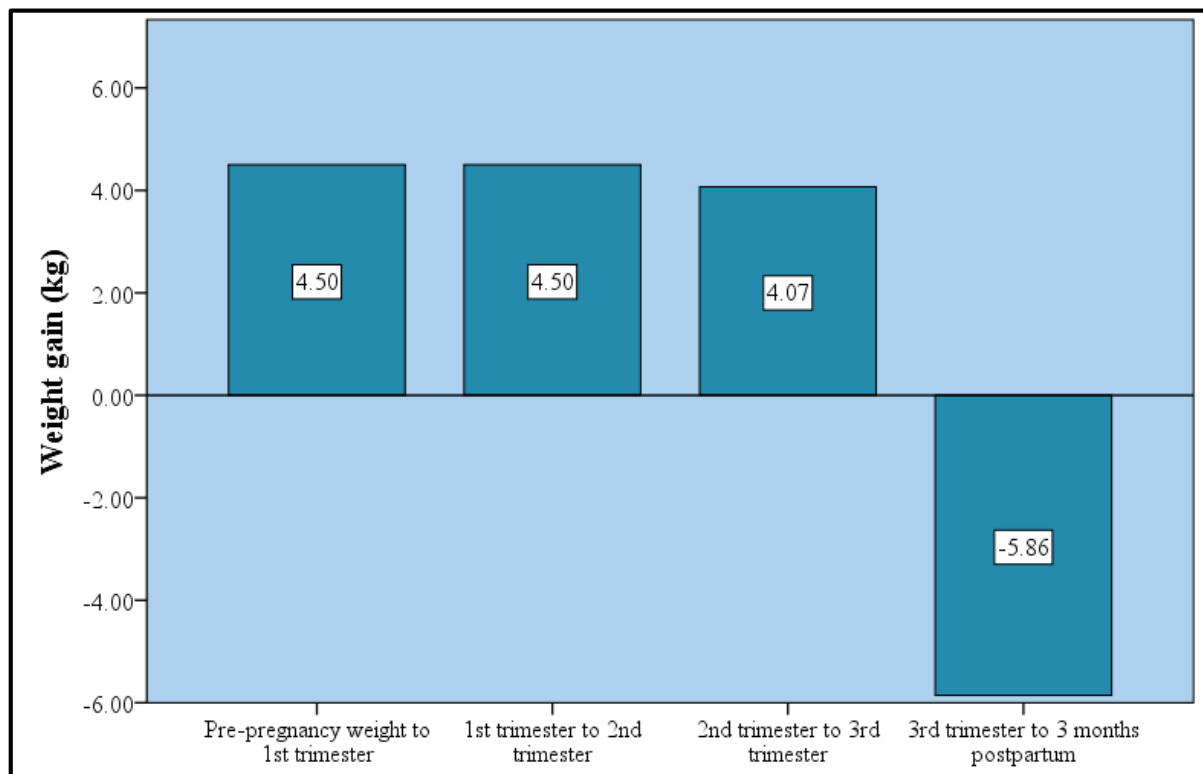


Figure 4.5: Changes in weight from pre-pregnancy to first trimester, per trimester, as well as weight loss from the third trimester to three months postpartum

Table 4.2: Changes in various lifestyle habits, anthropometrics and cardiovascular determinants of health values from pre-pregnancy, per trimester and three months postpartum

Variable	Pre-pregnancy		1 st Trimester		2 nd Trimester		3 rd Trimester		Post-pregnancy	
	N	Percentage (%)	N	Percentage (%)	N	Percentage (%)	N	Percentage (%)	N	Percentage (%)
Smoking status (%)	1	12.5	1	2.5	1	5.0	0	0	0	0
Alcohol use (%)	3	37.5	2	5.0	2	5.0	0	0	1	11.1
Drug use (%)	0	0	0	0	0	0	16	0	0	0
Medication use (%)	1	14.3	25	62.5	22	55.0	7	43.8	5	55.6
	N	Mean ± SD.	N	Mean ± SD.	N	Mean ± SD.	N	Mean ± SD.	N	Mean ± SD.
Weight (kg) measured	6	76.83 ± 18.29	35	68.74 ± 13.75	41	73.73 ± 14.72	18	76.78 ± 15.25	9	75.22 ±
Weight (kg) reported	35	63.06 ± 13.17								18.63
Height (m)	6	1.64 ± 0.06	35	1.63 ± 0.07	41	1.61 ± 0.07	18	1.64 ± 0.06	9	1.68 ± 0.05
BMI (kg/m ²)	6	28.67 ± 6.71	35	25.83 ± 4.90	41	28.54 ± 5.78	18	28.72 ± 6.77	9	26.89 ± 6.80
Waist circumference (cm)	6	80.00 ± 18.60	35	83.58 ± 13.47	41	96.82 ± 20.31	18	96.42 ± 7.98	9	86.83 ±
										15.26
Hip Circumference (cm)	6	106.69 ± 15.73	35	100.41 ± 11.27	41	105.52 ± 11.88	18	105.54 ± 9.84	9	106.17 ±
										14.30
Waist / Hip ratio	6	0.74 ± 0.07	35	0.83 ± 0.07	41	0.92 ± 0.19	18	0.92 ± 0.05	9	0.82 ± 0.07
Body fat (%)	6	26.81 ± 7.42	35	26.06 ± 6.48	41	27.82 ± 6.50	18	29.18 ± 6.66	9	27.14 ± 4.98
Resting heart rate (beats/min)	6	71 ± 9	35	65 ± 9	41	70 ± 11	18	73 ± 9	9	64 ± 11
Systolic Blood Pressure (mm Hg)	6	111 ± 6	35	116 ± 10	41	116 ± 9	18	114 ± 8	9	118 ± 1
Diastolic Blood Pressure (mm Hg)	6	73 ± 6	35	72 ± 8	41	72 ± 8	18	72 ± 9	9	77 ± 10

4.2.4. Changes in physical activity levels during pregnancy

Energy expenditure is influenced by various factors during pregnancy. This includes the Resting Metabolic Rate (RMR), the dietary intake and the level of physical activity or Activity Energy Expenditure (AEE) (Table 4.5). Physical Activity Level (PAL) was determined by the ratio between the total energy expenditure and resting metabolic rate. Changes in Resting Metabolic Rate (RMR) from pre-pregnancy to post-partum, as measured by the Cosmed Fitmate™ (Cosmed, Italy), are illustrated in Figure 4.6. RMR decreased from pre-pregnancy (1424 kCal/day) to first trimester (1335 kCal/day), and then again to the second trimester (1310 kCal/day). RMR increased from 2nd Trimester to 3rd Trimester (1403 kCal/day), as much as 93 kCal/day. Three months after birth, the RMR decreased to 1344 kCal/day.

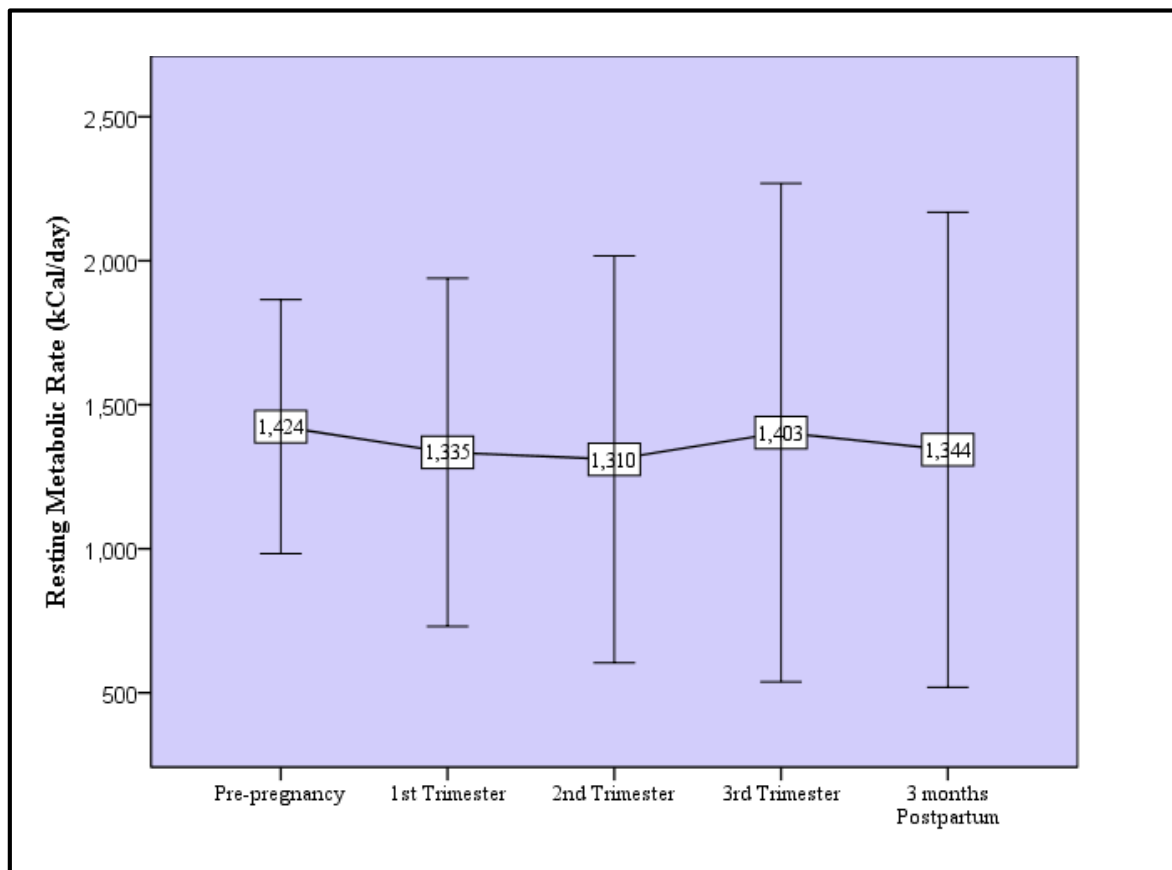


Figure 4.6: Change in resting metabolic rate from pre-pregnancy to three months postpartum

Table 4.3: Changes in energy expenditure and physical activity variables from pre-pregnancy, per trimester, to three months postpartum

Variable	Pre-pregnancy		1 st Trimester		2 nd Trimester		3 rd Trimester		3 months postpartum	
	N	Mean ± SD.	N	Mean ± SD.	N	Mean ± SD.	N	Mean ± SD.	N	Mean ± SD.
RMR (kCal/day) (Cosmed Fitmate®)	6	1424 ± 220	35	1334 ± 302	41	1310 ± 353	18	1403 ± 432	9	1344 ± 412
RMR (kCal/day) (ActiHeart®)	6	1614 ± 280	35	1453 ± 168	41	1520 ± 178	18	1542 ± 162	9	1538 ± 259
Days Actiheart worn (n)	6	5.83 ± 0.41	35	5.43 ± 1.31	41	5.49 ± 1.19	18	5.83 ± 0.79	9	5.33 ± 1.12
AEE (kCal/day)	6	1019 ± 592	35	803 ± 34	41	702 ± 471	18	592 ± 383	9	634 ± 520
DIT (kCal/day)	6	293 ± 77	35	251 ± 48	41	247 ± 56	18	237 ± 47	9	241 ± 66
TEE (kCal/day)	6	2927 ± 768	35	2506 ± 483	41	2459 ± 563	18	2371 ± 470	9	2414 ± 660
PAL	6	1.83 ± 0.41	35	1.73 ± 0.30	41	1.63 ± 0.34	18	1.54 ± 0.28	9	1.56 ± 0.36
Lost minutes (mins/week)	6	246 ± 250	35	232 ± 236	41	192 ± 146	18	253 ± 176	9	129 ± 66
Activity counts (counts/minute)	6	32 ± 21	35	29 ± 15	41	26 ± 10	18	24 ± 10	9	23 ± 8
Sedentary (MET.min/week)	6	859 ± 311	35	949 ± 212	41	1011 ± 257	18	1081 ± 225	9	1066 ± 225
Light (MET.min/week)	6	454 ± 211	35	386 ± 164	41	351 ± 184	18	304 ± 174	9	298 ± 124
Moderate (MET.min/week)	6	126 ± 100	35	103 ± 83	41	63 ± 210	18	55 ± 62	9	75 ± 115
Vigorous (MET.min/week)	6	2 ± 2	35	2 ± 4	41	1 ± 2	18	1 ± 2	9	0 ± 0

RMR = Resting Metabolic Rate, AEE = Active Energy Expenditure, DIT = Diet-induced Thermogenesis, TEE = Total Energy Expenditure (Total energy expenditure/Resting Metabolic Rate), PAL = Physical Activity Level, Sedentary = Time spent < 1.5 MET.min/week, Light = Time spent 1.5 – 3.0 MET.min/week, Moderate = Time spent 3.0 – 6.0 MET.min/week, Vigorous = Time spent > 6.0 MET.min/week.

Changes in AEE (Figure 4.7) decreased from pre-pregnancy (1020 kCal/day) to the first Trimester (802 kCal/day) and throughout the pregnancy period (Figure 4.7). There was a small increase in AEE from third trimester to three months postpartum of about 42 kCal/day. However, AEE three months postpartum did not reach pre-pregnancy activity levels. The results of the Mixed Model Statistical Analysis on the AEE for the entire period resulted in a non-significant ($p = 0.20$) change from pre-pregnancy to three months post-pregnancy while a significant lower AEE was found in the third trimester compared to pre-pregnancy ($p = 0.04$)

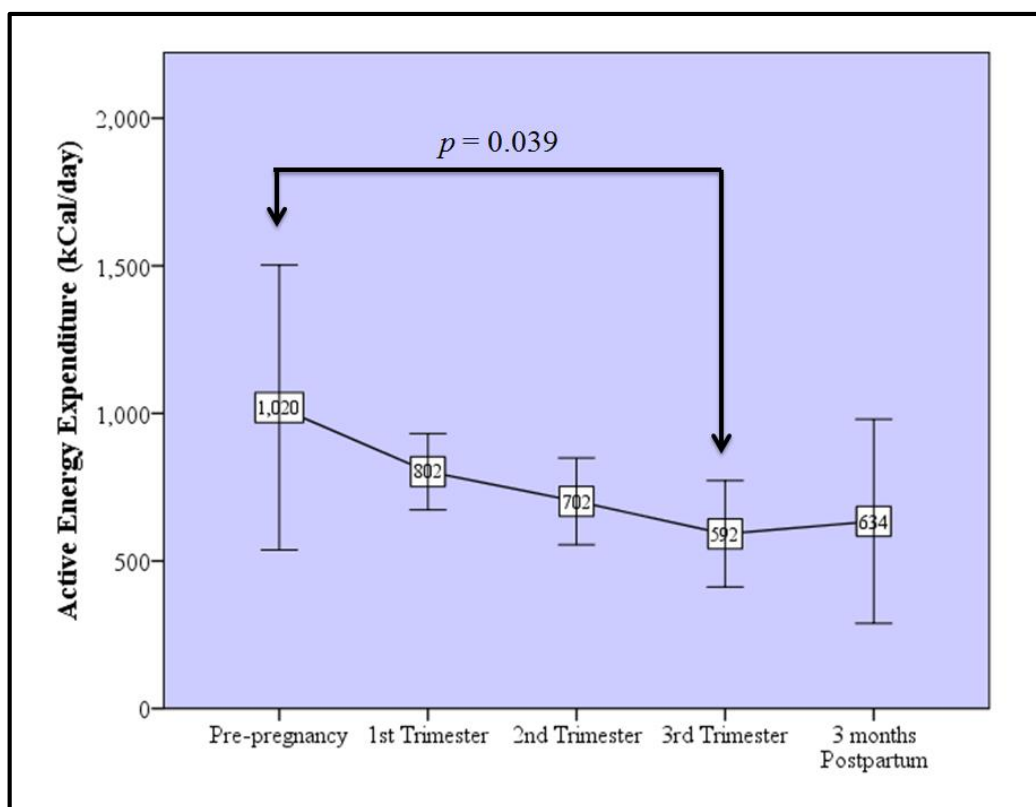


Figure 4.7: Changes in Activity Energy Expenditure (kCal) from pre-pregnancy to three months postpartum with the standard deviations

Diet-induced thermogenesis (DIT) (kCal/day) also decreased as pregnancy progressed. The mean pre-pregnancy DIT (293 kCal/day) decreased substantially by 42 kCal/day in the first trimester to 251 ± 48 kCal/day. A decrease was also noted from first to the second trimester to 247 ± 56 kCal/day, as well as from the second to the third trimester to 237 ± 47 kCal/day. DIT increased slightly to from the third trimester to three months postpartum 241 ± 66 kCal/day.

Total energy expenditure (TEE) (kCal) reported a similar decrease from pre-pregnancy (2927 ± 768 kCal/day), to 2506 ± 483 kCal/day in the first trimester, 2469 ± 563 kCal/day in the second

trimester and 2371 ± 470 kCal/day in the third trimester. However, TEE increased three months after giving birth to 2414 ± 670 kCal/day.

Although AEE was statistically analysed in detail, the ActiHeart® provides additional data that may be relevant to determine the physical activity patterns during pregnancy. This data is included in Table 4.3 and includes the Physical Activity Level (PAL), lost minutes per week (mins/week), Activity Counts (counts per minute) and minutes spent in various intensities as indicated by the METs.min/week.

PAL decreased from the first to the third trimester. During the first trimester, PAL was determined as 1.73 ± 0.30 . The second trimester showed a decrease in PAL to 1.63 ± 0.34 , and again to the third trimester to about 1.54 ± 0.28 . The PAL increased slightly three months after giving birth to 1.56 ± 0.37 .

Activity counts decreased from 32 ± 21 counts/min in the first trimester, to 29 ± 15 counts/min in the second trimester and to 26 ± 10 counts/min in the third trimester. Activity counts also slightly decreased from the third trimester to three months postpartum (23 ± 8 counts/min), unlike active energy expenditure and other physical activity measurements.

Minutes spent per week in various MET groups was further categorised in sedentary minutes spent per week (MET < 1.5), minutes spent doing light- (MET = 1.5 – 3), moderate- (MET = 3 – 6) and vigorous activity (MET > 6) per week from pre-pregnancy to three months postpartum. Figure 4.8 illustrates how minutes spent doing light-, moderate- and vigorous physical activity changed from pre-pregnancy, per trimester and three months postpartum. Sedentary time spent increased from pre-pregnancy (859 ± 311 min/week) to the first trimester (949 ± 212 min/week) by 67.88 min/week. This trend continued into the second trimester (1011 ± 257 min/week) and to the third trimester (1081 ± 225 min/week). However, minutes spent doing sedentary activity decreased three months after giving birth (298 ± 124 min/week).

Minutes spent per week in light physical activity and moderate activity decreased as pregnancy progressed. Minutes spent doing light activity decreased from 386 ± 164 min/week in the first trimester to 351 ± 184 min/week in the second trimester and decreased again in the third trimester to 304 ± 173 min/week. Minutes spent doing moderate activity also declined, similar to the decline observed in light activity. Minutes spent doing moderate activity decreased from 126

± 99 min/week in the pre-pregnancy period to 103 ± 82 min/week in the first trimester, 63 ± 210 min/week in the second trimester and 55 ± 62 min/week in the third trimester. Minutes spent in light activity increased slightly by 6 minutes/week from the third trimester to three months postpartum, while minutes spent doing moderate activity increased by 21 minutes/week. Minutes spent doing vigorous activity were few, but also showed a decrease from the first trimester to the third trimester.

