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

AF van Oort
20344562

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

Supervisor: Prof SJ Moss
Co-supervisor: Dr J Strydom

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.
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
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 daaglike fisieke aktiwiteit vir swanger vroue en het ook geleit tot die huidiglike bestaande, breë, algemene fisieke aktiwiteitsriglyne. Fisieke aktiwiteitsvlakke wat deur subjektiewe vraelyste bepaal is, het moontlik bygedra tot die bepaling van hierdie breë riglyne. Die kompleksiteit van fisieke aktiwiteit meting belemmer die bepaling van die optimale daaglike fisieke aktiwiteit vir swanger vroue en het ook geleien tot die huidiglike bestaande, breë, algemene fisieke aktiwiteitsriglyne. 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 uikomste 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 daaglike fisieke aktiwiteit uiers 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-automatiese bloeddruk- en hartklopmonitor) en metaboliese 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-daie-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.

Daaglike fisieke aktiwiteit, voorgestel as gemiddelde energie uitgawe (AEE), fisieke aktiwiteitsvlak (PAL), aktiwiteitstellings 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 posititiewe 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
# TABLE OF CONTENTS

**ACKNOWLEDGEMENTS** ................................................................................................. i

**SUMMARY** .................................................................................................................. ii

**OPSOMMING** ........................................................................................................ iv

**TABLE OF CONTENTS** ............................................................................................... vi

**LIST OF TABLES** ....................................................................................................... ix

**LIST OF FIGURES** ...................................................................................................... x

**LIST OF ABBREVIATIONS** ........................................................................................ xi

# CHAPTER 1: INTRODUCTION ......................................................................................... 1

1.1. Introduction .............................................................................................................. 1

1.2. Problem Statement .................................................................................................. 2

1.3. Aim and objectives .................................................................................................. 4

1.4. Hypothesis ............................................................................................................... 4

1.5. Structure of the dissertation .................................................................................... 4

# CHAPTER 2: THE RELATIONSHIP BETWEEN HABITUAL PHYSICAL ACTIVITY PATTERNS OF PREGNANT WOMEN AND FOETAL GROWTH PARAMETERS ............ 7

2.1. Introduction .............................................................................................................. 7

2.2. Physiological adaptations to pregnancy ................................................................ 8

2.2.1. Cardiovascular adaptations during pregnancy .................................................... 9

2.2.2. Respiratory adaptations during pregnancy .......................................................... 9

2.2.3. Musculoskeletal adaptations during pregnancy ................................................... 10

2.2.4. Endocrine adaptations during pregnancy ............................................................ 10

2.3. Metabolic adaptations to pregnancy ..................................................................... 11

2.3.1. Energy intake during pregnancy ......................................................................... 11

2.3.2. Energy expenditure during pregnancy ............................................................... 13

2.4. Physical activity during pregnancy ....................................................................... 15

2.4.1. Measurements .................................................................................................... 15

2.4.2. Physical activity patterns during pregnancy ....................................................... 18

2.4.3. Benefits of regular physical activity during pregnancy ....................................... 21
2.4.4. Risks associated with physical activity during pregnancy ................................................................. 22
2.2.2. Guidelines for physical activity during pregnancy ............................................................................. 26

2.5. Birth outcomes ................................................................................................................................. 27

2.5.1. Foetal growth parameters and confounders thereof ................................................................. 27
2.5.2. Birth weight ................................................................................................................................. 27
2.5.3. Theory of foetal origins ............................................................................................................... 29
2.5.4. Environmental pollution ........................................................................................................... 30
2.5.5. Lifestyle ...................................................................................................................................... 30
2.5.6. Genetics ...................................................................................................................................... 32
2.5.7. Labour ......................................................................................................................................... 33
2.5.8. Body composition of the baby and in later life ........................................................................... 35
2.5.9. Weight gain ................................................................................................................................. 36

2.6. Summary ......................................................................................................................................... 37

CHAPTER 3: METHODS ......................................................................................................................... 39

3.1. Introduction ................................................................................................................................... 39

3.2. Empirical investigation .................................................................................................................... 40