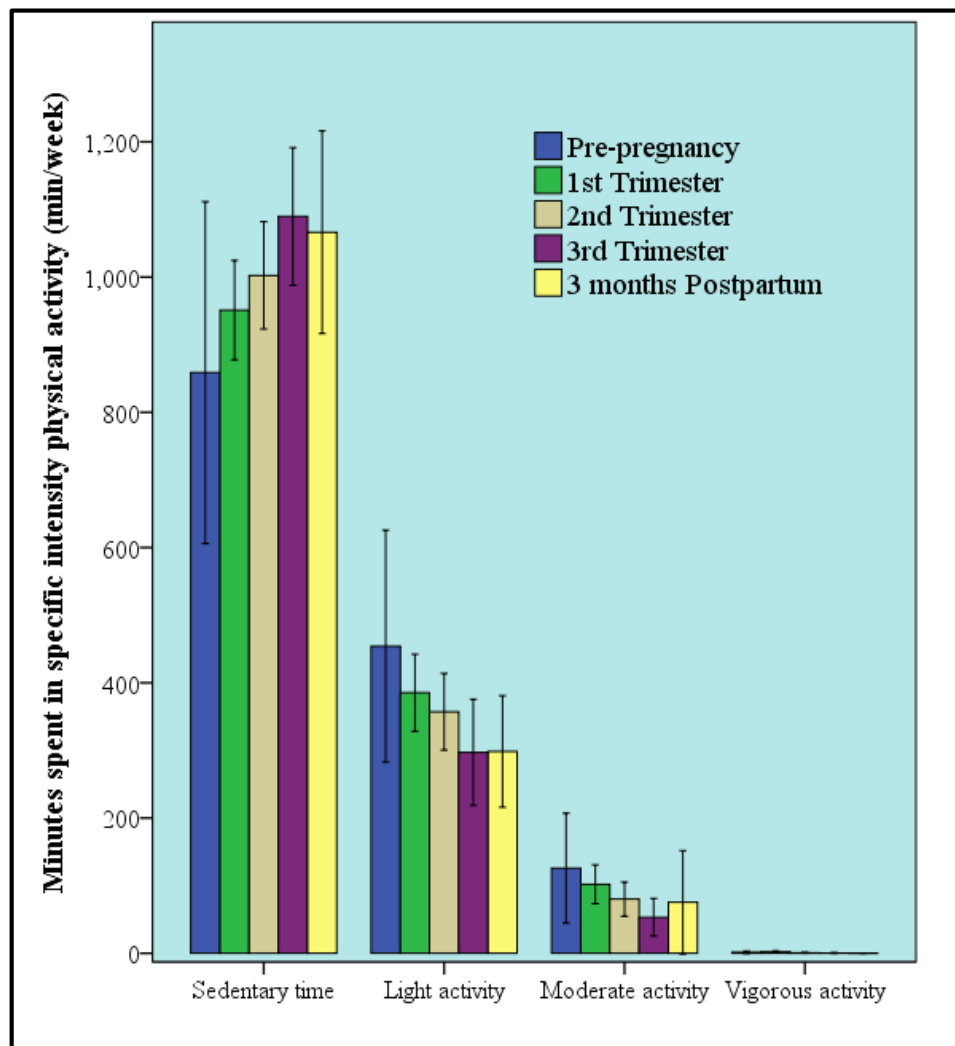


Figure 4.8: Changes in time spent in sedentary, light, moderate and vigorous activity during pregnancy

4.2.5. The influence of physical activity on foetal growth

The foetal growth measurements in Table 4.7 report on the gestational age, weight, length, head circumference and Ponderal Index of the baby at birth. The results of the 22 babies' already born are included, although only 9 post-partum participants (Figure 4.1) were measured to date. This

was possible due to birth records being provided by the mothers prior to the 3 months postpartum measurements.

The mean birth weight was 3.12 ± 0.56 kg, while the mean birth length was 48.5 ± 4.9 cm. The mean Ponderal Index at birth was 27.74 ± 5.63 kg/m³. Head circumferences of the babies were not all measured at birth (N = 17). Nevertheless, the mean of the head circumference was determined as 35.1 ± 0.5 cm. Delivery by means of Caesarean section was performed on 75% (N = 15) of the participants, while 25% (N = 5) gave birth naturally.

Table 4.4: Descriptive statistics of foetal growth measurements at birth

Variable	N	Minimum	Maximum	Mean	SD
Gestational age at birth	22	36	43	39	1.5
Birth weight (kg)	22	1.6	4.42	3.12	0.56
Birth length (cm)	22	44.0	58.0	48.5	3.2
Ponderal Index (kg/m³)	22	13.07	39.97	27.74	5.63
Head circumference (cm)	17	32	38	35.1	1.4

SD = Standard deviation

The second objective of this study is to determine the relationship between the AEE and the foetal growth outcomes. The objective was analysed by means of a partial correlation between the mean of AEE during all trimesters and foetal growth measurements as reported at birth, controlling for gestational age (Table 4.8). A negative relationship between average pregnancy AEE and all foetal growth measurements was found, except for head circumference at birth. The relationship between average pregnancy AEE and all foetal growth measurements was not statistically significant. Birth weight and AEE was negatively correlated ($r = -0.39$; $p = 0.45$), but was not statistically significant. Birth length was also slightly negatively correlated ($r = -0.16$, $p = 0.77$) with AEE, however, this partial correlation was also not statistically significant. The abovementioned resulted in a negative correlation between Ponderal Index and AEE expenditure ($r = -0.34$, $p = 0.51$). A significant positive relationship between average pregnancy AEE and head circumference ($r = 0.14$, $p = 0.79$) were found.

Table 4.5: Correlation between average Active Energy Expenditure (kCal/day) during all three trimesters and various foetal growth measurements

Variables	Average Active energy expenditure (kCal/day)	
	<i>r</i>	<i>p</i>
Birth weight (g)	- 0.39	0.45
Birth length (cm)	- 0.16	0.77
Ponderal Index (g/m ³)	- 0.34	0.51
Head circumference (cm)	0.14	0.79

4.3. Discussion

4.3.1. Habitual activity patterns during pregnancy

The main findings on the habitual activity patterns during pregnancy include a decreased activity energy expenditure (AEE), physical activity level (PAL), activity count, as well as minutes spent doing light-, moderate and vigorous activity, with a concomitant increase in sedentary minutes spent.

Total daily energy expenditure (TEE) consists of three general factors: resting metabolic rate (RMR), diet-induced thermogenesis (DIT) and Activity Energy Expenditure (Manini, 2010:1). The first objective of this dissertation is determining the habitual physical activity patterns during pregnancy. Numerous studies indicate a decrease in maternal physical activity patterns during pregnancy (Borodulin *et al.*, 2009:44; Chasan-Taber *et al.*, 2007:87; Hinton & Olson, 2001:7; Löf, 2011:1300; Poudevigne & O'Connor, 2006:22). The overall decrease in AEE during pregnancy can be explained by various reasons. Minor discomforts such as leg cramps, swelling, fatigue, shortness of breath (Horns *et al.*, 1996:49) as well as difficulties in movement related to a larger body mass may attribute to the decrease in physical activity during pregnancy (Melzer *et al.*, 2010a:499). A perception that physical activity may be damaging to the foetus might also lead to an observed decrease in physical activity during pregnancy (Cioffi *et al.*, 2010:458; Duncombe *et al.*, 2007:431). Reductions in physical activity could also be a method to meet the increased energy demands of pregnancy (Agarwal *et al.*, 2001:1019).

Subjectively measured physical activity questionnaires remain the most common method of assessing physical activity during pregnancy (Evenson *et al.*, 2012a:479). A South-African study

by Brunette *et al.*, (2012:139) measured physical activity during the second- and third trimester of pregnancy by means of a modified physical activity questionnaire called the EPAQ-2 (Epic Physical Activity Questionnaire) and found no significant relationship between the trimester of pregnancy and physical activity level. The previous finding is similar to our study's results, as no statistical significant decline in AEE was found, apart from pre-pregnancy to the third trimester. Brunette *et al.* (2012:141) conclude that the cross-sectional nature of their study might have contributed to this result, and recommended that longitudinal research must be performed to provide a better understanding of the change in physical activity during pregnancy. Another self-reported study on physical activity during pregnancy (Borodulin *et al.*, 2009:32) reports overall levels of physical activity to decrease from 17 – 22 weeks to 27 – 30 weeks of gestation, but the study does not specify whether the results are statistically significant.

Objectively determined physical activity provide a more accurate estimation of AEE during pregnancy and were implemented by Löf (2011:1300), whose results indicate that pregnant women's AEE was 18% lower than non-pregnant controls. These results are in line with Butte *et al.* (2004:1085) where AEE declined by 13% from pre-pregnancy to late pregnancy. Both Butte *et al.*, (2004:1296) and Löf (2011:1298) measured AEE by means of accelerometry, more specifically using the Intelligent Device for Energy Expenditure and Physical Activity (Minisun, Fresno, CA, USA). The results from this study reports a mean AEE during the entire pregnancy of 668 ± 346 kCal/day, whereas Löf (2011:1298) reports 1214 ± 225 kCal/day (converted from kJ) and Butte *et al.*, (2004:1083) reports 769 ± 362 kCal/day, indicating that women who participated in our study were less physically active in comparison. A study that analysed AEE during pregnancy by means of the ActiHeart® (Melzer *et al.*, 2009:1188) indicates a non-significant decrease during pregnancy, similar to this study's results. Melzer *et al.* (2009:1187) report an AEE of 697 ± 275 kCal/day (converted from kJ), indicating similar results to the HAPPY-study. It can therefore be deduced that varying physical activity reported during pregnancy can be attributed to studies that make use of subjectively determined physical activity, and that are cross-sectional in design.

When specifically comparing changes from each trimester, the results of this study indicate the largest decrease in average AEE was from pre-pregnancy to the first trimester. Physical activity tends to decline in the first trimester due to nausea, vomiting and fatigue (Clarke *et al.*, 2005:254; Rousham *et al.*, 2006:397). In the second trimester, symptoms of nausea and vomiting usually decrease and physical factors like uterine enlargement and changes in weight distribution

are the main cause of the decline in physical activity (Poudevigne & O'Connor, 2006:27). As this study's results indicate a statistically significant decline of AEE - was only found from pre-pregnancy to the third trimester – the decrease could be due to weight gain as a result of foetal growth, a shift in the centre of mass and sometimes due to the perception that physical activity might be damaging to the foetus, specifically in the third trimester (Cioffi *et al.*, 2010:458; Davies *et al.*, 2003:330; Duncombe *et al.*, 2007:431). Siega-Riz *et al.* (2009:339.e3) report that the recommended gestational weight gain ranges for women, on the basis of BMI, are between 12.5 kg and 18 kg for those with a low BMI (<19.8), between 11.5 kg and 16 kg for those with a normal BMI (19.8 –26.0), and between 7.0 kg and 11.5 kg (overweight, BMI >26.0 –29.0) or 6 kg for obese women (BMI $\geq$ 29.0).

The average AEE increased in the postpartum period, which according to Borodulin *et al.* (2009:38) might relate to care-giving physical activity, which constitutes the largest proportion of total physical activity characterised in this period. Although the AEE increased in the postpartum period from the third trimester, it did not reach pre-pregnancy levels. Davies *et al.* (2003:333) contributes this decline to the added fatigue of delivery and new-born care, resulting in a decrease in time available to be physically active. Another aspect to consider is the type of delivery as the practice of a surgical delivery are associated with lower physical activity, as stated by Kac *et al.* (2007:90). This study shows a high rate of caesarean-sections resulting in the low AEE in the postpartum period. Evenson *et al.* (2012b:19) measured physical activity in the postpartum period by means of self-reported and objective measures (accelerometry) and concludes that most women in the sample did not meet recommendations for physical activity in this period. They propose that interventions are needed to promote physical activity in the postpartum period (Evenson *et al.*, 2012b:19). Evenson (2011:44) and Sampsel *et al.* (1999:48) also state that the physical and psychological benefits gained from physical activity in the postpartum period warrants a support system specifically to promote physical activity in postpartum care plans. Some women believe that physical activity affect milk supply, which led to a decrease in their normal postpartum physical activity levels (Spowman *et al.*, 2004:85). Information regarding breastfeeding and lactation was not collected in this study,

Although PAL decreased during pregnancy, care should be taken with the interpretation thereof. As pointed out by Prentice *et al.* (1996:S108), PAL is calculated by dividing Total Energy Expenditure by Resting Energy Expenditure. Therefore, even if AEE is unchanged, PAL will still decrease as basal metabolic rate increases during pregnancy (Prentice *et al.*, 1996:S108).

However, Löf (2011:1300) found a significant lower PAL value during pregnancy, when compared to non-pregnant controls.

Activity counts were measured by the accelerometer of the ActiHeart® device, and similar to AEE and PAL, this variable also decreased from the first to the third trimester of pregnancy. A study by Chandonnet *et al.* (2012:2) made use of the ActiGraph® (Pensacola, USA) and measured physical activity by means of activity counts per minute. However, in the study they did not report the change of activity counts per minute as pregnancy progressed from first to third trimester. Another study by Rousham *et al.* (2006:395) expressed physical activity by means of activity counts/min and grouped their participants into trimesters. This particular study made use of the Actiwatch® monitor (Cambridge, U.K.). Their results indicate a decrease in the activity counts per minute from the first to the third trimester. Due to different Epoch-settings (movement occurring within a given period), the mean Activity counts of the ActiHeart® and Actiwatch® (Rousham *et al.*, 2006:395) cannot be compared.

When comparing the time spent doing light-, moderate- and intense activities during each trimester of pregnancy, an overall increase in sedentary time spent ($\text{MET} < 1.5$) is observed in conjunction with a decrease in time spent doing light activity ($\text{MET} = 1.5 - 3.0$), and moderate physical activity ($\text{MET} = 3 - 6$). A study by Löf (2011:1300) generated similar results, concluding that pregnant women spend more time on sedentary activities and less time performing light- and moderate intensity activities. Löf (2011:1296) measured physical activity by means of the doubly labelled water method and indirect calorimetry. Decreased time spent doing light- and moderate intensity physical activity was mainly due to selecting less demanding activities during pregnancy.

The American College of Sports Medicine (ACSM, 2014:194) recommend pregnant women to accumulate 30 minutes or more of moderate physical activity per day on most, if not all, days of the week. Participants in the HAPPY-study study spent 103 min/week in the first trimester, 63 min/week in the second trimester and 55 min/week in the third trimester doing moderate-intensity physical activity. Therefore, the participants did not reach the recommended amount of time performing moderate physical activity as per the ACSM (2014:194) guidelines.

The decrease in RMR from pre-pregnancy to the first trimester does not correspond with current research, as RMR tends to increase during pregnancy (Löf *et al.*, 2005:684). The increase of

RMR during pregnancy is needed for foetal development (Melzer *et al.*, 2009:1188), as well as the increase in weight that needs to be accounted for (Löf *et al.*, 2005:684; Melzer *et al.*, 2009:1188). RMR was measured by Löf *et al.* (2005:681) by means of calorimetry and reported 1331 ± 153 kCal/day for the first trimester, 1372 ± 162 kCal/day for the second trimester and 1640 kCal/day for the third trimester.

This study's results indicate a RMR of 1334 ± 302 kCal/day for the first trimester, 1310 ± 353 kCal/day for the second trimester and 1403 ± 432 kCal/day for the third trimester. Consequently, the RMR-results from the first trimester are similar to Löf *et al.* (2005:681), while the second and third trimester RMR differed. The decline from pre-pregnancy to the first trimester in RMR is due to a participant that enrolled in the study during pre-pregnancy, but did not conceive and was therefore not included in the follow-up data. The small sample size pre-pregnancy may have caused a skewed distribution of the RMR. Similarly, RMR decreased from the first trimester to the second. However, mean weight increased from the first to the second trimester, therefore the decrease in RMR cannot be attributed to weight. A possible explanation for this decrease could be from the recruitment / drop-out of participants in the second trimester (Figure 4.1), as well as the variability in RMR attributed to the nutritional situation of the women (Löf *et al.*, 2005:678).

The nutritional status of participants going to their nearest clinic varied greatly from the participants recruited from the gynaecologists, and most women recruited in their second trimester of pregnancy were primarily from the clinic. Malnutrition tends to lead to a decrease in RMR to minimise the negative energy balance (Emery, 2005:1030), and might therefore have led to the observed decline. As expected, RMR increased in the third trimester substantially. Factors responsible for the variability in RMR differ in the early and later trimesters of pregnancy (Löf *et al.*, 2005:684). The gain in body weight explains 40% of the variability, while fat gain accounts for about $55.5 \pm 20\%$ of total weight gain during pregnancy (Okereke *et al.*, 2004:368).

Changes in the DIT decreased as pregnancy progressed, which may be due to conservation of energy intake (increased absorption of nutrients), to provide energy for an increase in body weight, as well as providing nutrients essential for foetal growth (Whitney & Rolfes, 2008:520). However, caution must be taken when considering these results, as DIT was derived from the Total Energy Expenditure reported by the ActiHeart[®] device and not from dietary information collected from the participants.

4.3.2. Relationship between activity energy expenditure and foetal growth

The majority of studies on pregnancy focus on the influence of physical activity on foetal growth parameters, specifically birth weight. Foetal growth parameters include not only birth weight, but birth length, Ponderal Index and head circumference at birth. Most of these studies found women who were physically active during their pregnancy gave birth to infants with a lower birth weight compared to women that were sedentary during their pregnancy (Bell *et al.*, 1995:35; Campbell & Mottola, 2001:405; Dwarkanath *et al.*, 2007:709; Henriksen *et al.*, 1995:513; Magann *et al.*, 2002:469; Mohammadreza *et al.*, 2012:226; Roa *et al.*, 2003:537; Rose *et al.*, 1991:1079; Schramm *et al.*, 1996:216; Spinillo *et al.*, 1996:534; Takito *et al.*, 2005:329).

Similar to the abovementioned studies, the results from our study indicate a negative relationship between birth weight and physical activity (average AEE during all three trimesters); although the results were not statistically significant, the direction of the relationship indicates that an increase in AEE results in a trend toward a lower birth weight. Providing possible explanations for this decrease in birth weight as physical activity increases is difficult, because the origin of having a lower birth weight infant is multi-factorial. The mechanism by which physical activity might affect birth weight is unknown, and in the absence of strong randomised controlled trials, providing answers remains problematic. However, Pomeroy *et al.* (2013:269) found a statistically significant positive association between the mothers' gestational physical activity levels, assessed by means of the ActiHeart®, and the infants' fat-free mass. A lower birth weight might be explained by a decreased level of subcutaneous fat in the infant. Pomeroy *et al.* (2013:269) conclude that pregnant women's physical activity level is an important determinant of foetal growth and that a low physical activity during pregnancy may lead to a large-for-gestational-age infant at birth who in turn are prone to obesity during childhood.

Mohammadreza *et al.* (2012:224) did not find any significant correlation between physical activity, as determined by a specialised questionnaire, and the infants' head circumference at birth, inferring that neural development is not impaired by the mother's physical activity patterns during pregnancy. A reason for the statistically-insignificant relationship between birth weight and AEE is due to the very low physical activity level of the participants in this study, as the participants' physical activity levels did not meet the recommendations set by the ACSM (2014:194).