3.2.1. Research design ......................................................................................................................... 40
3.2.2. Participants ............................................................................................................................... 40
3.2.3. Ethical issues ............................................................................................................................ 41
3.2.4. Materials and methods ............................................................................................................. 42
3.2.5. Procedure .................................................................................................................................. 47

3.3. Statistical analysis of data .............................................................................................................. 48

CHAPTER 4: RESULTS AND DISCUSSION .......................................................................................... 49

4.1. Introduction ................................................................................................................................... 49

4.2. Results ........................................................................................................................................... 49

4.2.1. Participants ............................................................................................................................... 49
4.2.2. Demographic information at enrolment ....................................................................................... 51
4.2.3. Maternal anthropometric, lifestyle and biological variables during pregnancy ...................... 53
4.2.4. Changes in physical activity levels during pregnancy .............................................................. 57
4.2.5. The influence of physical activity on foetal growth ................................................................. 62

4.3. Discussion ...................................................................................................................................... 64

4.3.1. Habitual activity patterns during pregnancy ............................................................................ 64
4.3.2. Relationship between activity energy expenditure and foetal growth .................................. 69

4.4. Summary ......................................................................................................................................... 72
CHAPTER 5: SUMMARY, CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH

5.1. Summary ........................................................................................................... 74
5.2. Conclusions ........................................................................................................ 76
5.3. Limitations ......................................................................................................... 78
5.4. Recommendations ............................................................................................ 79
5.5. Future research .................................................................................................. 79

REFERENCES ............................................................................................................. 80

Appendices .................................................................................................................. 124
Appendix A ................................................................................................................ 125
Appendix B ................................................................................................................ 129
Appendix C ................................................................................................................ 136
Appendix D ................................................................................................................ 137
# LIST OF TABLES

## Chapter 2

Table 2.1: Mapping the evidence: Physical activity and foetal growth (Randomised Controlled Trials) .................28  
Table 2.2: Recommended gestational weight gain ranges for women on the basis of body mass index (Siega-Riz *et al.* 2009:339.e3) ........................................................................................................................................37

## Chapter 4

Table 4.1: Demographic information of the participants ...............................................................................................51  
Table 4.2: Changes in various lifestyle habits, anthropometrics and cardiovascular determinants of health values from pre-pregnancy, per trimester and three months postpartum .............................................................56  
Table 4.3: Changes in energy expenditure and physical activity variables from pre-pregnancy, per trimester, to three months postpartum .................................................................................................................................58  
Table 4.4: Descriptive statistics of foetal growth measurements at birth ...............................................................................63  
Table 4.5: Correlation between average Active Energy Expenditure (kCal/day) during all three trimesters and various foetal growth measurements .................................................................................................................64
# LIST OF FIGURES

## Chapter 1
Figure 1.1: Context of the dissertation within the HAPPY-study ................................................................. 5

## Chapter 2
Figure 2.1: Summary of the physiological adaptations during pregnancy ......................................................... 12
Figure 2.2: ActiHeart® device placement for the measurement of habitual activity energy expenditure .......... 18
Figure 2.3: Possible risks associated with physical activity during pregnancy ...................................................... 23
Figure 2.4: Multifactorial influences on foetal growth ......................................................................................... 34

## Chapter 3
Figure 3.1: Course of the study and measurement times .................................................................................... 41
Figure 3.2: Cosmed Fitmate™ (Cosmed, Italy) ................................................................................................. 44
Figure 3.3: The ActiHeart® ............................................................................................................................. 45

## Chapter 4
Figure 4.1: Overview of the recruitment and drop-out rates of subjects ........................................................... 50
Figure 4.2: Distribution of representation of the ethnic groups participating in the HAPPY-study ................. 53
Figure 4.3: Socio-economic status distribution categorised by household income per annum ....................... 53
Figure 4.4: Weight gain (kg) from pre-pregnancy (reported) to post-partum with standard deviations .......... 54
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 ................................................................. 55
Figure 4.6: Change in resting metabolic rate from pre-pregnancy to three months postpartum ...................... 57
Figure 4.7: Changes in Activity Energy Expenditure (kCal) from pre-pregnancy to three months postpartum with the standard deviations .................................................................................................................. 60
Figure 4.8: Changes in time spent in sedentary, light, moderate and vigorous activity during pregnancy ........ 62
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
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPAQ</td>
<td>Pregnancy Physical Activity Questionnaire</td>
</tr>
<tr>
<td>R</td>
<td>Rand</td>
</tr>
<tr>
<td>RCOG</td>
<td>Royal College of Obstetricians and Gynaecologists</td>
</tr>
<tr>
<td>REE</td>
<td>Resting Energy Expenditure</td>
</tr>
<tr>
<td>RMR</td>
<td>Resting Metabolic Rate</td>
</tr>
<tr>
<td>RQ</td>
<td>Respiratory Quotient</td>
</tr>
<tr>
<td>S</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SOGC</td>
<td>Society of Obstetricians and Gynaecologists of Canada</td>
</tr>
<tr>
<td>T</td>
<td>Total Daily Energy Expenditure</td>
</tr>
<tr>
<td>TEE</td>
<td>Total Energy Expenditure</td>
</tr>
<tr>
<td>U</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>United States of America</td>
</tr>
<tr>
<td>VO₂</td>
<td>Oxygen consumption</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
</tr>
</tbody>
</table>
CHAPTER 1: INTRODUCTION

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 Habitual Activity Patterns during Pregnancy (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.
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

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 PCO$_2$ to facilitate effective exchange of CO$_2$ 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, adrenocorticotropic 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 (Damjanociv, 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 (Glinoer, 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% ± 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 be 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 QPAQ 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, Sørenson 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).

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 (≥ 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), unevaleduated 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

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). Cutoff 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)

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Title</th>
<th>Study Design</th>
<th>Method</th>
<th>Foetal Growth</th>
<th>Outcome</th>
</tr>
</thead>
</table>
Experimental: Mothers were identified by random sampling of Colorado live births 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 foetalplacental 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 foetalplacental 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 foetalplacental 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 foetalplacental 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). Inhalating 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-Bocca & 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 (IFG-I) gene imprint disruption may lead to low circulating IFG-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).
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 & Mkenzie, 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

Figure 2.4: Multifactorial influences on foetal growth
(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 Guszkowska (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 (Guszkowska, 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; Sørenson 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)

<table>
<thead>
<tr>
<th>Body mass classification</th>
<th>Body mass index (kg/m²)</th>
<th>Recommended weight gain range (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 19.8</td>
<td>12.5 – 18</td>
</tr>
<tr>
<td>Normal</td>
<td>19.8 – 26.0</td>
<td>11.5 – 16</td>
</tr>
<tr>
<td>Overweight</td>
<td>26.0 – 29.0</td>
<td>7.0 – 11.5</td>
</tr>
<tr>
<td>Obese</td>
<td>≥ 29.0</td>
<td>6</td>
</tr>
</tbody>
</table>

Weight gain during pregnancy is an important factor to consider to determine long-term obesity (Rooney & Schaubberger, 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

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](image)

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

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 an 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 (m²).

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.

![FitMate™](image.jpg)

**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\textsubscript{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:

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

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

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 Habitual Activity Patterns during Pregnancy (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