Mohammadreza *et al.* (2012:226) conclude that higher levels of physical activity during pregnancy are negatively correlated with the new-born's weight at delivery. Mohammadreza *et al.* (2012:224) report a mean birth weight of 3.31 ± 0.47 kg, while this study measured 3.12 ± 0.56 kg. Mahmoodi *et al.* (2013:576) states that an increase in the time spent on sport and home activities during pregnancy was accompanied by an increased chance of giving birth to a lower weight infant. Mahmoodi *et al.* (2013:576) also indicate that a one hour increase of leisure activities decreased the probability of giving birth to low birth weight infants (Mahmoodi *et al.*, 2013:576). Mahmoodi *et al.* (2013:5757) determined the time spent doing physical activity by means of a questionnaire. More specifically, Dwarkanath *et al.* (2007:709) found women with a high physical activity level (obtained by a physical activity questionnaire) in the first trimester to be 1.58 times (odds ratio) more likely of giving birth to a baby with a low birth weight, even after adjusting for maternal weight and energy intake. Dwarkanath *et al.* (2007:706) measured a 2.81 ± 4.71 kg mean birth weight, which is lower than the results from the HAPPY-study. Spinillo *et al.* (1996:534) found the decrease in birth weight, in conjunction with a moderate- or vigorous occupational physical activity (assessed by a questionnaire) profound and concludes that the risk for intrauterine growth restriction is higher in pregnant women who reported moderate- or vigorous occupational physical activity during the pregnancy.

However, Jahromi *et al.* (2011:18) concludes contradicting findings when compared to the abovementioned studies, where infants of mothers who exercised before or during pregnancy had a significant higher birth weight than the non-exercise group. This conflicting result may be due to not taking into account the habitual physical activity patterns of pregnant women, and only focusing on one constituent of physical activity, namely exercise. Jahromi *et al.* (2011:17) reports a 3.06 ± 0.58 kg mean birth weight, comparable to the results of the HAPPY-study. Hatch *et al.* (1993:1112) states that pregnant women who participated in light- or moderate leisure-time physical activity showed an increase of 117g in birth weight, compared to sedentary women. Vigorous exercise (energy expenditure approximately 2000 kCal/week) during the pregnancy period resulted in an increase of 276g in birth weight in the same study (Hatch *et al.*, 1993:1112). Another study by Leiferman and Evenson (2003:61) shows that pregnant women who did not participate in any leisure-time physical activity during pregnancy were more susceptible to having new-borns with a very low birth weight when compared to women who participated in leisure-time physical activity. However, Leiferman and Evenson (2003:60) used data collected from the 1988 National Maternal and Health Survey (NMIHS) that only assessed

regular leisure physical activity by means of two questions in the survey that were purely based on exercise and sport.

Similar to the results of the HAPPY-study, numerous studies report no statistically-significant correlation between physical activity and birth weight (Bonzini *et al.*, 2009:689; Florack *et al.*, 1995:203; Klebanoff *et al.*, 1990:1454; Mudd *et al.*, 2012:1770; Rabkin *et al.*, 1990:528; Rose *et al.*, 1991:1079; Takito *et al.*, 2005:329). Alderman (1998:518) reports no significant relationship between physical activity (determined by means of an interview) and risk of small-for-gestational-age new-borns. However, this study discovered associations between leisure physical activity and a decreased risk of having a large-for-gestational-age new-born (Alderman, 1998:518). Jarrett and Spellacy (1983:707) also found no statistical significant correlation between leisure-time physical activity during pregnancy and birth weight. Takito and Benício (2010:100) propose that physical activity during pregnancy might decrease the risk of having a large- or small size-for-gestational-age infant. Hegaard *et al.* (2010:6) conclude that women who engaged in leisure-time physical activity or sports (assessed by a questionnaire) during the early second and third trimester gave birth to infants with a similar birth weight as sedentary women. Another study, Horns *et al.* (1996:51), found similar results where physical activity, specifically brisk walking during the pregnancy, had no significant effect on birth weight. Nonetheless, multiple studies report a statistically-significant relationship between maternal habitual physical activity and birth weight (Bell *et al.*, 1995:35; Campbell & Mottola, 2001:405; Dwarkanath *et al.*, 2007:707; Henriksen *et al.*, 1995:513; Leiferman & Evenson, 2003:61; Magann *et al.*, 2002:469; Mahmoodi *et al.*, 2013:576; Rao *et al.*, 2003:537 Schramm *et al.*, 1996:216; Spinillo *et al.*, 1996:534). The variability of numerous studies regarding the relationship between birth outcomes and physical activity might be due to the subjective determination of physical activity, as this relationship is likely to be modest. Therefore, it is essential to measure recreational physical activity objectively (Chasan-Taber *et al.*, 2007:101)

The relationship between physical activity and the remaining foetal growth parameters have not been as extensively investigated (Bonzini *et al.*, 2009:690; Mohammadreza *et al.*, 2012:227; Rao *et al.*, 2003:536). Although our results indicate a small positive correlation between head circumference and average AEE during all trimesters of pregnancy, this was not statistically-significant. Rao *et al.* (2003:536) associate vigorous physical activity during pregnancy, determined by means of a questionnaire, with a lower head- and arm circumference at birth. The results from this study contradicts Rao *et al.* (2003:536), due to a non-significant, yet positive

correlation between average AEE and head circumference. Another study found small head circumference was more common in babies born to women who had a high occupational physical activity as assessed by interviews, but other associations between small abdominal circumference, small-for-gestational-age infants, pre-term delivery and physical activity was not statistically-significant (Bonzini *et al.*, 2009:690). The results from Mohammadreza *et al.* (2012:227) also show no significant differences in height and head circumferences of new-borns of active or non-active mothers. Head circumference is mainly determined by genetic factors, and the influence of physical activity might be negligible. The variability in head circumference at birth might also be attributed to the external conjugate diameter of the mother's pelvis (Barker *et al.*, 1993:425).

The partial relationship between birth length and AEE was slightly negative, and also not statistically-significant. This is due to birth length being mainly determined by genetic factors. Only one study could be found that researched the influence of physical activity on birth length (Gopinath *et al.*, 2013:476), however no associations were observed between birth length and physical activity. Due to the effect of birth length, as well as birth weight, on Ponderal Index, a small negative correlation was observed between physical activity during pregnancy and Ponderal Index. This negative correlation was not statistically-significant.

Data regarding birth outcomes and physical activity from developing countries are scarce due to difficulties in collecting data throughout pregnancy in rural environments. Furthermore, due to the varying dietary behaviours among the South-African population, from malnutrition to over nutrition, a different approach might be needed when recommending physical activity and dietary information during pregnancy in the South-African context. Comparing South-African data with data from developing countries might provide insight into the relationship between dietary habits, physical activity and birth outcomes, because of the broad spectrum of behaviours in South-Africa. The information gathered can be used to compose clear physical and dietary guidelines for a safe pregnancy.

4.4. Summary

The American College of Sports Medicine (ACSM, 2014:194) recommends pregnant women to spend 30 minutes or more of moderate physical activity per day on most, if not all, days of the week. The results of this study indicate that participants in the HAPPY-study did not follow

these guidelines. Concomitantly, measurements of physical activity declined from the first to the third trimester of pregnancy in average AEE, PAL, activity counts per week, as well as minutes spent doing light-, moderate- and vigorous intensity physical activity. The decrease in activity therefore resulted in sedentary minutes spent increased from the first to the third trimester. These results correspond with multiple studies about physical activity and pregnancy.

Takito and Benício (2010:100) propose a U-shaped relationship between physical activity and pregnancy outcomes, where excessive and insufficient physical activity lead to deleterious effects in foetal outcomes, while foetal outcomes improved with a moderate amount of physical activity during pregnancy. The results from this study augment this proposed relationship. In summary, light- and moderate physical activity during pregnancy may be protective against giving birth to a small- or large-for-gestational-age infant. Respectively, sedentary pregnant women may give birth to large-for-gestational-age infants, while women participating in vigorous physical activity during their pregnancy might give birth to a small-for-gestational age infant. Meeting the recommendations for a healthy physical activity level during pregnancy may result in improved foetal outcomes, protecting against preterm birth and decreasing the risk of giving birth to both a small- or large-for-gestational age infant.

CHAPTER 5: SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

5.1. Summary

5.2. Conclusions

5.3. Limitations

5.4. Recommendations

5.5. Future Research

5.1. Summary

The objectives of this study were, firstly, to determine the habitual physical activity patterns of pregnant women and secondly, to determine the relationship between foetal growth parameters and the habitual physical activity patterns of pregnant women. In Chapter 1 the problem statement indicates the inconsistency of research findings regarding the habitual physical activity patterns of pregnant women, with emphasis on the limited data thereof in South-Africa. Maternal and foetal body compositions are affected by the habitual physical activity pattern of the mother. A low habitual physical activity pattern during pregnancy may result in detrimental effects on long-term health outcomes such as excess maternal weight retention post-pregnancy. The lack of information on objectively-determined habitual physical activity during pregnancy, especially longitudinal data of South African women resulted in the formulation of the research question for this study: What are the objectively-measured, habitual, physical activity patterns of pregnant women across all trimesters of pregnancy, and what is the relationship between the habitual, physical activity during pregnancy and foetal growth parameters?

In Chapter 2, the literature review presents the current evidence of the effects of lifestyle, of which physical activity is a part, on pregnancy, birth and foetal and maternal outcomes post-partum. Early environmental influences, as early as in the womb, explain the long term effects on an individual's health. One of these early environmental influences is maternal physical activity. Regular physical activity during pregnancy not only provides numerous maternal

benefits, but also improves foetal- and birth outcomes. Despite these known benefits, physical activity levels tend to decrease as pregnancy progresses. This reduction in activity levels has led to discrepancies between physical activity and the guidelines set by various institutional and governmental entities, primarily developed in developing countries. The reduction in physical activity might be due to the mother's uncertainties regarding the influence of physical activity on pregnancy and birth outcomes. Despite the large amount of international evidence on physical activity and pregnancy, the habitual activity patterns of pregnant women in South-Africa are unknown. What is however known of the South African female population, is that the levels of overweight and obese women are as high as 60% with inactivity levels matching the overweight and obese statistics. The lack of physical activity in women, combined with weight gain during pregnancy and weight retention post-partum, may contribute to the obesity issue in South Africa.

In addition to the existing literature, the lack of research on objective, habitual, physical activity and pregnancy contributes to misconceptions. The lack of objective research is due to the methodological difficulties in measuring habitual, physical activity patterns. Objectively-determined, physical activity minimises possible inaccuracies of subjectively-determined habitual activity patterns by means of questionnaires. A valid and reliable tool to measure physical activity objectively is the ActiHeart® - a dual heart rate monitor and accelerometer. Determining the influence of physical activity on foetal growth is difficult due to multiple determinants, including lifestyle factors (high risk behaviours, nutrition and physical activity), genetics (maternal and paternal), as well as environmental factors (socio-economic status, environmental pollution). Regular physical activity tends to decrease the risk of having a small- or large for gestational age baby.

Therefore, a longitudinal study investigating the habitual physical activity patterns during pregnancy was necessary to reach the objectives for the study. In Chapter 3, the research methods, a longitudinal observational cohort study design, describes the measurements performed during the study for data collection and the four stages of measurement during the participants' pregnancies: first trimester (9 – 12 weeks), second trimester (20 – 22 weeks), third trimester (28 -32 weeks) and three months post-partum. Habitual physical activity patterns were assessed by means of the ActiHeart®, while foetal growth parameters were collected from medical records.

The main findings and discussion of the HAPPY-study (Chapter 4) on the patterns of habitual physical activity indicate a decline from the first to the third trimester of pregnancy in average AEE, PAL, activity counts, as well as minutes spent doing light-, moderate- and vigorous physical activity. Subsequently, sedentary minutes spent increased from the first to the third trimester. A non-significant negative relationship between average pregnancy AEE and all foetal growth measurements (birth weight, birth length, Ponderal Index) was found, while a non-significant positive relationship was found between head circumference at birth and average AEE.

5.2. Conclusions

The conclusions that are drawn from this study are based on the hypotheses stated in Chapter 1.

Hypothesis 1:

The objectively-determined habitual, physical activity patterns of pregnant women are lower than the prescribed American College of Sports Medicine guidelines and will decrease between the first and third trimester of pregnancy.

The first part of the hypothesis, “habitual, physical activity patterns of pregnant women are lower than the prescribed American College of Sports Medicine guidelines” is *accepted*. The participants in this study only accumulated 103 min/week in the first trimester, 63 min/week in the second trimester and 55 min/week in the third trimester doing moderate intensity physical activity instead of the 30 minutes or more per day on most, if not all, days of the week as recommended by the American College of Sports Medicine.

The second part of the hypothesis “and will decrease from the first to the third trimester of pregnancy” is *rejected*. Although there was a decline in the AEE from the first to the third trimester of pregnancy, this decline was not statistically significant ($p = 0.20$). The only statistical significant decline in AEE observed was from pre-pregnancy to the third trimester of pregnancy ($p = 0.04$). Furthermore, PAL, activity count, as well as minutes spent doing light-, moderate- and vigorous activity decreased.

Hypothesis 2:

Habitual, physical activity patterns have a significant, inverse relationship to foetal growth parameters.

Negative, statistically non-significant correlations were reported between average AEE during pregnancy and birth weight ($r = -0.39$, $p = 0.45$), birth length ($r = -0.16$, $p = 0.77$) and Ponderal Index ($r = -0.34$, $p = 0.51$), while a positive, non-significant correlation was found between average AEE during pregnancy and head circumference ($r = 0.14$, $p = 0.79$). Consequently, the hypothesis is *rejected* due to these non-significant relationships.

In conclusion, habitual physical activity levels, as determined by objective measurements, indicate that participants in the HAPPY-study were not meeting the requirements of at least 30 minutes of moderate physical activity per day as stated in the American College of Sports Medicine guidelines for pregnant women. The reason for the insufficient levels of habitual physical activity might be due to the psychological and physiological changes commonly observed during pregnancy such as an increase body weight, reduced body image and increased symptoms of depression and fatigue. The participants in this study comprise of the three major ethnic groups in South Africa. The low levels of physical activity that were seen in the general female population of South Africa, is therefore supported by the findings of this study. As pregnancy progressed, the physical activity levels decreased even more, and more significantly toward the third trimester compared to the pre-pregnancy period. These findings were expected, because the discomfort levels increase as the foetus increases in weight and size over the 40-weeks of pregnancy. Although AEE was measured, which includes heart rate and movement, heart rate during pregnancy is known to be elevated. The usual movement of a larger body weight with the higher than usual heart rate is expected to increase the AEE. However, this was not the case, as AEE declined in combination to the weight gained during pregnancy. The implication of these results is that the reduced AEE, together with the weight gain during pregnancy lead to excess weight retention post-partum. Excess weight gain during pregnancy is a precursor to long-term obesity and a predictor of other health risks such as pre-eclampsia and other adverse birth outcomes. Promotion of physical activity during pregnancy may limit excess weight retention during pregnancy and lead to overall improved health outcome for not only the mother, but also the baby.

Foetal growth and habitual, physical activity during pregnancy according to the results of this study are not significantly correlated. This study supports the existing literature in the fact that there is no coherent relationship between foetal growth and physical activity. The negative correlation between AEE and birth weight, birth length and Ponderal Index can be attributed to physical activity providing protection against giving birth to a small- or large-for-gestational-age infant. The proposed relationship can be illustrated as an U-curve, where low physical activity during pregnancy contribute to giving birth to a large-for-gestational age infant and where a high level physical activity might contribute to the birth of a small-for-gestational age infant. The low levels of habitual physical activity and subsequently large-for-gestational age infants observed in the participants in the HAPPY-study might explain the predominantly negative relationship between various foetal growth parameters and physical activity. The positive relationship between head circumference and habitual, physical activity indicates that neural development of the foetus is not impaired in mothers that are habitually physically active. Therefore, adhering to the recommendations for a healthy, habitual, physical activity level during pregnancy might improve foetal outcomes.

In the South African context, the study outcomes can augment the importance of habitual, physical activity during pregnancy on the maternal and foetal health benefits in the local community, as well as similar communities in developing countries. Habitual, physical activity does not have to constitute a formal exercise regimen. Consideration of the socio-ecological factors associated with physical activity specific to the rural setting will aid the promotion of a healthy lifestyle during pregnancy.

5.3. Limitations

The limitations experienced, which should be noted when interpreting the results of this study and which could be surmounted in future research, are:

- The compliance to the longitudinal design in this study was weak, especially pertaining to women measured from low socio-economic areas.
- The sample size of the study limited the grouping of participants according to categories of physical activity, which would have assisted in the correlation analyses. According to the number of babies born in the Potchefstroom area, the target of 20 pregnant women to be recruited per month from a possible 80 pregnancies seemed obtainable. However, the target

was not realistic since very few participants were referred for participation via the gynaecologists. The nature of the design also extended the period available for completion of the study.

- It is a challenge to obtain pre-pregnancy measurements, resulting in self-reported pre-pregnancy weight being recorded, which might be underestimated or incorrect.
- Some of the subjects' home language was neither Afrikaans nor English – the language of the researcher. Furthermore, some of the pregnant women felt uncomfortable to be measured by a man, and would have preferred to be measured by a woman.

5.4. Recommendations

The following recommendations are given in order to obtain a clearer understanding regarding the influence of physical activity during pregnancy on foetal growth:

- The sample size of the study can be increased by establishing better multidisciplinary collaboration between doctors, nurses, gynaecologists and clinic health workers.
- In order to ensure a sample size that is adequate to categorise levels of activity, appropriate incentives should be included in order to increase compliance in the study. When working in a Public health environment, it is recommended that appropriate incentives are providing food after the measurements have been completed and a form of travel and communication support.
- Measuring women before they conceive will enhance understanding of multiple variables affecting physical activity, resting metabolic rate and gestational weight gain. during pregnancy.
- A translator for the study/multilingual researcher could overcome the language barrier.

5.5. Future research

A possible intervention, randomised, controlled trial can be piloted, where physical activity recommendations are given to pregnant mothers (experimental group). Similar data sampling can then be done in both the experimental and control group. The information gathered from this intervention can then be used to develop South-African specific physical activity guidelines for pregnant women.

REFERENCES

Aaron, D.L., Jekal, Y.S. & LaPorte, R.E. 2005. Epidemiology of physical activity from adolescence to young adulthood. *Word Revue of Nutrition and Diet*, 94:36-41.

ACOG (American College of Obstetricians and Gynecologists). 2002. Exercise during pregnancy and the postpartum period. ACOG Committee Opinion. *International Journal of Gynaecology and Obstetrics: The Official Organ of the International Federation of Gynaecology and Obstetrics*, 77(1):79-81.

ACSM (American College of Sports Medicine). 2014. ACSM's Guidelines for Exercise Testing and Prescription. 9th ed. Philadelphia, PA: Lippincott Williams and Wilkins.

Adams, T.B., Moore, M.T. & Dye, J. 2007. The relationship between physical activity and mental health in a national sample of college females. *Women & Health*, 45(1):69-85.

Agarwal, S., Agarwal, A., Agarwal, K.N., Agarwal, D.K. & Bansal, A. 2001. Physical activity and pregnancy outcome in rural undernourished women. *Indian Pediatrics*, 38:1017-1022.

Ainslie, P.N., Reilly, T. & Westerterp, K.R. 2003. Estimating human energy expenditure; a review of techniques with particular reference to doubly labelled water. *Sports Medicine*, 33(9):683-698.

Ainsworth, B.E., Haskell, W.L., Whitt, M.C., Irwin, M.L., Swartz, A.M., Strath, S.J., O'brien, W.L., Basset, D.R., Schmitz, K.H., Emplaincourt, P.O., Jacobs, D.R., & Leon, A.S. 2000. Compendium of physical activities: an update of activity codes and MET intensities. *Medicine and science in sports and exercise*, 32(9 Suppl): S498-S504.

Ainsworth, B.E., Richardson, M., Jacobs, D.R. & Leon, A.S. 1993. Gender differences in physical activity. *Women in Sport and Physical Activity Journal*, 2(1):1-17.

Aldabe, D. 2012. Pregnancy-related pelvic girdle pain and its relationship with relaxin levels during pregnancy: a systematic review. *European Spine Journal: Official Publication Of The European Spine Society*, 21(9):1769-1776.

Alderman, B.W., Zhao, H., Holt, V.L., Watts, D.H. & Beresford, S.A.A. 1998. Maternal physical activity in pregnancy and infant size for gestational age. *Annals of epidemiology*, 8(8):513-519.

Aittasalo, M., Pasanen, M., Fogelholm, M. & Ojala, K. 2010. Validity and repeatability of a short pregnancy leisure time physical activity questionnaire. *Journal of Physical Activity and Health*, 7(1):109-118.

Albright, C., Maddock, J.E. & Nigg, C.R. 2005. Physical activity before pregnancy and following childbirth in a multiethnic sample of healthy women in Hawaii. *Women Health*, 42(3):95-110.

Alderman, B.W., Zhao, H., Holt, V.L., Watts, D.H. & Beresford, A.A. 1998. Maternal Physical Activity in Pregnancy and Infant Size for Gestational Age. *Annals of Epidemiology*, 8(8):513-519.

American Pregnancy Association. 2008. Eating for two when over/or under weight. At what rate should I gain weight during my pregnancy?
<http://americanpregnancy.org/pregnancyhealth/eatingfortwo.html> Date of access: 22 Jan 2013.

Andersson, K. & Arner, P. 2001. Systemic nicotine stimulates human adipose tissue lipolysis through local cholinergic and catecholaminergic receptors. *International Journal of Obesity & Related Metabolic Disorders*, 25(8):1225-1233.

Arena, B. & Maffulli, N. 2002. Exercise in pregnancy: how safe is it? *Sports medicine arthroscopy review*, 10(1):15-22.

Armstrong, T. & Bull, F. 2006. Development of the World Health Organization Global Physical Activity Questionnaire (GPAQ). *Journal of Public Health*, 14(2):66-70.

- Artal, R. 1992. Exercise and pregnancy. *Clinical Sports Medicine*, 11(2):363-377.
- Artal, R. & O'Toole, M. 2003. Guidelines of the American College of Obstetricians and Gynaecologists for exercise during pregnancy and the postpartum period. *British journal of sports medicine*. 37(1):6–12.
- Baciuk, E.P., Pereira, R.I., Cecatti, J.G., Braga, A.F. & Cavalcante, S.R. 2008. Water aerobics in pregnancy: cardiovascular response, labor and neonatal outcomes. *Reproductive Health*, 21(5): 10-21,.
- Baicker, K., Buckles, K.S. & Chandra, A. 2006. Geographic variation in the appropriate use of cesarean delivery. *Health Affairs*, 25:w355-w367.
- Bailit, J.L., Love, T.E. & Mercer, B. 2004. Rising cesarean rates: Are patients sicker? *American Journal of Obstetrics and Gynecology*, 191(3):800-803.
- Barbet, J.P., Thornell, L.E. & Butler-Browne, G.S. 1991. Immunocytochemical characterisation of two generations of fibres during the development of the human quadriceps muscle. *Mechanisms of Development*, 35(1):3-11.
- Barker, D.J.P. 1995. Fetal origins of coronary heart disease. *British Medical Journal*, 311(6998):171-174.
- Barker, D.J.P., Gluckman, P.D. & Robinson, J.S. 1995. Conference report: fetal origins of adult disease-report of the First International Study Group. *Placenta*, 16(3):317-320.
- Barker, D.J.P., Osmond, C., Goding, J. Kuh, D. & Wadsworth, M.E.J. 1989. Growth in utero, blood pressure in childhood and adult life, and mortality from cardiovascular disease. *British Medical Journal*, 298(6673):564-567.
- Barker, D.J.P., Osmond, C., Simmonds, S.J. & Wield, G.A. 1993. The relation of small head circumference and thinness at birth to death from cardiovascular diseases in adult life. *British Medical Journal (International Edition)*, 306(6875):422-426.

Barker, D.J.P., Winter, P.D., Osmond, C. & Margetts, B. 1989. Weight in infancy and death from ischemic heart disease. *Lancet*, 2(8663):577-580.

Barnes, D.L., Adair, L.S. & Popkin, B.M. 1991. Women's physical activity and pregnancy outcome: a longitudinal analysis from the Philippines. *International journal of epidemiology*, 20(1):162-172.

Barr, H.M., Bookstein, F.L., O'Malley, K.D., Connor, P.D., Huggins, J.E. & Streissguth, A.P. 2006. Binge Drinking During Pregnancy as a Predictor of Psychiatric Disorders on the Structured Clinical Interview for DSM-IV in Young Adult Offspring. *The American Journal of Psychiatry*, 163(6):1061-1065.

Barreira, T.V., Minsoo, K., Caputo, J.L., Farley, R.S., Renfrow, M.S. 2009. Validation of the Actiheart Monitor for the Measurement of Physical Activity. *International Journal of Exercise Science*, 2(2):60-72.

Barsky, E., Smith, T., Patricios, J., Collins, R., Branfield, A. & Ramagole, M. 2012. South African Sports Medicine Association Position Statement on Exercise in Pregnancy. *The South African Journal of Sports Medicine*, 24(2):69-71.

Batista, D.C., Chiara, V.L., Gugelmin, S.A., Martins, P.D. 2003. Physical activity and pregnancy: non-athletic pregnant women's health and fetal growth. *The Brazilian Journal of Mother and Child Health*, 3(2):151-158.

Bauman, A.E. & Sallis, J.F. 2008. Global problems require global studies. *American Journal of Preventive Medicine*, 34(6):544-545.

Beckmann, C.R. & Beckman, C.A. 1990. Effect of a structured antepartum exercise program on pregnancy and labor outcome in primiparas. *The Journal of Reproductive Medicine*, 35(7):704-709.

Bell, R. 2002. The Effects of Vigorous Exercise During Pregnancy on Birth Weight. *Journal of science and medicine in sports*, 5(1):32-36.

Bell, R.J., Palma, S.M. & Lumley, J.M. 1995. The effect of vigorous exercise during pregnancy on birth-weight. *Journal of science & medicine in sport*, 5(1):32-36.

Bell, R.J. & O'Neill, M. 1994. Exercise and pregnancy: a review. *Birth*, 21(2):85-89.

Bell, R.J. & Palma, S. 2000. Antenatal exercise and birthweight. *The Australian & New Zealand Journal of Obstetrics & Gynaecology*, 40(1):70-73.

Bell, R.J., Palma, S.M. & Lumley, J.M. 1995. The effect of vigorous exercise during pregnancy on birth-weight. *Australian and New Zealand journal of obstetrics and gynaecology*, 35(1):46–51.

Bernstein, I.M., Horbar, J.D., Badger, G.J., Ohlsson, A. & Golan, B. 2000. Morbidity and mortality among very-low-birth-weight neonates with intrauterine growth restriction: the Vermont Oxford Network. *American journal Of Obstetrics And Gynecology*, 182(1 Pt 1):198-206.

Bernstein, I.M., Mongeon, J.A., Badger, G.J., Solomon, L., Heil, S.H. & Higgins, S.T. 2005. Maternal smoking and its association with birth weight. *Obstetrics & Gynecology*, 106(5 Part 1):986-991.

Biolo, G., Heer, M., Nirici, M., Strollo, F. 2003. Microgravity as a model of ageing. *Current Opinion In Clinical Nutrition And Metabolic Care*, 6(1):31-40.

Blackburn, S.T. 2003. Maternal, Fetal, & Neonatal Physiology: A Clinical Perspective. 2nd ed. St. Louis, MO: Saunders.

Bobak, M. 2000. Outdoor air pollution, low birth weight, and prematurity. *Environmental Health Perspective*, 108(2):173-176.

Bonzini, M., Coggon, D., Godfrey, K., Inskip, H., Crozier, S. & Palmer, K.T. 2009. Occupational physical activities, working hours and outcome of pregnancy: findings from the Southampton Women's Survey. *Occupational & environmental medicine*, 66(10):685-690.

- Borg-Stein, J., Dugan, S.A. & Gruber, J. 2005. Musculoskeletal aspects of pregnancy. *American Journal of Physical Medicine and Rehabilitation*, 84(3):180-192.
- Borodulin, K., Evenson, K.R. & Herring, A.H. 2009. Physical activity patterns during pregnancy through postpartum. *BMC Women's Health*, 19(9):32-39.
- Boudet, G. & Chamoux, A. 2000. Heart Rate Monitors and Abnormal Heart Rhythm Detection. *Archives of Physiology & Biochemistry*, 108(4):371-379.
- Bovbjerg, M.L. & Siega-Riz, A.M. 2009. Exercise during Pregnancy and Cesarean Delivery: North Carolina PRAMS, 2004-2005. *Birth*, 36(3):200-207.
- Brage, S., Brage, N., Ekelund, U., Franks, P.W. & Wareham, N.J. 2006. Effect of combined movement and heart rate monitor placement on physical activity estimates during treadmill locomotion and free-living. *European Journal of Applied Physiology*, 96(5):517-524.
- Brage, S., Brage, N., Franks P.W., Ekelund U. & Wareham, N.J. 2005. Reliability and validity of the combined heart rate and movement sensor Actiheart. *European journal of clinical nutrition*, 59(4):561–570.
- Breeze, A.C.G. & Lees, C.C. 2007. Prediction and perinatal outcomes of fetal growth restriction. *Seminars in Fetal & Neonatal Medicine*, 12(5):383-397.
- Bronstein, M.N., Mak, R.P. & King, J.C. 1995. The thermic effect of food in normal-weight and overweight pregnant women. *British Journal of Nutrition*, 74(2):261-275.
- Brook, C.G. 1972. Evidence for a sensitive period in adipose-cell replication in man. *Lancet*, 2(7778):624-627.
- Bruchova, H., Vasikova, A., Merkerova, M., Milcova, A., Topinka, J., Balascak, I., Pastorkova, A., Sram, R.J. & Brdicka, R. 2010. Effect of Maternal Tobacco Smoke Exposure on the Placental Transcriptome. *Placenta*, 31(3):186-191.

Brunette, E.L., Kotze, J., Wood, P.S., Du Toit, P.J. & Grant, C.C. 2012. An epidemiological study of physical activity patterns and weight gain in physically active and sedentary pregnant women in Tshwane, South Africa. *African Journal for Physical, Health education, Recreation and Dance*, 18(1):132-143.

Bung, P. & Artal, R. 1996. Gestational diabetes and exercise: a survey. *Seminar in Perinatology*, 20(4):328-333.

Bung, P., Artal, R. & Khodiguian, N. & Kjos, S. 1991. Exercise in gestational diabetes: an optional therapeutic approach? *Diabetes*, 40(2):182-185.

Bungum, T.J., Peaslee, D.L., Jackson, A.W. & Perez, M.A. 2000. Exercise during pregnancy and type of delivery in nulliparae. *Journal of Obstetrics, Gynecologic and Neonatal Nursing*, 29(3):258-264.

Burchfiel, C.M., Sharp, D.S., Curb, J.D., Rodriguez, B.L., Hwang, L.J. & Marcus, B. 1995. Physical activity and incidence of diabetes: The Honolulu heart program. *American Journal of Epidemiology*, 141(4):360-368.

Burd, L., Roberts, D., Olson, M. & Odendaal, H. 2007. Ethanol and the placenta: a review. *Journal of Maternal-Fetal and Neonatal Medicine*, 20(5):361-375.

Butte, N.F., Wong, W.W., Treuth, M.S., Ellis, K.J. & Smith, E.O. 2004. Energy requirements during pregnancy based on total energy expenditure and energy deposition. *American journal of clinical nutrition*, 79(6):1078-1087.

Calguneri, M., Bird, H.A. & Wright, V. 1982. Changes in joint laxity occurring during pregnancy. *Annals of the Rheumatic Diseases*, 41(2):126-128.

Campbell, M.K. & Mottola. 2001. Recreational exercise and occupational activity during pregnancy and birth weight: a case-control study. *American journal of Obstetrics and Gynecology*, 184(3):403-408.

Campbell, N., Prapavessis, H., Gray, C., McGowan, E., Rush, E. & Maddison, R. 2012. The Actiheart in Adolescents: A Doubly Labelled Water Validation. *Pediatric Exercise Science*, 24(4):589-602.

Capeless, E.L. & Clapp, J.F. 1989. Cardiovascular changes in early phase of pregnancy. *American Journal of Obstetrics and Gynecology*, 161(6 Pt 1):1449-1453.

Carey, G.B. & Quinn, T.J. 2001. Exercise and lactation: are they compatible? *Canadian Journal of Applied Physiology*, 26(1):44-74.

Carlin, A. & Alfirevic, Z. 2008. Physiological changes of pregnancy and monitoring. *Best Practice & Research Clinical Obstetrics and Gynaecology*, 22(5):801-823.

Caspersen, C.J., Powell, K.E. & Christenson, G.M. 1985. Physical Activity, Exercise and Physical Fitness: Definitions and Distinctions for Health-Related Research. *Public Health Reports*, 100(2):126-131.

Cedergren, M. 2006. Effects of gestational weight gain and body mass index on obstetric outcome in Sweden. *International Journal of Gynecology & Obstetrics*, 93(3):269-274.

Chamberlain, G. & Pipkin, F.B. 1998. Clinical Physiology in Obstetrics. 3rd ed. Nottingham, U.K.: Blackwell Scientific Publisher.

Chandonnet, N., Saey, D., Alm  ras, N. & Marc, I. 2012. French pregnancy physical activity questionnaire compared with an accelerometer cut point to classify physical activity among pregnant obese women. *PLoS ONE*, 7(6):1-9.

Chasan-Taber, L., Evenson, K.R., Sternfeld, B. & Kengeri, S. 2007. Assessment of recreational physical activity during pregnancy in epidemiologic studies of birthweight and length of gestation: methodologic aspects. *Women and health*, 45(4):85-107.

Chasan-Taber, L., Schmidt, M.D., Roberts, D.E., Hosmer, D., Markenson, G. & Freedson, P.S. 2004. Development and validation of a Pregnancy Physical Activity Questionnaire. *Medicine & Science in Sports and Exercise*, 36(10):1750-1760.

Chasan-Taber, L., Silveira, M., Marcus, B.H., Braun, B., Stanek, E. & Markenson, G. 2011. Feasibility and Efficacy of a Physical Activity Intervention Among Pregnant Women: The Behaviors Affecting Baby and You (B.A.B.Y) Study. *Journal of Physical Activity & Health*, 8(Suppl. 2):S228-S239.

Chiriboga, C.A. 2003. Fetal alcohol and drug effects. *Neurologist*, 9(6):267-279.

Chu, S.Y., Bachman, D.J., Callaghan, W.M., Whitlock, E.P., Dietz, P.M., Berg, C.J., O’Keeffe-Rosetti, M., Bruce, F.C. & Hornbook, M.C. 2008. Association between obesity during pregnancy and increased use of health care. *New England Journal of Medicine*, 358(14):1444-1453.

Cioffi, J., Schmied, V., Dahlen, H., Mills, A., Thornton, C., Duff, M., Cummings, J. & Kolt, G.S. 2010. Physical Activity in Pregnancy: Women’s Perceptions, Practices, and Influencing Factors. *Journal of midwifery and women’s health*, 55(5):455–461.

Clapp, J.F. 1989. The effects of maternal exercise on early pregnancy outcome. *American journal of obstetrics and gynecology*, 161(6 Pt. 1):1453-1457.

Clapp, J.F. 1990. The course of labor after endurance exercise during pregnancy. *American Journal of Obstetrics and Gynecology*, 163(6 Pt 1):1799-1805.

Clapp, J.F. 1991. Exercise and fetal health. *Journal of Developmental Physiology*, 15(1):9-14.

Clapp, J.F. 2000. Exercise during pregnancy: a clinical update. *Clinical Sports Medicine*, 19(2):273-286.

Clapp, J.F. 2006. Influence of endurance exercise and diet on human placental development and fetal growth. *Placenta*, 27(6):527–534.

Clapp, J.F. & Little, K.D. 1995. The interaction between regular exercise and selected aspects of women’s health. *American Journal Of Obstetrics And Gynecology*, 173(1):2-9.

- Clapp, J.F. 2003. The effects of maternal exercise on foetal oxygenation and feto-placental growth. *European journal of obstetrics and gynecology and reproductive biology*, 110 (supp. 1):S80–S85.
- Clapp, J.F., & Dickstein, S. 1984. Endurance exercise and pregnancy outcome. *Medicine and science in sports and exercise*, 16(6):556–562.
- Clapp, J.F., Kim, H., Burciu, B. & Lopez, B. 2000. Beginning regular exercise in early pregnancy: effect on fetoplacental growth. *American journal of obstetrics and gynecology*, 183(6):1484–1488.
- Clapp, J.F., Kim, H., Burciu, B., Schmidt, S., Petry, K. & Lopez, B. 2002. Continuing regular exercise during pregnancy: effect of exercise volume on fetoplacental growth. *American journal of obstetrics and gynecology*, 186(1):142–147.
- Clapp, J.F., Lopez, B. & Harcar-Swvcik, R. 1999. Neonatal behavioural profile of the offspring of women who continued to exercise regularly throughout pregnancy. *American Journal of Obstetrics and Gynecology*, 180(1):91-94.
- Clapp, J.F., Rockey, R., Treadway, J.L., Carpenter, M.W., Artal, R.M. & Warnes, C. 1992. Exercise in pregnancy: a short review. *Medicine & Science in Sports & Exercise*, 24(6):S294-S300.
- Clapp, J.F., Simonian, S., Lopez, B., Appleby-Wineberg, S. & Harcar-Sevcik, R. 1998. The one-year morphometric and neurodevelopmental outcome of the offspring of women who continued to exercise regularly throughout pregnancy. *American Journal of Obstetrics and Gynecology*, 178(3):594-599.
- Clarke, P.E., Rousham, E.K., Gross, H., Halligan, A.W. & Bosio, P. 2005. Activity patterns and time allocation during pregnancy: a longitudinal study of British women. *Annals of Human Biology*, 32(3):247-259.

Cliver, S.P., Goldenberg, M.D., Cutter, G.R., Hoffman, H.J., Davis, R.O. & Nelson, K.G. 1995. The effect of cigarette smoking on neonatal anthropometric measurements. *Obstetrics and Gynecology*, 85(4):625-630.

Cnattingius, S. & Lambe, M. 2002. Trends in smoking and overweight during pregnancy: prevalence, risk of pregnancy complications and adverse pregnancy outcomes. *Seminars in Perinatology*, 26(4):286-295.

Cohen, T., Plourde, H. & Koski, K.G. 2013. Use of the Pregnancy Physical Activity Questionnaire (PPAQ) to Identify Behaviors Associated With Appropriate Gestational Weight Gain During Pregnancy. *Journal of Physical Activity & Health*, 10(7):1000-1007.

Collins, J. & David, R. 1997. Urban violence and African-American pregnancy outcome: an ecologic study. *Ethnicity & Disease*, 7(3):184-190.

Collins, J., David, R., Symons, R., Handler, A., Wall, S. & Andes, S. 1998. African-American mothers' perception of their residential environment, stressful life events, and very low birthweight. *Epidemiology*, 9(3):286-289.

Contaldo, F., Scalfi, L., Coltorti, A., Di Palo, M.R., Martinelli, P. & Guerritore, T. 1987. Reduced regulatory thermogenesis in pregnant and ovariectomized women. *International Journal for Vitamin and Nutrition Research*, 57(3):299-304.

Copper, R., Goldenberg, R., Das, A., Elder, N., Swain, M., Norman, G., Ramsey, R., Cotroneo, P., Collins, B.A., Johnson, F., Jones, P. & Meier, A. 1996. The Preterm Prediction Study: Maternal stress is associated with spontaneous preterm birth at less than thirty five weeks' gestation. *American Journal of Obstetrics and Gynecology*, 175(5):1286-1292.