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Mean</th>
<th>SD.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>69</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>Pre-pregnancy weight (kg)</td>
<td>35</td>
<td>63.06</td>
<td>13.17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Marital status</th>
<th>n</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmarried</td>
<td>40</td>
<td>58.0</td>
</tr>
<tr>
<td>Married</td>
<td>29</td>
<td>42.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of children at home (n)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>None (%)</td>
<td>26</td>
<td>37.7</td>
</tr>
<tr>
<td>One (%)</td>
<td>29</td>
<td>42.0</td>
</tr>
<tr>
<td>Two (%)</td>
<td>12</td>
<td>17.4</td>
</tr>
<tr>
<td>Three (%)</td>
<td>2</td>
<td>2.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of previous miscarriages (n)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>None (%)</td>
<td>57</td>
<td>82.6</td>
</tr>
<tr>
<td>One (%)</td>
<td>10</td>
<td>14.5</td>
</tr>
<tr>
<td>Two (%)</td>
<td>2</td>
<td>2.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>White (%)</td>
<td>26</td>
<td>37.7</td>
</tr>
<tr>
<td>Black (%)</td>
<td>23</td>
<td>33.3</td>
</tr>
<tr>
<td>Coloured (%)</td>
<td>20</td>
<td>29.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Home language</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Afrikaans (%)</td>
<td>41</td>
<td>59.4</td>
</tr>
<tr>
<td>English (%)</td>
<td>2</td>
<td>2.9</td>
</tr>
<tr>
<td>Tswana (%)</td>
<td>17</td>
<td>24.6</td>
</tr>
<tr>
<td>Other (%)</td>
<td>9</td>
<td>13.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Socio-economic status</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (&lt; R 100 000)</td>
<td>36</td>
<td>52.5</td>
</tr>
<tr>
<td>Middle (R 100 000 – R 300 000)</td>
<td>19</td>
<td>27.5</td>
</tr>
<tr>
<td>High (&gt; R 300 000)</td>
<td>14</td>
<td>20.3</td>
</tr>
</tbody>
</table>
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 (BMI = kg/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](image-url)
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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-pregnancy</th>
<th>1st Trimester</th>
<th>2nd Trimester</th>
<th>3rd Trimester</th>
<th>Post-pregnancy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Percentage (%)</td>
<td>N</td>
<td>Percentage (%)</td>
<td>N</td>
</tr>
<tr>
<td>Smoking status (%)</td>
<td>1</td>
<td>12.5</td>
<td>1</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>Alcohol use (%)</td>
<td>3</td>
<td>37.5</td>
<td>2</td>
<td>5.0</td>
<td>2</td>
</tr>
<tr>
<td>Drug use (%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Medication use (%)</td>
<td>1</td>
<td>14.3</td>
<td>25</td>
<td>62.5</td>
<td>22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
<th>Mean ± SD.</th>
<th>N</th>
<th>Mean ± SD.</th>
<th>N</th>
<th>Mean ± SD.</th>
<th>N</th>
<th>Mean ± SD.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg) measured</td>
<td>6</td>
<td>76.83 ± 18.29</td>
<td>35</td>
<td>68.74 ± 13.75</td>
<td>41</td>
<td>73.73 ± 14.72</td>
<td>18</td>
</tr>
<tr>
<td>Weight (kg) reported</td>
<td>35</td>
<td>63.06 ± 13.17</td>
<td>35</td>
<td>1.64 ± 0.06</td>
<td>35</td>
<td>1.63 ± 0.07</td>
<td>41</td>
</tr>
<tr>
<td>Height (m)</td>
<td>6</td>
<td>1.64 ± 0.06</td>
<td>35</td>
<td>1.63 ± 0.07</td>
<td>41</td>
<td>1.61 ± 0.07</td>
<td>18</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>6</td>
<td>28.67 ± 6.71</td>
<td>35</td>
<td>25.83 ± 4.90</td>
<td>41</td>
<td>28.54 ± 5.78</td>
<td>18</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>6</td>
<td>80.00 ± 18.60</td>
<td>35</td>
<td>83.58 ± 13.47</td>
<td>41</td>
<td>96.82 ± 20.31</td>
<td>18</td>
</tr>
<tr>
<td>Hip Circumference (cm)</td>
<td>6</td>
<td>106.69 ± 15.73</td>
<td>35</td>
<td>100.41 ± 11.27</td>
<td>41</td>
<td>105.52 ± 11.88</td>
<td>18</td>
</tr>
<tr>
<td>Waist / Hip ratio</td>
<td>6</td>
<td>0.74 ± 0.07</td>
<td>35</td>
<td>0.83 ± 0.07</td>
<td>41</td>
<td>0.92 ± 0.19</td>
<td>18</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>6</td>
<td>26.81 ± 7.42</td>
<td>35</td>
<td>26.06 ± 6.48</td>
<td>41</td>
<td>27.82 ± 6.50</td>
<td>18</td>
</tr>
<tr>
<td>Resting heart rate (beats/min)</td>
<td>6</td>
<td>71 ± 9</td>
<td>35</td>
<td>65 ± 9</td>
<td>41</td>
<td>70 ± 11</td>
<td>18</td>
</tr>
<tr>
<td>Systolic Blood Pressure (mm Hg)</td>
<td>6</td>
<td>111 ± 6</td>
<td>35</td>
<td>116 ± 10</td>
<td>41</td>
<td>116 ± 9</td>
<td>18</td>
</tr>
<tr>
<td>Diastolic Blood Pressure (mm Hg)</td>
<td>6</td>
<td>73 ± 6</td>
<td>35</td>
<td>72 ± 8</td>
<td>41</td>
<td>72 ± 8</td>
<td>18</td>
</tr>
</tbody>
</table>
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