Corder, K., Brage, C., Mattocks, C., Ness, A., Riddoch, C., Wareham, N.J. & Ekelund, U. 2007. Comparison of two methods to assess PAEE during six activities in children. *Medicine & Science in Sports and Exercise*, 39(12):2180-2188.

Crowther, C.A. & Han, S. 2010. Hospitalisation and bed rest for multiple pregnancy. *Cochrane Database of Systematic Reviews (Online)*, 7:CD000110, Jul. (Abstract).

Da Costa, D., Rippen, N., Dritsa, M. & Ring, A. 2003. Self-reported leisure-time physical activity during pregnancy and relationship to psychological well-being. *Journal Of Psychosomatic Obstetrics And Gynaecology*, 24(2):111-119.

Damjanovic, S.S., Stojic, R.V., Lalic, N.M., Jotic, A.Z., Macut, D.P., Ognjanovic, S.I., Petakov, M.S. & Popovic, B.M. 2009. Relationship between basal metabolic rate and cortisol secretion throughout pregnancy. *Endocrine*, 35(2):262-268.

Davies, G.A., Wolfe, L.A., Mottola, M.F., Mackinnon, C. 2003. Joint SOGC/CSEP clinical practice guideline: exercise in pregnancy and the postpartum period. *Journal of obstetrics and gynaecology of Canada*, 28(3):329–341.

De Santis, M. De Luca, C., Mappa, I., Quattrocchi, T., Angelo, L. & Cesari, E. 2011. Smoking, alcohol consumption and illicit drug use in an Italian population of pregnant women. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, 159(1):106-110.

Declercq, E., Meacker, F. & Macdorman, M. 2006. Maternal risk profiles and the primary cesarean rate in the United States, 1991-2002. *American Journal of Public Health*, 96(5):867-872.

Dehghan, M., Jaramillo, P.L., Ruby, D., Anaya, L.L., Garcia, R.G., Xiaohe, Z., Islam, S. & Merchant, A.T. 2012. Development and Validation of a Quantitative Food Frequency Questionnaire among Rural- and Urban-dwelling Adults in Colombia. *Journal of Nutrition Education & Behavior*, 44(6):609-613.

Dejmek, J., Selevan, S.G., Benes, I., Solansky, I. & Sram, R.J. 1999. Fetal growth and maternal exposure to particulate matter during pregnancy. *Environmental Health Perspective*, 107(6):475-480.

Dekeyser-Boccaro, J. & Milliez, J. 2005. Smoking and ectopic pregnancy: is there a causal relationship? *Journal de Gynecologie*, 34(1):S119-123, Apr.

- Dempsey, J.C., Sorensen, T.K., Williams, M.A., Lee, I.M., Miller, R.S., Dashow, E.E. & Luthy, D.A. 2004. Prospective study of gestational diabetes mellitus risk in relation to maternal recreational physical activity before and during pregnancy. *American Journal of Epidemiology*, 159(7):663-670.
- Derbyshire, E., Davies, G.J., Costarelli, V. & Dettmar, P.W. 2008. Habitual patterns of physical activity during pregnancy and postnatally. *Maternal Health*, 16(1):20-24.
- Devine, C.M., Bove, C.F. & Olson, C.M. 2000. Continuity and change in women's weight orientations and lifestyle patterns and the postpartum period: the influence of life course trajectories and transitional events. *Social Science and Medicine*, 50(4):567-582.
- Dewey, K.G. & McCrory, M.A. 1994. Effects of dieting and physical activity on pregnancy and lactation. *American Journal of Clinical Nutrition*, 59(2S):446S-453S.
- Domingues, M.R. & Barros, A.J. 2007. Leisure-time physical activity during pregnancy in the 2004 Pelotas Birth Cohort Study. *Journal of Public Health*, 41(2):173-180.
- Domingues, M.R., Matijasevich, A., Santos, I. & Barros, A. 2012. Fetal growth and leisure-time physical activity during pregnancy. *Journal of Science and Medicine in Sport*, 15(4):S283-S283.
- Downs, D.S., Chasan-Taber, L., Evenson, K., Jenn, L. & Yeo, S. 2012. Physical activity and Pregnancy: Past and Present Evidence and Future Recommendations. *Research Quarterly for Exercise & Sport*, 83(4):485-502.
- Duncombe, D., Wertheim, E.H., Skouteris, H., Paxton, S.J. & Kelly, L. 2007. Factors related to exercise over the course of pregnancy including women's beliefs about the safety of exercise during pregnancy. *Midwifery*, 25(4):430-438.
- Duncombe, M.D., Skouteris, H., Wertheim, E.H., Kelly, L., Fraser, V. & Paxton, S.J. 2006. Vigorous exercise and birth outcomes in a sample of recreational exercisers: A prospective study across pregnancy. *Australian and New Zealand journal of obstetrics and gynaecology*, 46(2):288-292.

Durnin, J.V., McKillop, F.M., Grant, S., Fitzgerald, G. 1987. Energy requirements of pregnancy in Scotland. *Lancet*, 2(8564):897-900.

Dwarkanath, P., Muthayya, S., Vaz, M., Thomas, T., Mhaskar, A., Mhaskar, R., Thomas, A., Bhat, S. & Kurpad, A. 2007. The relationship between maternal physical activity during pregnancy and birth weight. *Asia Pacific journal of clinical nutrition*, 16(4):704-710.

Edwards, M.J. 1986. Hyperthermia as a teratogen: a review of experimental studies and their clinical significance. *Teratogenesis, Carcinogenesis, and Mutagenesis*, 6(6):563-582.

Ekbom, A., Hsieh, C.C., Lipworth, L., Wolk, A., Pontén, J., Adami, H.O. & Trichopoulos, D. 1996. Perinatal characteristics in relation to incidence of and mortality from prostate cancer. *British Medical Journal (Clinical Research Ed.)*, 313(7053):337-341.

Ellekjær, H., Holmen, J., Ellekjaer, E. & Vatten, L. 2000. Physical activity and stroke mortality in women: ten-year follow-up of the Nord-Trøndelag health survey, 1984-1986. *Stroke*, 31(1):14-18.

Emery, P.W. 2005. Metabolic changes in malnutrition. *Nature Publishing Group*, 19(10):1029-1034.

Eskenazi, B., Prehn, A.W., Christianson, R.E. 1995. Passive and active maternal smoking as measured by serum cotinine: the effect on birthweight. *American Journal of Public Health*, 85(3):395-398.

Eston, R.G., Rowlands, A.V. & Ingledew, D.K. 1998. Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. *Journal of Applied Physiology*, 84(1):362-371.

Evenson, K.R. 2011. Towards an understanding of change in physical activity from pregnancy through postpartum. *Psychology of sports & exercise*, 12(1):36-43.

- Evenson, K.R., Chasan-Taber, L., Downs, D.S. & Pearce, E.E. 2012a. Review of self-reported physical activity assessments for pregnancy: summary of the evidence for validity and reliability. *Paediatric and perinatal*, 26(5):479-494.
- Evenson, K.R., Herring, A.H. & Wen, F. 2012b. Self-Reported and Objectively Measured Physical Activity Among a Cohort of Postpartum Women: The PIN Postpartum Study. *Journal of physical activity and health*, 9(1):5-20.
- Evenson, K.R. & Wen, F. 2010. Measuring physical activity among pregnant women using a structured one-week recall questionnaire: evidence for validity and reliability. *The International Journal of Behavioral Nutrition and Physical Activity*, 7(21):1-12.
- Evenson, K.R. & Wen, F. 2011. Prevalence and correlates of objectively measured physical activity and sedentary behaviour among US pregnant women. *Preventive Medicine*, 53(1):39-43.
- Evenson, K.R., Savits, D.A. & Huston, S.L. 2004. Leisure-time physical activity among pregnant women in the U.S. *Paediatrics, Perinatal and Epidemiology*, 18(6):400-407.
- Fall, C.H.D., Osmond, C., Barker, D.J.P., Clark, P.M., Hales, C.N., Stirling, Y. & Meade, T.W. 1995. Fetal and infant growth and cardiovascular risk factors in women. *British Medical Journal*, 310(6977):428-432.
- Fang, J., Madhavan, S. & Alderman, M. 1999. Low birth weight: race and maternal nativity - impact of community income. *Pediatrics*, 103(1):1-6.
- Fantuzzi, G., Aggazzotti, G., Righi, E., Faccinetti, F., Bertucci, E. & Kanitz, S. 2007. Preterm delivery and exposure to active and passive smoking during pregnancy: a case-control study from Italy. *Paediatric & Perinatal Epidemiology*, 21(3):194-200.
- Figueras, F., Meler, E., Eixarch, E., Francis, A., Coll, O., Gratacos, E. & Gardosi, J. 2008. Association of smoking during pregnancy and fetal growth restriction: Subgroups of higher susceptibility. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, 138(2):171-175.

Florack, E.I., Pellegrino, A.E., Zielhuis, G.A. & Rolland, R. 1995. Influence of occupational physical activity on pregnancy duration and birth-weight. *Scandinavian journal of work, environment & health*, 21(3):199-207.

Forsum, E., Kabir, N., Sadurkis, A. & Weterterp, K. 1992. Total energy expenditure of healthy Swedish women during pregnancy and lactation. *The American Journal of Clinical Nutrition*, 56(2):334-342.

Freedson, P.S. & Miller, K. 2000. Objective monitoring of physical activity using motion sensors and heart rate. *Research Quarterly for Exercise and Sport*, 71(2):S21-S29.

Freedson, P.S., Melanson, E. & Sirard, J. 1998. Calibration of the Computer Science and Applications, Inc. accelerometer. *Medicine & Science in Sports & Exercise*, 30(5):777-781.

Fried, P.A., Watkinson, B. & Willan, A. 1984. Marijuana use during pregnancy and decreased length of gestation. *American Journal of Obstetrics And Gynecology*, 150(1):23-27.

Gale, C.R., Martyn, C.N., Kellingray, S., Eastell, R., Cooper, C. 2001. Intrauterine programming of adult body composition. *The Journal Of Clinical Endocrinology And Metabolism*, 86(1):267-272.

Garcia-Rio, F., Pino, J.M., Gomez, L., Alvarez-Sala, R., Villasante, C. & Villamor, J. 1996. Regulation of breathing and perception of dyspnoea in healthy pregnant women. *Chest*, 110(2):446-453.

Gardosi, J., Mul, T., Mongelli, M. & Fagan, D. 1998. Analysis of birthweight and gestational age in antepartum stillbirths. *British Journal of Obstetrics and Gynaecology*, 105(5):524-530.

Ghodsi, Z., Asltoghiri, M. & Hajiloomohajerani, M. 2012. Exercise and pregnancy: duration of labor stages and perinea tear rates. *Procedia – Social and Behavioral Sciences*, 31:441-445.

Glinoe, D. 2004. The regulation of thyroid function during normal pregnancy: importance of the iodine nutrition status. *Best Practice & Research Clinical Endocrinology & Metabolism*, 18(2):133-152.

Goldenberg, R.L., Cliver, S.P., Bronstein, J., Cutter, G.R., Andrews, W.W., Mennemeyer, S.T. 1994. Bed rest in pregnancy. *Obstetrics And Gynecology*, 84(1):131-136.

Gopinath, B., Hardy, L.L., Baur, L.A., Burlutsky, G. & Mitchell, P. 2013. Birth weight and time spent in outdoor physical activity during adolescence. *Medicine & science in sports & exercise*, 45(3):475-480.

Guillaume, M., Lapidus, L., Beckers, F., Lambert, A., Björntorp, P. 1995. Familial trends of obesity through three generations. *International Journal of Obesity and Related Metabolic Disorders: Journal of International Association for the Study of Obesity*, 19(3):S5-S9.

Gupta, R. & Gupta, V.P. 1996. Meta-analysis of coronary heart disease in India. *Indian Heart Journal*, 48(3):241-245.

Guszkowska, M. 2011. Physical activity in relation to affective states and labor anxiety in pregnant women. *Medicina Sportiva*, 15(3):114-119.

Guthold, R., Ono, T., Strong, K.L., Chatterji, S. & Morabia, A. 2008. Worldwide Variability in Physical Inactivity: A 51-Country Survey. *American Journal of Preventive Medicine*, 34(6):486-494.

Ha, E.H., Hong, Y.C., Lee, B.E., Woo, B.H., Schwartz, J. & Christiani, D.C. 2001. Is air pollution a risk factor for low birth weight in Seoul? *Epidemiology*, 12(6):643-648.

Haakstad, L.A. & Voldner, N. & Bø, K. 2012. Stages of change model for participation in physical activity during pregnancy. *Journal of Pregnancy*, 2013:1-8.

Haakstad, L.A.H. & Bø, K. 2011. Exercise in pregnant women and birth weight: a randomized controlled trial. *BMC Pregnancy and Childbirth*, 11:66-73.

Hales, C.N., Barker, D.J.P., Clark, P.M.S., Cox, L.J., Fall, C.H.D., Osmond, C. & Winter, P.D. 1991. Fetal and infant growth and impaired glucose tolerance at age 64. *British Medical Journal*, 303(6809):1019-1022.

Hall, D.C. & Kaufmann, D.A. 1987. Effects of aerobic and strength conditioning on pregnancy outcomes. *American Journal of Obstetrics and Gynecology*, 157(5):1199-1203.

Hall, M.H., Chng, P.K. & MacGillivray, I. 1980. Is routine antenatal care worthwhile? *Lancet*, 2(8185):78-80, Jul.

Hammami, M., Walters, J.C., Hockman, E.M. & Koo, W.W. 2001. Disproportionate alterations in body composition of large for gestational age neonates. *The Journal of Pediatrics*, 138(6):817-821.

Hansen, C., Sorensen, L.D., Asmussen, I. & Autrup, H. 1992. Transplacental exposure to tobacco smoke in human-adduct formation in placenta and umbilical cord vessels. *Teratogenesis, Carcinogenesis, And Mutagenesis*, 12(2):51-60.

Hatch, E.E. & Bracken, M.B. 1986. Effect of marihuana use in pregnancy on fetal growth. *Journal of Ethnopharmacology*, 20(3):986-993.

Hatch, M.C., Ji, B.T., Shu, X.O. & Susser, M. 1997. Does standing, lifting, climbing or long hours of working during pregnancy have an effect during fetal growth? *Epidemiology*, 8(5):530-536.

Hatch, M.C., Shu, X.O., Mclean, D.E., Levin, B., Begg, M., Reuss, L. & Susser, M. 1993. Maternal exercise during pregnancy, physical fitness, and fetal growth. *American Journal of Epidemiology*, 137(10):1105–1114.

Hattersley, A.T. & Tooke, J.E. 1999. The fetal insulin hypothesis: an alternative explanation of the association of low birthweight with diabetes and vascular disease. *Lancet*, 353(9166):1789-1792.

Hausenblas, H., Giacobbi, P., Cook, B., Rhodes, R. & Cruz, A. 2011. Prospective examination of pregnant and nonpregnant women's physical activity beliefs and behaviours. *Journal of Reproductive and Infant Psychology*, 29(4):308-319.

Hayatbakhsh, M.R., Kingsbury, A.M., Flenady, V., Gilshenan, K.S., Hutchinson, D.M. & Najman, J.M. 2010. Illicit drug use before and during pregnancy at a tertiary maternity. *Drug & Alcohol Review*, 30(2):181-187.

Hediger, M.L., Overpeck, M.D., Kuczmarski, R.J., McGlynn, A., Maurer, K.R. & Davis, W.W. 1998. Muscularity and fatness of infants and young children born small- or large-for-gestational-age. *Pediatrics*, 102(5):E60-E67.

Hegaard, H.K., Damm, P., Hedegaard, M., Henriksen, T.B., Ottesen, B., Dykes, A. & Kjaergaard, H. 2011. Sports and Leisure Time Physical Activity During Pregnancy in Nulliparous Women. *Maternal Child Health Journal*, 15(6):806-813.

Hegaard, H.K., Petersson, K., Hedegaard, M., Ottesen, B., Dykes, A.K., Henriksen, T.B. & Damm, P. 2010. Sports and leisure-time physical activity in pregnancy and birth weight: a population-based study. *Scandinavian journal of medicine & science in sports*, 20(1):1-7.

Heidemann, B.H. & McClure, J.H. 2003. Changes in maternal physiology during pregnancy. *British Journal of Anaesthesia*, 3(3):65-68.

Heini, A., Scuttz, Y., Diaz, E., Prentice, A.M., Whitehead, R.G., Jequier, E. 1991. Free-living energy expenditure measured by two independent techniques in pregnant and nonpregnant Gambian women. *American Journal of Physiology*, 261(1 Pt 1):E9-E17.

Helmrich, S.P., Ragland, D.R., Leung, R.W. & Paffenbarger, R.S. 1991. Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *New England Journal of Medicine*, 325(3):147-152.

Hendelman, D., Miller, K., Baggett, C., Debold, E. & Freedson, P. 2000. Validity of accelerometry for the assessment of moderate intensity physical activity in the field. *Medicine & Science in Sports & Exercise*, 32(9):S442-S449.

Henderson, J., Gray, R. & Brocklehurst, P. 2007. Systematic review of effects of low-moderate prenatal alcohol exposure on pregnancy outcome. *BJOG: An International Journal of Obstetrics & Gynaecology*, 114(3):243-252.

Henderson, J., Kesmodel, U. & Nordstrom, B. 2007. Systematic review of the fetal effects of prenatal binge-drinking. *Journal of Epidemiology & Community Health*, 61(12):1069-1073.

Henriksen, T.B., Hedegaard, M. & Secher, N.J. 1995. Standing and walking at work and birthweight. *Acta obstetrica et gynecologica Scandinavica*, 74(7):509-516.

Hernández-Martínez, C., Val, V.A., Subías, J.E. & Sans, J.C. 2012. A longitudinal study on the effects of maternal smoking and seondhand smoke exposure during pregnancy on neonatal neurobehavior. *Early Human Development*, 88(6):403-408.

Herrmann, S.D., Heumann, K.J., Der Ananian, C.A. & Ainsworth, B.E. 2013. Validity and Reliability of the Global Physical Activity Questionnaire (GPAQ). *Measurement in Physical Education and Exercise Science*, 17(3):221-235.

Hickey, C.A., Cliver, S.P., Mulvihill, F.X., McNeal, S.F., Hoffman, H.J. & Goldenberg, R.L. 1995. Employment-related stress and preterm delivery: a contextual examination. *Public Health Reports*, 110(4):410-418.

Hingson, R., Alpert, J.J., Day, N., Dooling, E., Kayne, H., Morelock, S., Oppenheimer, E. & Zuckerman, B. 1982. Effects of maternal drinking and marijuana. *Pediatrics*, 70(4):539-545.

Hinton, P.S. & Olson, C.M. 2001. Predictors of pregnancy-associated change in physical activity in a rural white population. *Maternal and child health journal*, 5(1):7-14.

Hoffman, S. & Hatch, M. 1996. Stress, social support and pregnancy outcome: a reassessment based on recent research. *Paediatric and Perinatal Epidemiology*, 10(4):380-405.

Holan, S., Mathiesen, M. & Petersen, K. 2005. A National Clinical Guideline for Antenatal Care. <http://helsedirektoratet.no/publikasjoner/retningslinjer-for-svangerskapsomsorgen-kortversjon/Publikasjoner/a-national-clinical-guideline-for-antenatal-care%E2%80%93short-version.pdf> Date of access: 8 Jul. 2013.

Holschen, J.C. 2004. The female athlete. *Southern Medical Journal*, 97(9):852-858.

Horns, J.F., Ratcliffe, L.P., Leggett, J.C. & Swanson, M.S. 1996. Pregnancy outcomes among active and sedentary primiparous women. *Journal of obstetrics, gynaecology and neonatal nursing*, 25(1):49–54.

Horta, B.L., Victora, C.G., Menezes, A.M., Halpern, R. & Barros, F.C. 1997. Low birth weight, preterm births and intrauterine growth retardation in relation to maternal smoking. *Paediatric and Perinatal Epidemiology*, 11(2):140-151.

Hu, G., Jousilahti, P., Barengo, N.C., Qiao, Q., Lakka, T.A. & Tuomilehto, J. 2005. Physical activity, cardiovascular risk factors, and mortality among Finnish adults with diabetes. *Diabetes Care*, 28(4):799-805.

Hutch, R. & Erkkola, R. 1990. Pregnancy and exercise-exercise and pregnancy. A short review. *British Journal of Obstetrics and Gynaecology*, 97(3):208-214.

Hutchinson, S.L. 2011. Physical Activity, Recreation, Leisure, and Sport: Essential Pieces of the Mental Health and Well-being Puzzle.

<http://www.recreationns.ns.ca/files/Mental%20Health%20Lit%20Review%20full%20doc.pdf>

Date of access: 6 July 2012

Illingworth, P.J., Jung, R.T., Howie, P.W. & Isles, T.E. 1987. Reduction in postprandial energy expenditure during pregnancy. *British Medical Journal (Clinical Research Edition)*, 294(6587):1573-1577.

Innes, K., Byers, T. & Schymura, M. 2000. Birth characteristics and subsequent risk for breast cancer in very young women. *American Journal of Epidemiology*, 152(12):1121-1128.

Jahromi, M.K., Jahromi, B.N. & Hojjati, S. 2011. Relationship between Daily Physical Activity During Last Month of Pregnancy and Pregnancy Outcome. *Iranian red crescent medical journal*, 13(1):15-20.

Janz, K.F. 2002. Use of heart rate monitors to assess physical activity. (In Welk, G.J., 1st ed. Physical activity assessments for health-related research. United States: Human Kinetics. p. 143-161).

Jarrett, J.C. & Spellacy, W.N. 1983. Jogging during pregnancy: an improved outcome. *Obstetrics and gynaecology*, 61(1):705-709.

Jarski, R.W. & Tripett, D. L. 1990. The risks and benefits of exercise during pregnancy. *Journal of family practice*, 30(2):185-189.

Jauniaux, E. & Burton, G.J. 2007. Morphological and biological effects of maternal exposure to tobacco smoke on the feto-placental unit. *Early Human Development*, 83(11):699-706.

Jauniaux, E. & Greenough, A. 2007. Short and long term outcomes of smoking during pregnancy. *Early Human Development*, 83(11):697-698.

Jauniaux, E., Gulbis, B., Acharya, G., Thiry, P. & Rodeck, C. 1999. Maternal tobacco exposure and cotinine levels in fetal fluids in the first half of pregnancy. *Obstetrics and Gynecology*, 93(1):25-29.

Jensen, D., Webb, K.A. & O'Donnell, D.E. 2007. Chemical and mechanical adaptations of the respiratory system at rest and during exercise in human pregnancy. *Applied Physiology, Nutrition, And Metabolism*, 32(6):1239-1250.

Jensen, D., Wolfde, L.A., Slatkovska, L., Webb, K.A., Davies, G.A.L. & O'Donnell, D.E. 2005. Effects of human pregnancy on ventilator chemoreflex response to carbon dioxide. *American Journal of Physiology – Regulatory, Integrative and Comparative Physiology*, 288(5):1369-1375.

Jones, J., Housman, J. & Willis, M. 2010. Exercise, nutrition, and weight management during pregnancy. *American Journal of Health Studies*, 25(3):120-129.

Juhl, M., Anderson, P.K., Olsen, J., Madsen, M., Jørgensen, T., Nøhr, E.A. & Andersen, A.M. 2008. Physical exercise during pregnancy and the risk of preterm birth: a study within the Danish National Birth Cohort. *American Journal of Epidemiology*, 167(7):63e1-63e8.

Juhl, M., Olsen, J., Anderson, P.K., Nøhr, E.A. & Anderson, A.N. 2010. Physical exercise during pregnancy and fetal growth measures: a study within the Danish National Birth Cohort. *American journal of obstetrics and gynecology*, 202(1):63e1-63e8.

Kabir, A.A., Steinmann, W.C., Myers, L., Khan, M.M. Herrera, E.A., Yu, S. & Jooma, N. 2004. Unnecessary cesarean delivery in Louisiana: an analysis of birth certificate data. *American Journal of Obstetrics and Gynaecology*, 190(1):10-19.

Kac, G., Pacheco, A.H.R.N. Araújo, D.M.R., Rocha, C.M.M, Sousa, E.B., Coelho, N.L.P., Oliveira, L.C. & Muniz, B.M. 2007. Associated factors to physical activity practice in leisure in postpartum women. *Revista Brasileira de Medicina do Esporte*, 13(2):86-90.

Kalisiak, B. & Spitznagle, T. 2009. What effect does an exercise program for healthy pregnant women have on the mother, fetus, and child? *American academy of physical medicine and rehabilitation*, 1:261-267.

Källén, K. 2001. The impact of maternal smoking during pregnancy on delivery outcome. *European Journal of Public Health*, 11(3):329-333.

Kardel, K.E. & Kase, T. 1998. Training in pregnant women: effects on fetal development and birth. *American journal of obstetrics and gynecology*, 178(2):280–286.

Karter, A.J., Rowell, S.E., Ackerman, L.M., Mitchell, B.D., Ferrara, A., Selby, J.V. & Newman, B. 1999. Excess maternal transmission of type 2 diabetes. *Diabetes Care*, 22(6):938-943.

Kawaguchi, J.K. & Pickering, R.K. 2010. The Pregnant Athlete, Part 1: Anatomy and Physiology of Pregnancy. *Athletic Therapy Today*, 15(2):39-43.

- Klebanoff, M.A., Shiono, P.H. & Carey, J.C. 1990. The effect of physical activity during pregnancy on preterm delivery and birth weight. *American journal of obstetrics and gynecology*, 163(5 Pt 1):1450-1456.
- Knight, B., Shields, B.M., Turner, M., Powell, R.J., Yajnik, C.S. & Hattersley, A.T. 2005. Evidence of genetic regulation of fetal longitudinal growth. *Early Human Development*, 81(10):823-831.
- Kopp-Hoolihan, L.E., Van Loan M.D., Wong W.W. & King, J.C. 1999. Longitudinal assessment of energy balance in well-nourished, pregnant women. *American Journal of Clinical Nutrition*, 69(4):697-704.
- Kramer, M.S. 1987. Determinants of low birth weight: methodological assessment and meta-analysis. *Bulletin World Health Organization*, 65(5):663-737.
- Kritz-Silverstein, D., Barrett-Conner, E. & Corbeau, C. 2001. Cross-sectional and prospective study of exercise and depressed mood in the elderly. *American Journal of Epidemiology*, 153(6):596-603.
- Kuijper, E.A.M., Ket, J.C.F., Caanen, M.R. & Lambalk, C.B. 2013. Reproductive hormone concentrations in pregnancy and neonates: a systematic review. *Reproductive BioMedicine Online*, 27(1):33-63.
- Kulpa, P.J., White, B.M & Visscher, R. 1987. Aerobic exercise in pregnancy. *American Journal of Obstetrics and Gynecology*, 156(6):1395-1403.
- Kushi, L. Fee, R., Folsom, A.R., Mink, P.J., Anderson, K.E. & Sellers, T.A. 1989. Physical activity and mortality in postmenopausal women. *Journal of the American Medical Association*, 277(16):1287-1292.
- Kyrklund-Blomberg, N.B., Genuser, G. & Cnattingius, S. Placental abruption and perinatal death. 2001. *Paediatric and Perinatal Epidemiology*, 15(3):290-297.

- Laaksonen, D.E., Lakka, H.M., Lynch, J., Lakka, T.A., Kishanen, L., Rauramaa, R., Salonen, J.T. & Kauhanen, J. 2003. Cardiorespiratory fitness and vigorous leisure-time physical activity modify the association of small size at birth with the metabolic syndrome. *Diabetes Care*, 26(7):2156-2164.
- Law, C.M. & Shiell, A.W. 1996. Is blood pressure inversely related to birth-weight? The strength of evidence from a systematic review of the literature. *Journal of Hypertension*, 14(8):935-941.
- Law, C.M., Barker, D.J.P., Osmond, C., Fall, C.H.D., Simmonds, S.J. 1992. Early growth and abdominal fatness in adult life. *Journal of Epidemiology & Community Health*, 46(3):184-186.
- Lawrence, M. & Whitehead, R.G. 1988. Physical activity and total energy expenditure of child-bearing Gambian village women. *European Journal of Clinical Nutrition*, 42(2):145-160.
- Lawrence, M., Singh, J., Lawrence, F. & Whitehead, R.G. 1985. The energy cost of common daily activities in African women: increased expenditure in pregnancy? *American Journal of Clinical Nutrition*, 42(5):753-763.
- Lazzaroni, F., Bonassi, S., Magnani, M., Calvi, A., Repetto, E., Serra, F., Podestà, F. & Pearce, N. 1993. Moderate maternal drinking and outcome of pregnancy. *European Journal of Epidemiology*, 9(6):599-606.
- LeClere, F.B. & Wilson, J.B. 1997. Smoking behaviour of recent mothers, 18-44 years of age, before and after pregnancy: United States, 1990. *Advance data*, 288:1-10.
- Lee, C.D., Blair, S.N. & Jackson, A.S. 1999. Cardiorespiratory fitness, body composition, and all-cause and cardiovascular disease mortality in men. *American Journal of Clinical Nutrition*, 69(3):373-380.
- Lee, P.H., Macfarlane, D.J., Lam, T.H. & Stewart, S.M. 2011. Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. *International Journal of Behavioural Nutrition and Physical Activity*, 8:115-126.

Leiferman, J.A. & Evenson, K.R. 2003. The Effect of Regular Leisure Physical Activity on Birth Outcomes. *Maternal and Child Health Journal*, 7(1):59-64.

Lewis, B., Avery, M., Jennings, E., Sherwood, N., Martinson, B. & Crain, A.L. 2008. The effects of exercise during pregnancy on maternal outcomes: practical implications for practice. *American Journal of Lifestyle Medicine*, 2(5):441-455.

Lichtensteiger, W., Ribary, U., Schiumpf, M., Odermatt, B. & Widemer, H.R. 1988. Prenatal adverse effects of nicotine on the developing brain. *Progress in Brain Research*, 73:137-157.

Little, R.E. & Wendt, J.K. 1991. The effects of maternal drinking in the reproductive period: an epidemiologic review. *Journal of Substance Abuse*, 3(2):187-204.

Lobos, H., Rennie, J.M. & Lees, C. 2005. The natural history of fetal growth restriction in women with abnormal uterine artery Doppler. *Prenatal Diagnosis*, 25(4):331-332.

Löf, M. 2011. Physical activity pattern and activity energy expenditure in healthy pregnant and non-pregnant Swedish women. *European Journal of Clinical Nutrition*, 65(12):1295-1301.

Löf, M. & Forsum, E. 2006. Activity patterns and energy expenditure due to physical activity before and during pregnancy in healthy Swedish women. *The British Journal of Nutrition*, 95(2):296-302.

Löf, M., Olausson, H., Bostrom, K., Janerot-Sjöberg, B., Sohlstrom, A. & Forsum, E. 2005. Changes in basal metabolic rate during pregnancy in relation to changes in body weight and composition, cardiac output, insulin-like growth factor I, and thyroid hormones in relation to fetal growth. *American Journal of Clinical Nutrition*, 81(3):678-685.

Lokey, E.A., Tran, Z.V., Wells, C.L., Meyers, B.C. & Tran, A.C. 1991. Effects of physical exercise on pregnancy outcomes: a meta-analytic review. 23(11):1234-1239.

- Loos, R.J., Beunen, G., Fagard, R., Derom, C., Vlietinck, R. 2001. Birth weight and body composition in young adult men – a prospective twin study. *International Journal of Obesity and Related Metabolic Disorders: Journal of the International Association for the Study of Obesity*, 25(10):1537-1545.
- Lucas, A. 1991. Programming by early nutrition in man. (In Bock, G.R. Whelan, J., ed. *The childhood environment and adult disease*. Chichester: John Wiley, p. 38-50).
- Lucas, A. 1994. Role of nutritional programming in determining adult morbidity. *Archives of disease in childhood*, 71(4):288-290.
- Luck, W., Nau, H., Hansen, R. & Steding, R. 1985. Extent of nicotine and cotinine transfer to the human fetus, placenta and amniotic fluid of smoking mothers. *Developmental Pharmacology And Therapeutics*, 8(6):384-395.
- Lui, J., Blair, S.N., Teng, Y., Ness, A.R., Lawlor, D.A. & Riddoch, C. 2010. Physical activity during pregnancy in a prospective cohort of British women: results from the Avon longitudinal study of parents and children. *European journal of epidemiology*, 26(3):237-247, Dec.
- Luke, B. & Papiernik, E. 1997. The effects of lifestyle on prematurity. (In Elder, M.G., Lamont, R.F., Romero, R., ed. *Preterm labor*. New York: Churchill Livingstone, p. 127-152).
- Macera, C.A., Ham, S.A., Yore, M.M., Jones, D.A., Ainsworth, B.E., Kimsey, C.D. & Kohl, H.W. 2001. Prevalence of physical activity in the United States: Behavioral Risk Factor Surveillance System. *Preventing Chronic Disease*, 2(2):A17.
- Maconochie, N., Doyle, P., Prior, S. & Simmons, R. 2007. Risk factors for the first trimester miscarriage – results from a UK-population-based case-control study. *BJOG: An International Journal of Obstetrics & Gynaecology*, 114(2):170-186.
- Magann, E.F., Evans, S.F., Newnham, J.P. 1996. Employment, exertion, and pregnancy outcome: assessment by kilocalories expended each day. *American Journal of Obstetrics and Gynecology*, 175(1):182-187.

- Magann, E.F., Evans, S.F., Weitz, B. & Newnham, J. 2002. Antepartum, intrapartum, and neonatal significance of exercise on healthy low-risk pregnant working women. *Obstetrics and Gynecology*, 99(3):466-472.
- Magnus, P., Gjessing, H.K., Skrondal, A. & Skjaerven, R. 2001. Paternal contribution to birth weight. *Journal of Epidemiology & Community Health*, 55(12):873-877.
- Mahmoodi, Z., Karimlou, M., Sajjadi, H., Dejman, M., Vameghi, M., Dolatian, M. & Eftekhari, M.B. 2013. Physical activity pattern and personal-social factors of mothers during pregnancy and infant birth weight based on MET scale: a case-control study. *Iranian red crescent medical journal*, 15(7):573-580.
- Maisonet, M., Bush, T.J., Correa, A., Jaakkola, J.K. 2001. Relation between ambient air pollution and low birth weight in the northeastern United States. *Environmental Health Perspective*, 109(3):351-356.
- Maisonet, M., Correa, A., Misra, D. & Jaakkola, J.J.K. 2004. A review of the literature on the effects of ambient air pollution on fetal growth. *Environmental Research*, 95(1):106-115.
- Manini, T.M. 2010. Energy expenditure and aging. *Ageing Research Reviews*, 9(1):1-11.
- Marquez-Sterling, S., Perry, A.C., Kaplan, T.A., Halberstein, R.A. & Signorile, J.F. 2000. Physical and psychological changes with vigorous exercise in sedentary primigravidae. *Medicine & Science in Sports & Exercise*, 32(1):58-62.
- Marshall, E.S., Bland, H. & Melton, B. 2013. Perceived Barriers to Physical Activity Among Pregnant Women Living in a Rural Community. *Public Health Nursing*, 30(4):361-369.
- Marshall, E.S., Bridget, M., Helen, B. & Jacquelyn, N. 2013. Physical Activity and Muscular Strengthening in Pregnancy: A Rural Urban Comparison. *Online Journal of Rural Nursing & Health Care*, 13(1):50-65.

- Martin, J.A., Hamilton, B.E., Sutton, P.D., Ventura, S.J., Menacker, F. & Munson, M.L. 2005. Births: final data for 2003. *National vital statistics report: from the centers for disease control and prevention, national center for health statistics, national vital statistics system*, 54(2):1-116.
- Masset, H.A., Greenup, M., Ryan, C.E., Staples, D.A., Green, N.S. & Maibach, E.W. 2003. Public perceptions about prematurity: a national survey. *American journal of preventive medicine*, 24(2):120-127.
- McArdle, W.D., Katch, F.I. & Katch, V.L. 2010. *Exercise Physiology: Nutrition, Energy, and Human Performance*. 7th ed. Baltimore, M.D: Lippincott Williams & Wilkins.
- McCance, R.A. & Widdowson, E.M. 1974. The determinants of growth and form. *Proceedings of the Royal Society of London*, 185(1078):1-17, Jan.
- McKeigue, P.M., Shah, B. & Marmot, M.G. 1991. Relation of central obesity and insulin resistance with high diabetes prevalence and cardiovascular risk in South Asia. *Lancet*, 377(8738):330-336.
- McMurray, R.G., Mottola, M.F., Wolfe, L.A. Artal, R., Millar, L. & Pivarnik, J.M. 1993. Recent advances in understanding maternal and fetal responses to exercise. *Medicine in Science in Sports & Exercise*, 25(12):1305-1321.
- Melzer, K., Lazzeri, M., Armand, S., Boulvain, M., Schutz, Y. & Kayser, B. 2012. Validation of the Actiheart for estimating physical activity related energy expenditure in pregnancy. *E-Spen Journal*, 7(1):e5-e10.
- Melzer, K., Schutz, Y., Boulvain, M. & Kayser, B. 2009. Pregnancy-related changes in activity energy expenditure and resting metabolic rate in Switzerland. *European Journal of Clinical Nutrition*, 63(10):1183-1191.
- Melzer, K., Schutz, Y., Boulvain, M. & Kayser, B. 2010a. Physical Activity and Pregnancy: Cardiovascular Adaptations, Recommendations and Pregnancy Outcomes. *Sport medicine*, 40(6):493–507.

- Melzer, K., Schutz, Y., Soehnchen, N., Othenin-Girard, V., Martinez de Tejada, B., Irion, O., Boulvain, M. & Kayser, B. 2010b. Effects of recommended levels of physical activity on pregnancy outcomes. *American Journal of Obstetrics And Gynecology*, 202(3):226.e1-226.e6.
- Miles, L. 2007. Physical activity and health. *Nutrition bulletin*, 32:314–363.
- Milunsky, A., Ulcickas, M., Rothman, K.J., Willett, W., Jick, S.S. & Jick, H. 1992. Maternal heat exposure and neural tube defects. *Journal of the American Medical Association*, 268(7):882-885.
- Mitchell, E.A. & Milerad, J. 2006. Smoking and the sudden infant death syndrome. *Reviews of environmental health*, 21(2):81-104.
- Mittlemark, R.A., Wiswell, R.A. & Drinkwater, B.L. 1991. Exercise in pregnancy. 2nd ed. Baltimore, MD: Williams & Wilkins.
- Mohammadreza, D., Mehdi, S., Mehdi, Z. & Tahereh, A. 2012. Relationship between physical activity of mothers before and during pregnancy with the newborn health and pregnancy outcome. *Journal of physical education & sport*, 12(2):222-230.
- Mojtahedi, M., De Groot, L.C.P., Boekholt, H.A. & Van Raaij, J.M.A. 2002. Nitrogen balance of healthy Dutch women before and during pregnancy. *American Journal of Clinical Nutrition*, 75(6):1078-1083.
- Morley, R., Leeson, P.C., Lister, G. & Lucas, A. 1995. Maternal smoking and blood pressure in 7.5 to 8 year old offspring. *Archives of disease in childhood*, 72(2):120-124.
- Mottola, M.F. 2002. Exercise in the postpartum period: practical applications. *Current Sports Medicine Reports*, 1(6):362-368.
- Mottola, M.F. & Campbell, M.K. 2003. Activity patterns during pregnancy. *Canadian Journal of Applied Physiology*, 28(4):642-653.

- Mozurkewich, E.L., Luke, B., Avni, M. & Fredric, M.W. 2000. Working conditions and adverse pregnancy outcome: a meta-analysis. *Obstetrics & Gynecology*, 95(4):623-635.
- Mudd, L.M., Pivarnik, J., Holzman, C.B., Paneth, N., Pfeiffer, K. & Hwan, C. 2012. Leisure-Time Physical Activity in Pregnancy and the Birth Weight Distribution: Where Is the Effect? *Journal of physical activity & health*, 9(8):1168-1178.
- Nagy, L.E. & King, J.C. 1984. Postprandial energy expenditure and respiratory quotient during early and late pregnancy. *American Journal of Clinical Nutrition*, 40(6):1258-1263.
- Nair, L., Nair, M.K.C. Chacko, D.S. 2009. Markers of Fetal Onset Adult Diseases. *Indian Pediatrics*, 46:S48-S54.
- Nguyen, R.H.N. & Wilcox, A.J. 2005. Terms in reproductive and perinatal epidemiology: 2. perinatal terms. *Journal of epidemiology and community health*, 59(12):1019-1021.
- Nieman, D.C., Austin, M.D., Benezra, L., Pearce, S., McInnis, T., Unick, J. & Gross, S.J. 2006. Validation of Cosmed's Fitmate™ in measuring oxygen consumption and estimating resting metabolic rate. *Research in Sports Medicine*, 14(2):1-8.
- Ning, Y., Williams, M.A., Dempsey, J.C., Sorensen, T.K., Frederick, I.O & Luthy, D.A. 2003. Correlates of recreational physical activity in early pregnancy. *The Journal of Maternal-Fetal & Neonatal Medicine*, 13(6):385-393.
- Norwitz, E.R., Edusa, V. & Park, J.S. 2005. Maternal physiology and complications of multiple pregnancy. *Seminars in perinatology*, 29(5):338-348.
- O'Campo, P., Xu, X., Wang, M-C. & Caughy, M. 1997. Neighborhood risk factors for low birthweight in Baltimore: a multilevel analysis. *American Journal of Public Health*, 87(7):1113-1118.
- O'Leary, C.M., Nassar, N., Kurinczuk, J.J. & Bower, C. 2009. The effect of maternal alcohol consumption on fetal growth and preterm birth. *An International Journal of Obstetrics & Gynaecology*, 116(3):390-400.

O'Neill, M.E. 1996. Maternal rectal temperature and fetal heart rate responses to upright cycling in late pregnancy. *British Journal of Sports Medicine*, 30(1):32-35.

Odent, M., 2001. New reasons and new ways to study birth physiology. *International Journal of Gynecology and Obstetrics*, 75(1):S39-S45.

Oken, E. & Gillman, M.W. 2003. Fetal Origins of Obesity. *Obesity Research*, 11(4):496-506.

Okereke, N.C., Huston-Presley, L., Saeid, B.A., Kalhan, S. & Patrick, M.C. 2004. Longitudinal changes in energy expenditure and body composition in obese women with normal and impaired glucose tolerance. *American Journal of Physiology – Endocrinology and Metabolism*, 287(3): E472-E479.

Okun, N., Verma, A., Mitchell, B.F. & Flowerdew, G. 1997. Relative importance of maternal constitutional factors and glucose intolerance of pregnancy in the development of newborn macrosomia. *The Journal of Maternal-Fetal Medicine*, 6(5):285-290.

Paisley, T.S., Joy, E.A. & Price, R.J. 2003. Exercise during pregnancy: a practical approach. *Current Sports Medicine Reports*, 2(6):325-330.

Parsons, T.J., Power, C. & Manor, O. 2001. Fetal and early life growth and body mass index from birth to early adulthood in 1958 British cohort: longitudinal study. *British Medical Journal*, 323(7325):1331-1335.

Parsons, T.J., Power, C., Logan, S. & Summerbell, C.D. 1999. Childhood predictors of adult obesity: a systematic review. *International Journal of Obesity & Related Metabolic Disorders*, 23(8):S1-S107.

Penney, D.S. 2008. The Effect of Vigorous Exercise During Pregnancy. *Journal of midwifery and women's health*, 53(2):155–159.

- Pereira, M.A., Rifas-Shiman, S.L., Kleinman, K.P., Rich-Edwards, J.W., Peterson, K.E. & Gillman, M.W. 2007. Predictors of Change in Physical Activity During and After Pregnancy. *American journal of preventive medicine*. 32(4):312–319.
- Perkins, C.C., Pivarnik, J.M., Paneth, N. & Stein, A.D. 2007. Physical activity and fetal growth during pregnancy. *Obstetrics and Gynecology*, 109(1):81-87.
- Piers, L.S., Diggavi, S.N., Thangam, S., Van Raaij, J.M., Shetty, P.S., Hautvast, J.G. 1995. Changes in energy expenditure, anthropometry, and energy intake during the course of pregnancy and lactation in well-nourished Indian women. *The American Journal of Clinical Nutrition*, 61(3):501-513.
- Pivarnik, J.M., Chambliss, H.O., Clapp, J.F. III., Dugan, S.A., Hatch, M.C., Lovelady, C.A., Mottola, M.F. & Williams, M.A. 2006. Special communications, roundtable consensus statement: impact of physical activity during pregnancy and postpartum on chronic disease risk. *Medicine and science in sports and exercise*, 38(4):989–1006.
- Ployhart, R.E. & Vandenberg, R.J. 2010. Longitudinal Research: The Theory, Design, and Analysis of Change. *Journal of Management*, 36(1):94-120.
- Pollack, H., Lantz, P.M. & Frohna, J.G. 2000. Maternal smoking and adverse birth outcomes among singletons and twins. *American Journal of Public Health*, 90(3):395-341.
- Pomeroy, J., Renström, F., Gradmark, A.M., Mogren, I., Persson, M., Bluck, L., Wright, A., Kahn, S.E., Domellöf, M. & Franks, P.W. 2013. Maternal physical activity and insulin action in pregnancy and their relationships with infant body composition. *Diabetes care*, 36(2):267-269.
- Poppitt, S.D., Prentice, A.M., Jequier, E., Schults, Y. & Whitehead, R.G. 1993. Evidence of energy sparing in Gambian women during pregnancy: a longitudinal study using whole-body calorimetry. *The American Journal of Clinical Nutrition*, 57(3):353-364.
- Poudevigne, M.S. & O’Conner, P.J. 2005. Physical activity and mood during pregnancy. *Medicine and science in sports and exercise*. 37(8):1374–1380.

- Poudevigne, M.S. & O'Conner, P.J. 2006. A review of physical activity patterns in pregnant women and their relationship to psychological health. *Sports medicine*, 36(1):19–38.
- Power, C. & Jefferis, B.J. 2002. Fetal environment and subsequent obesity: a study of maternal smoking. *International Journal of Epidemiology*, 31(2):413-419.
- Power, J., Evans, G. & Tsintzas, K. 2013. Pilot validation of the clinical use physical activity questionnaire for pregnancy (CPAQPREG). *British Journal of Sports Medicine*, 47(17):A1133.
- Preece, M.A. & Moore, G.E. 2000. Genomic Imprinting, Uniparental Disomy and Foetal Growth. *Trends in Endocrinology And Metabolism: TEM*, 11(7):270-275.
- Prentice, A.M., Spaaij, C.J., Goldberg, G.R., Poppitt, S.D., Van Raaij, J.M., Totton, M., Swann, D. & Black, A.E. 1996. Energy requirements of pregnant and lactating women. *European Journal of Clinical Nutrition*, 50(1):S82-S111.
- Prevedel, T., Calderon, I., Abadde, J. Borges, V. Rudge, M. 2003. Maternal and perinatal effects of hydrotherapy in pregnancy. *Revista Brasileira de Ginecologia e Obstetrícia*, 25(1):53-59.
- Price, B.B. Amini, S.B. & Kappeler, K. 2012. Exercise in Pregnancy: Effect on Fitness and Obstetric Outcomes – A Randomized Trial. *Medicine & Science in Sports & Exercise*, 44(12):2263-2270.
- Rabkin, C.S., Anderson, H.R., Bland, J.M., Brooke, O.G., Chamberlain, G. & Peacock, J.L. 1990. Maternal activity and birth weight: a prospective, population-based study. *American journal of epidemiology*, 131(3):522-531.
- Rao, S., Kanade, A., Margetts, B.M., Yajnik, C.S., Lubree, H., Rege, S., Desai, B., Jackson, A., Fall, C.H.D. 2003. Maternal activity in relation to birth size in rural India: The Pune Maternal Nutrition Study. *European Journal of Clinical Nutrition*., 57(4):531-542.
- Rasmussen, S. & Irgens, L.M. 2006. The effects of smoking and hypertensive disorders on fetal growth. *BMC Pregnancy And Childbirth*, 6:16-23.

RCOG (Royal College of Obstetricians and Gynaecologists). 2006. Exercise in Pregnancy (Statement 4). <http://www.rcog.org.uk/womens-health/clinical-guidance/exercise-pregnancy>
Date of access: 2 Jul. 2012.

Reeves, S. & Bernstein, I. 2008. Effects of maternal tobacco-smoke exposure on fetal growth and neonatal size. *Expert Review of Obstetrics & Gynecology*, 3:719-739.

Revelli, A., Durandom A. & Massobrio, M. 1992. Exercise and pregnancy: a review of maternal and fetal effects. *Obstetrical and Gynecological Survey*, 47(6):355-367.

Rich-Edwards, J.W., Colditz, G.A., Stampfer, M.J., Manson, J.E., Rosner, B., Hankinson, S.E., Colditz, G.A., Willet, W.C. & Hennekens, C.H. 1999. Birth-weight and the risk for type 2 diabetes mellitus in adult women. *Annals Of Internal Medicine*, 130(4 Pt 1):278-284.

Rich-Edwards, J.W., Stampfer, M.J., Manson, J.E., Rosner, B., HanKinon, S.E., Colditz, G.A., Willet, W.C. & Hennkens, C.H. 1997. Birth weight and risk of cardiovascular disease in a cohort of women followed up since 1976. *British Medical Journal*, 315(7105):396-400.

Riemann, M.K. & Kanstrup Hansen, I.L. 2000. Effects on the foetus of exercise in pregnancy. *Scandinavian Journal of Medicine & Science in Sports*, 10(1):12-19.

Ritz, B. & Yu, F. 1999. The effect of ambient carbon monoxide on low birth weight among children born in Southern California between 1989 and 1993. *Environmental Health Perspective*, 107(1):17-25.

Ritz, B., Yu, F., Chapa, G., Fruin, S. 2000. Effect of air pollution on preterm birth among children born in Southern California between 1989 and 1993. *Epidemiology*, 11(5):502-511.

Roberts, E.M. 1997. Neighborhood social environments and the distribution of low birthweight in Chicago. *American Journal of Public Health*, 87(4):597-603.

- Rode, L., Langhoff-Roos, J., Andersson, C., Dinesen, J., Hammerum, M.S., Mohapeloa, H. & Tabor, A. 2009. Systematic review of progesterone for the prevention of preterm birth in singleton pregnancies. *Acta Obstetrica et Gynecologica*, 88(11):1180-1189.
- Rogers, I. 2003. The influence of birthweight and intrauterine environment on adiposity and fat distribution in later life. *International Journal of Obesity & Related Metabolic Disorders*, 27(7):755-777.
- Rooney, B.L. & Schauburger, C.W. 2002. Excess pregnancy weight gain and long-term obesity: one decade later. *Obstetrics and Gynecology*, 100(2):245-252.
- Rose, N.C., Haddow, J.E., Palomaki, G.E. & Knight, G.J. 1991. Self-rated physical activity level during the second trimester and pregnancy outcome. *Obstetrics and gynaecology*, 78(6):1078–1080.
- Rousham, E.K., Clarke, P.E. & Gross, H. 2006. Significant changes in physical activity among pregnant women in the UK as assessed by accelerometry and self-reported activity. *European Journal of Clinical Nutrition*, 60(3):393-400.
- Sallis, J.F. & Saelens, B.E. 2000. Assessment of physical activity by self-report: status, limitations, and future directions. *Research Quarterly for Exercise & Sport*, 71(2):1-7.
- Salvesen, K.L. & Mørkved, S. 2004. Randomised controlled trial of pelvic floor muscle training during pregnancy. *British Medical Journal (Clinical Research edition)*, 329(7462):378-380.
- Samper, M.P., Jiménez-Muro, A., Nerín, I., Marqueta, A., Ventura, P. & Rodríguez, G. 2012. Maternal active smoking and newborn body composition. *Early Human Development*, 88(3):141-145.
- Sampselle, C.M., Seng, J., Yeo, S., Killion, C. & Oakley, D. 1999. Physical activity and postpartum well-being. *Journal of obstetric, gynecologic & neonatal nursing*, 28(1):41-49.

- Sandman, C.A., Wadhwa, P.D., Chicz-DeMet, A., Dunkel-Schetter, C. & Porto, M. 1997. Maternal stress, HPA activity, and fetal/infant outcome. *Annals of the New York Academy of Sciences*, 814(1):266-275.
- Sandvik, L., Erikssen, J., Thaulow, E. Erikssen, G., Mundal, R. & Rodahl, K. 1993. Physical fitness as a predictor of mortality among healthy, middle-aged Norwegian men. *New England Journal of Medicine*, 328(8):533-537.
- Sayer, A.A. & Cooper, C. 2005. Fetal programming of body composition and musculoskeletal development. *Early Human Development*, 81(9):735-744.
- Schick-Boschetto, B. & Rose, N.C. 1991. Exercise in pregnancy. *Obstetrical & Gynecological Survey*, 47(1):10-13.
- Schmidt, M.D., Freedson, P.S., Pekow, P., Roberts, D., Sternfeld, B. & Chasan-Taber, L. 2006. Validation of the Kaiser Physical Activity Survey in pregnant women. *Medicine & Science in Sports and Exercise*, 38(1):42-50.
- Schramm, W.F., Stockbauer, J.W. & Hoffman, H.J. 1996. Exercise, employment, other daily activities, and adverse pregnancy outcomes. *American journal of epidemiology*, 143(3):211-218.
- Shaheen, S.O., Sterne, J.A., Montgomery, S.M. & Azima, H. 1999. Birth weight, body mass index and asthma in young adults. *Thorax*, 54(5):396-402.
- Shangold, M.M. 1989. Exercise during pregnancy: current state of the art. *Canadian Family Physician*, 25:1675-1689.
- Shearer, E.L. 1993. Cesarean section: medical benefits and costs. *Social Science & Medicine*, 37(10):1223-1231.
- Shephard, R.J. 2003. Limits to the measurement of habitual physical activity by questionnaires. *British journal of sports medicine*, 37(3):197-206.

Siega-Riz, A.M., Viswanathan, M., Moos, M.K., Deierlein, A., Mumford, S., Knaack, J., Thieda, P., Lux, L.J. & Lohr, K.N. 2009. A systematic review of outcomes of maternal weight gain according to the Institute of Medicine recommendations: birthweight, fetal growth, and postpartum weight retention. *American Journal of Obstetrics & Gynecology*, 201(4):339.e1-339.e14.

Sigal, J.R., Kenny, G.P., Wasserman, D.H., Castaneda-Sceppa, C. & White, R.D. 2006. Physical activity / exercise and type 2 diabetes: a consensus statement from the American Diabetes Association. *Diabetes Care*, 29(6):1433-1438.

Silverman, B.L., Rizzo, T., Green, O.C., Cho, N.H., Winter, R.J., Ogata, E.S., Richards, G.E. & Metzger, B.E. 1991. Long-term prospective evaluation of offspring of diabetic mothers. *Diabetes*, 40(Suppl 2):121-125.

Singh, J., Prentice, A.M., Diaz, E., Coward, W.A., Ashford, J., Sawyer, M. 1989. Energy expenditure of Gambian women during peak agricultural activity measured by the doubly-labelled water method. *British Journal of Nutrition*, 62(2):315-329.

Skjaerven, R., Wilcox, A.J., Oyen, N. & Magnus, P. 1997. Mothers' birth weight and survival of their offspring. *British Medical Journal (Clinical Research Ed.)*, 314(7091):1376-1380.

Snyder, J.L. 1990. Aerobic exercise during pregnancy. *Journal of the American board of family practice*, 3(1):50-53.

Sokol, R.J., Delaney-Black, V. & Nordstrom, B. 2003. Fetal alcohol spectrum disorder. *The Journal of the American Medical Association*, 290(22):2996-2999.

Sørensen, H.T., Sabroe, S., Rothman, K.J., Gillman, M., Fischer, P., Sørensen, T.I.A. 1997. Relation between weight and length at birth and body mass index in young adulthood. *British Medical Journal (Clinical Research Ed.)*, 315(7116):1137.

Sørensen, T.K., Williams, M.A., Lee, I.M., Dashow, E.E., Thompson, M.L. & Luthy, D.A. 2003. Recreational physical activity during pregnancy and risk of preeclampsia. *Hypertension*, 41(6):1273-1280.

Spaaij, C.J., Van Raaij, J.N., Van der Heijden, L.J., Schouten, F.J., Drijvers, J.J., De Groot, L.C., Boekholt, H.A. & Hautvast, J.G.A.J. 1994. No substantial reduction of the thermic effect of a meal during pregnancy in well-nourished Dutch women. *British Journal of Nutrition*, 71(1):335-344.

Speakman, J.R. 1998. The history and theory of the doubly labelled water technique. *American Journal of Clinical Nutrition*, 68(4):932S-938S.

Spierer, D.K., Hagins, M., Rundle, A. & Pappas, E. 2011. A Comparison of energy expenditure estimates from the Actiheart and Actical physical activity monitors during low intensity activities, walking and jogging. *European Journal of Applied Physiology*, 111(4):659-668.

Spinillo, A., Capuzzo, E., Baltaro, F., Piazzzi, G., Nicola, S. & Iasci, A. 1996. The effect of work activity in pregnancy on the risk of fetal growth retardation. *Acta obstetrica et gynecologica Scandinavica*, 75(6):531-536.

Sports Medicine Australia. 2009. Exercise in pregnancy. <http://sma.org.au/wp-content/uploads/2009/10/WIS-ExPreg.pdf> Date of access: 8 Jul. 2013.

Spowman, K., Heinig, J. & Ishii, K. 2004. ILCA's inside track: a resource for breastfeeding moms: physical activity: part of your healthy lifestyle. *Journal of human lactation*, 20(1):85-86.

Stein, A.D., Rivera, J.M. & Pivarnik, J.M. 2003. Measuring energy expenditure in habitually active and sedentary pregnant women. *Medicine and science in sports and exercise*, 27(5):634-640.

Sternfeld, B. 1997. Physical activity and pregnancy outcome: review and recommendations. *Sports Medicine*, 23(1):33-47.

Sternfeld, B., Quesenberry, C.P., Eskenazi, B. & Newman, L.A. 1995. Exercise during pregnancy and pregnancy outcome. *Medicine and science in sports and exercise*, 27(5):634-640.

Stevenson, L. 1997. Exercise in pregnancy: part 2: recommendations for individuals. *Canadian Family Physician*, 43:107-111.

Stewart, A., Marfell-Jones, M., Olds, T. & De Ridder, H. 2011. International standards for anthropometric assessment. Lower Hutt, New Zealand: ISAK.

Stien, C.E., Fall, C.H.D., Kumaran, K., Osmond, C., Cox, V. & Barker, D.J.P. 1996. Fetal growth and coronary heart disease in South India. *Lancet*, 348(9037):1269-1273.

Strath, S.J., Bassett, D.R., Thompson, D.L. & Swartz, A.M. 2002. Validity of the simultaneous heart rate-motion sensor technique for measuring energy expenditure. *Medicine & Science in Sports & Exercise*, 34(5):888-894.

Strath, S.J., Swartz, A.M., Bassett, D.R., O'Brien, W.L., King, G.A. & Ainsworth, B.E. 2000. Evaluation of heart rate as a method for assessing moderate intensity physical activity. *Medicine & Science in Sports & Exercise*, 32(9):S465-S470.

Strawbridge, W.J., Deleger, S., Roberts, R.E. & Kaplan, G.A. 2002. Physical activity reduces the risk of subsequent depression for older adults. *American Journal of Epidemiology*, 156(4):328-334.

Szumilewicz, A., Wojtyła, A., Zarębska, A., Drobnik-Kozakiewicz, I., Sawczyn, M. & Kwitneiwka, A. 2013. Influence of prenatal physical activity on the course of labour and delivery according to the new Polish standard for perinatal care. *Annals of Agricultural and Environmental Medicine*, 20(2):380-389.

Takito, M.Y. & Benício, M.H.D. 2010. Physical activity during pregnancy and fetal outcomes: a case-control study. *Journal of Public Health*, 44(1):90-101.

Takito, M.Y., Benício, M.H.D. & Latorre, M.R.D.O. 2005. Maternal posture and its influence on birthweight. *Revista de Saúde Pública*, 39(3):325-332.

Takito, M.Y., Benício, M.H. & Neri, L.C. 2009. Physical activity by pregnant women and outcomes for newborns: a systematic review. *Revista De Saúde Pública*, 43(6):1059-1069.

Tower, C. & Baker, P. 2006. The genetics of fetal growth restriction: implications for management. *Reviews in Gynaecological Practice*, 6(1-2):99-105.

Treuth, M.S. 2002. Applying multiple methods to improve the accuracy of activity assessments. (In Welk, G.J., 1st ed. *Physical activity assessments for health-related research*. United States: Human Kinetics. p. 213-224).

US Department of Health and Human Services. 2008. 2008 Physical Activity Guidelines for Americans. <http://www.health.gov/paguidelines/pdf/paguide.pdf> Date of access: 8 Jul. 2013.

Vaessen, N., Janssen, J.A., Heutink, P., Hofman, A., Lamberts, S.W.J., Oostra, B.A., Pols, H.A.P. & Van Duijn, C.M. 2002. Association between genetic variation in the gene for insulin-like growth factor-I and low birthweight. *Lancet*, 359(9311):1036-1037.

Vagero, D., Koupilova, I., Leon, D.A. & Lithell, U.B. 1999. Social determinants of birthweight, ponderal index and gestational age in Sweden in the 1920s and the 1980s. *Acta Paediatrica*, 88(4):445-453.

Valgesoo, T. & Linkberg, R. 1997. Effect of different physical exercises on pregnancy outcome. *Acta Medica Baltica*, 4(1):101-106.

Van Raaij, J.M., Vermaat-Miedema, S.H., Schonk, C.M., Peek, M.E., Hautvast, J.G. 1987. Energy requirements of pregnancy in the Netherlands. *Lancet*, 2(8565):953-955.

Vielwerth, S.E., Jensen, R.B., Larsen, T. & Greisen, G. 2007. The impact of maternal smoking on fetal and infant growth. *Early Human Development*, 83(8):491-495.

Wadhwa, P., Dunkel-Schetter, C., Shicz-DeMet, A., Porto, M. & Sandman, C. 1996. Prenatal psychosocial factors and the neuroendocrine axis in human pregnancy. *Psychosomatic Medicine*, 58(5):432-446.

Wahlqvist, M.L. 2005. Physical activity for health: an overview. *World Revue of Nutrition and Diet*, 95:62-72.

- Wakefield, M., Gillies, P., Graham, H., Madeley, R. & Symonds, M. 1993. Characteristics associated with smoking cessation during pregnancy among working class women. *Addiction*, 88(10):1423-1430.
- Wallace, A.M., Boyer, D.B., Dan, A. & Holm, K. 1986. Aerobic exercise, maternal self-esteem, and physical discomforts during pregnancy. *Journal of Nurse-Midwifery*, 31(6):255-262.
- Walsh, R.A. 1994. Effects of maternal smoking on adverse pregnancy outcomes: examination of the criteria of causation. *Human Biology*, 66(6):1059-1092.
- Wang, T.W. & Apgar, B.S. 1998. Exercise during pregnancy. *American Family Physician*, 57(8):1847-1852.
- Wang, X., Ding, H., Ryan, L. & Xu, X. 1997. Association between air pollution and low birth weight: a community-based study. *Environmental Health Perspective*, 105(5):514-520.
- Warburton, D.E., Nicol, C.W. & Bredin, S.S. 2006. Health benefits of physical activity: the evidence. *Canadian Medical Association Journal*, 174(7):801-809.
- Warren, K.R. & Foudin, L.L. 2001. Alcohol-Related Birth Defects – The Past, Present, and Future. *Alcohol Research & Health*, 25(3):153-158.
- Warren, M.P. 1991. Exercise in women: effects on reproductive system and pregnancy. *Clinical sports medicine*, 10(1):131-139.
- Welk, G.J. 2002. Use of accelerometry-based activity monitors to assess physical activity. (In Welk, G.J., 1st ed. *Physical activity assessments for health-related research*. United States: Human Kinetics. p. 125-140).
- Whitcome, K.K., Shapiro, L.J. & Lieberman, D.E. 2007. Fetal load and the evolution of lumbar lordosis in bipedal hominins. *Nature*, 450(7172):1075-1078.

Whitney, E. & Rolfes, S.R. 2008. Understanding Nutrition. 11th ed. Belmont, CA: Thomson Wadsworth.

Williams, S. & Poulton, R. 1999. Twins and maternal smoking: ordeals for the fetal origins hypothesis: a cohort study. *British Medical journal*, 318(7188):897-900.

Windham, G.C., Hopkins, B., Fenster, L. & Swan, S.H. 2000. Prenatal active or passive tobacco smoke exposure and the risk of preterm delivery or low birth weight. *Epidemiology*, 11(4):427-433.

Wisborg, K., Kesmodel, U., Henriksen, T.B., Olsen, S.F. & Secher, N.J. 2001. Exposure to tobacco smoke in utero and the risk of stillbirth and death in the first year of life. *American Journal of Epidemiology*, 154(4):322-327.

Wolfe, L.A. & Mottola, M.F. 2000. Validation of guidelines for aerobic exercise in pregnancy. (In Kumbhare, D.A., Basmajian, J.V., ed. Decision making and outcomes in sport rehabilitation. New York: Churchill Livingstone. p. 205-222).

Wolfe, L.A. Hall, P., Webb, K.A., Goodman, L., Monga, M. & McGrath, M.J. 1989. Prescription of aerobic exercise during pregnancy. *Sports Medicine*, 8(5):273-301, Nov.

Wong, S.C. & McKenzie, D.C. 1987. Cardiorespiratory fitness during pregnancy and its effect on outcome. *International Journal of Sports Medicine*, 8(2):79-83.

Wylie, L. 2005. Essential Anatomy And Physiology in Maternity Care. 2nd ed. United Kingdom: Churchill Livingstone.

Xu, X., Ding, H. & Wang, X. 1995. Acute effects of total suspended particles and sulphur dioxides on preterm delivery: a community-based cohort study. *Archives of Environmental Health*, 50(6):407-415.

Yajnik, C.S., Fall, C.H.D., Vaidya, U., Pandit, A.N., Bavdekar, A., Bhat, D.S., Osmond, C., Hales, C.N. & Barker, D.J. 1995. Fetal growth and glucose and insulin metabolism in four year

old Indian children. *Diabetic Medicine: A Journal of the British Diabetic Association*, 306(4):422-426.

Yang, X., Telama, R., Hirvensalo, M., Hintsanen, M., Heintsa, T., Pulkki-Raback, L. & Viikari, J.S.A. 2010. The benefits of sustained leisure-time physical activity on job strain. *Occupational Medicine*, 60(5):369-375.

Zhang, J. & Ratcliffe, J.M. 1993. Paternal smoking and birthweight in Shanghai. *American Journal of Public Health*, 83(2):207-210.

Zhang, J. & Savits, D.A. 1996. Exercise during pregnancy among US women. *Annals Of Epidemiology*, 6(1):53-59.

Zuckerman, R., Frank, D.A., Hingson, R., Amaro, H., Levenson, S.M., Kayne, H, Parker, S., Vinci, R., Aboagye, K., Fried, L.E., Cabral, H., Timperi, R. & Bauchner, H. 1989. Effects of maternal marijuana and cocaine use on fetal growth. *International Journal of Gynecology & Obstetrics*, 30(3):289-290.

Appendices

Appendix A. Informed consent form

Appendix B. HAPPY study Questionnaire

Appendix C. Ethics approval of project

Appendix D. Acknowledgement of Language Review and Reference Editing

Appendix A



Habitual Activity Patterns during Pregnancy (HAPPY-study)



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Physical activity, Sport and Recreation

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E-Mail: Hanlie.moss@nwu.ac.za

25 January 2010

Informed consent

PART 1

You are invited to participate in the above study conducted by the North West University with the purpose to understand the role of habitual physical activity and nutrition in the development of the unborn child and the post pregnancy health outcomes of the mother.

Measurements will be conducted during four stages/measurement points of your pregnancy. These stages are: 1st trimester (9 - 12 weeks), 2nd trimester (20 - 22 weeks), 3rd trimester (28 - 32 weeks) and 3 months after the birth of the baby. The duration of the test will be approximately one hour and 30 minutes. The test protocol will be explained during the evaluation. You will be requested to remove your upper clothes for accurate anthropometric- and body composition measurements. Your habitual physical activity will be measured by Actiheart® heart rate monitor with integrated accelerometer (CamNtech Ltd., UK), which will require you to wear this instrument for 7 consecutive days and return it in its original state. After this, an eight minute step test with a ramp protocol on a step box (21.5 cm in height) will be performed. As with any exercise test, certain risks and discomforts may apply. The risks involved in this exercise test may include abnormal blood pressure, fainting, disorder of heartbeat, and in the most extreme instances, heart attack, stroke or death. Every effort will be made to minimize these risks by continuously monitoring participants throughout exercise testing. It is the participant's responsibility to inform the

study investigator if you feel dizzy, ill-feeling or any other symptoms. If any discomfort is experienced, you may stop at any time during the step test. A resting metabolic rate measurement will also be performed. You will be requested to breathe through an anti-bacterial filter for 15 minutes after a 10 minute resting period.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without penalty. Ethical approval has been obtained from the North-West University (NWU-00044-10-A1).

1. Department performing the research: **Physical activity, Sport and Recreation (PhASRec)**
2. Title of the project: **Longitudinal patterns of Habitual physical activity in Healthy pregnant South African women and associations with foetal growth parameters and birth outcomes**
3. Full names, surname and qualifications of the researcher/project leader: **Sarah Johanna Moss (PhD., MBA. Registered Biokineticist)**
4. Job title of the project leader/researcher: **Associate Professor, Niche area research leader: PhASRec**
5. Full names, surname and qualifications of the persons performing the tests: **Abie van Oort, BSc (Hon), Registered Biokineticist**
6. Name of supervising doctor: **Dr's Strydom, Thomas & Van Rensburg**
7. Precautions taken to protect the participants: **All measurements will be performed by a registered biokineticist who is trained to identify risk factors in pregnant women during exercise testing. The supervising gynaecologists are informed of the time of testing and will be contacted in case of an emergency.**

.....

Signature: Project leader

.....

Date:

PART 2

To the under signed of part 3 of this document:

It is important that you read and understand the following general principles that are applicable to all participants in research projects:

1. Participation in this project is completely voluntarily and no pressure however subtle may be placed on you to participate.
2. It is possible that you may personally not obtain any personal advantage from participating. The knowledge that is however generated by your participation may be to the advantage of others

3. By consenting to participation in this project, you also consent to the data obtained by the researchers to be used as they see fit for scientific purposes with the prerequisite that the identity of the participant will be kept confidential and the participant will not be connected to the data without consent
4. You are free to withdraw from the project at any time without any explanation and without receiving any penalty as a consequence. You are however requested to consider that your withdrawal can influence the statistical reliability of the project negatively.
5. A summary of the project, the risks associated and any discomfort that might be experienced during the project, as well as the advantages of the project is explained in Part 1 on this document.
6. You are encouraged to direct any questions with regards to the project and the measurements to be taken to the project leader and staff involved. They will be happy to answer you and discuss the research with you.
7. If you are under the age of 18 years, you are not permitted to participate in this study
8. You are informed that it is requested of you to state that you will not hold the University accountable for any damages, injuries or death unless there were neglect from the University or any of its employees or staff.
9. If you are married, your spouse is requested to distance himself from any claims against the University in the event of damages or death with regards to the project as explained in part 1 unless it is due to negligence from the University, the employees or the students.

PART 3

Consent

Title of the project: **Longitudinal patterns of Habitual physical activity in Healthy pregnant South African women and associations with foetal growth parameters and birth outcomes**

I, the undersigned.....(full names) have read the information with regards to the project as explained in Part 1 and Part 2. I have also heard the oral version thereof and declare that I understand. I was given the chance to discuss relevant aspects of the project with the leader and here with declare that I voluntarily participate in the project. I here with give consent to participate in the project.

I will not hold the University or any of its employees or students accountable for any damages incurred by me during participation in the project except in the case of negligence from the University. I further agree not to process any legal action against the university due to damages of good of personally as a result of participation in the project, unless it was due to the negligence of the University, its employees or students.

.....

(Signature of the participant)

Signed at POTCHEFSTROOM on the

WITNESSES

1.

2.

Signed at POTCHEFSTROOM on the

Research on married participants the following consent is requested:

I,.....(full names), the spouse of the participant in this project,
here with declare that I will not place any legal complaints against the University for any treatment of
injuries, damages or death of the person participating in this project unless it was as the result of
negligence from the university, its staff or students

Signature: Date:

Appendix B



Habitual Activity Patterns during Pregnancy (HAPPY-study)

Initials and Surname: _____

Date: _____

Trimester: _____

Measurement:

0 1 2 3 4



Demographic Information

ID number		
Birth date	DD / MM / YYYY	
Marital status		
Nationality		
Ethnicity		
Home language		
Occupation		
Highest level of education		
Mean household income per annum (encircle the applicable amount)		
< R 50 000	R 50 000 – R 100 000	R 100 000 – R 150 000
R 150 000 – R 200 000	R 200 000 – R 250 000	R 250 000 – R 300 000
R 300 000 – R 400 000	R 400 000 – R 500 000	> R 500 000

Pregnancy Demographic Information

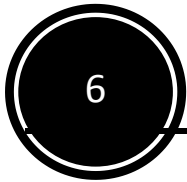
Pre-pregnancy weight (kg)			
Weeks of pregnancy (weeks)			
Type of pregnancy (single, twin or triplets)			
Expected date of birth			
Number of children at home			
Number of previous miscarriages			
Medicinal use	Yes		No
Type of medication	Name of medication	Type of medication	Dosage
	1.		
	2.		
	3.		
	4.		
Smoking status	Current smoker	Ex smoker	Non-smoker
	Number of cigarettes per day _____	Date which you stopped smoking _____ DD / MM / JJJJ	
Alcohol use in the last 3 months	Non drinker	Drinker	
		Number of drinks per day _____/ wine/beer/spirits	
Drug use in the last 3 months	Yes		No

Do you have one of the following conditions	Yes	No
Anemia		
Cardiac dysrhythmia		
Chronic bronchitis		
Poorly controlled type 1 diabetes		
Extreme morbid obesity		
Extreme underweight (BMI < 12)		
Extremely sedentary lifestyle		
Intrauterine growth restriction in current pregnancy		
Poorly controlled hypertension		
Orthopedic limitations		
Poorly controlled hyperthyroidism		
Heavy smoker		
Hemodynamically significant heart disease		
Restrictive lung disease		
Incompetent cervix / cerclage		
Multiple gestation at risk for premature labor		
Persistent second- or third trimester bleeding		
Placenta previa after 26 weeks of gestation		
Premature labor during the current pregnancy		
Ruptured membranes		
Preeclampsia / pregnancy-induced hypertension		

Body mass index								
Length			Weight			BMI		
Waist / Hip ratio								
Waist circum- ference			Hip circum-ference			Waist / Hip circum-ference		
Skinfolds								
Triceps			Supra-iliac			Mid thigh		
Fat percentage								
Bod-Pod Body composition								
Fat percentage				Lean body mass				
Fat mass				Lung volume				
Bio-electrical Impedance								
Total Body Water				Fat percentage				

Blood pressure, Resting Metabolic Rate and Nutritional information

Heart rate (beats/min)	
Blood pressure (mm Hg)	/
Resting Metabolic Rate (ml O ₂ / kg)	
ActiHeart	
AEE	
DEE	
TEE	
Nutritional calculations	
Total Dietary Intake	



Foetal growth parameters

Expected birth weight (grams)	
Head circumference (cm)	
Abdominal circumference (cm)	
Femur length (cm)	
Bi-parietal diameter (cm)	
Ponderal Index	

Appendix C



NORTH-WEST UNIVERSITY
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Prof SJ Moss

Ethics Committee

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ETHICS APPROVAL OF PROJECT

The North-West University Ethics Committee (NWU-EC) hereby approves your project as indicated below. This implies that the NWU-EC grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the project may be initiated, using the ethics number below.

Project title : Longitudinal Patterns of Habitual Physical Activity in Healthy Pregnant South-African Women and Associations with Foetal Growth Parameters and Birth Outcomes

Ethics number:

N	W	U	-	0	0	4	4	-	1	0	-	A	1
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Approval date: 2010-07-13

Expiry date: 2015-07-12

Special conditions of the approval (if any): None

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- The project leader (principle investigator) must report in the prescribed format to the NWU-EC:
 - annually (or as otherwise requested) on the progress of the project,
 - without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.
- The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the NWU-EC. Would there be deviated from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.
- The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-EC and new approval received before or on the expiry date.
- In the interest of ethical responsibility the NWU-EC retains the right to:
 - request access to any information or data at any time during the course or after completion of the project;
 - withdraw or postpone approval if:
 - any unethical principles or practices of the project are revealed or suspected,
 - it becomes apparent that any relevant information was withheld from the NWU-EC or that information has been false or misrepresented,
 - the required annual report and reporting of adverse events was not done timely and accurately,
 - new institutional rules, national legislation or international conventions deem it necessary.

The Ethics Committee would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the Ethics Committee for any further enquiries or requests for assistance.

Yours sincerely

Prof MMJ Lowes
(chair NWU Ethics Committee)

Appendix D

Carissa M. Nel | **Copywriter|
Language
Practitioner**

21 February 2014

Acknowledgement of Language Review and Reference Editing

To whom it may concern,

This serves to confirm that I performed the task of language review and reference editing on Abie van Oort's dissertation, entitled: **The relationship between habitual physical activity patterns of pregnant women and foetal growth parameters** for submission in April 2014.

I, Carissa Maude Nel, obtained a degree in English (specialising in Journalism, Language Editing and English) cum laude from the University of Pretoria in 2009. My post-graduate studies include an honours degree in French and Visual Studies also from the same institution.

I am a seasoned freelance Language Practitioner with more than 5 years' experience, with various high-profile tertiary education clients, including the University of Pretoria, UNISA and North-West University. In addition, I am a member of the Professional Editors' Group (PEG).

Should any further particulars be required, please do not hesitate to contact me.

Carissa Nel



Copywriter | Language Practitioner

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