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

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](image)

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](image)

**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 $3.12 \pm 0.56$ kg, while the mean birth length was $48.5 \pm 4.9$ cm. The mean Ponderal Index at birth was $27.74 \pm 5.63$ kg/m$^3$. Head circumferences of the babies were not all measured at birth ($N = 17$). Nevertheless, the mean of the head circumference was determined as $35.1 \pm 0.5$ 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

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gestational age at birth</td>
<td>22</td>
<td>36</td>
<td>43</td>
<td>39</td>
<td>1.5</td>
</tr>
<tr>
<td>Birth weight (kg)</td>
<td>22</td>
<td>1.6</td>
<td>4.42</td>
<td>3.12</td>
<td>0.56</td>
</tr>
<tr>
<td>Birth length (cm)</td>
<td>22</td>
<td>44.0</td>
<td>58.0</td>
<td>48.5</td>
<td>3.2</td>
</tr>
<tr>
<td>Ponderal Index (kg/m$^3$)</td>
<td>22</td>
<td>13.07</td>
<td>39.97</td>
<td>27.74</td>
<td>5.63</td>
</tr>
<tr>
<td>Head circumference (cm)</td>
<td>17</td>
<td>32</td>
<td>38</td>
<td>35.1</td>
<td>1.4</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Variables</th>
<th>Average Active energy expenditure (kCal/day)</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth weight (g)</td>
<td>- 0.39</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Birth length (cm)</td>
<td>- 0.16</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>Ponderal Index (g/m³)</td>
<td>- 0.34</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>Head circumference (cm)</td>
<td>0.14</td>
<td>0.79</td>
<td></td>
</tr>
</tbody>
</table>

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 ≥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 Sampselle 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 (MET < 1.5) is observed in conjunction with a decrease in time spent doing light activity (MET = 1.5 – 3.0), and moderate physical activity (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 ± 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., 1996:534l; 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.
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.


Date of access: 6 July 2012


Date of access: 2 Jul. 2012.


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

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 my personally not obtain any personal advantage from participating. The knowledge that is however generate by your participation my 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 experiences 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 of 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

<table>
<thead>
<tr>
<th>ID number</th>
<th>Birth date</th>
<th>Marital status</th>
<th>Nationality</th>
<th>Ethnicity</th>
<th>Home language</th>
<th>Occupation</th>
<th>Highest level of education</th>
<th>Mean household income per annum (encircle the applicable amount)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; R 50 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R 150 000 – R 200 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R 300 000 – R 400 000</td>
</tr>
</tbody>
</table>
## Pregnancy Demographic Information

<table>
<thead>
<tr>
<th>Pre-pregnancy weight (kg)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weeks of pregnancy (weeks)</td>
<td></td>
</tr>
<tr>
<td>Type of pregnancy (single, twin or triplets)</td>
<td></td>
</tr>
<tr>
<td>Expected date of birth</td>
<td></td>
</tr>
<tr>
<td>Number of children at home</td>
<td></td>
</tr>
<tr>
<td>Number of previous miscarriages</td>
<td></td>
</tr>
<tr>
<td>Medicinal use</td>
<td>Yes</td>
</tr>
<tr>
<td>Type of medication</td>
<td>Name of medication</td>
</tr>
<tr>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
</tr>
<tr>
<td>Smoking status</td>
<td>Current smoker</td>
</tr>
<tr>
<td>Number of cigarettes per day</td>
<td>Date which you stopped smoking</td>
</tr>
<tr>
<td>__________</td>
<td>__________</td>
</tr>
<tr>
<td>Alcohol use in the last 3 months</td>
<td>Non drinker</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of drinks per day</td>
</tr>
<tr>
<td></td>
<td>__________ / wine/beer/spirits</td>
</tr>
<tr>
<td>Drug use in the last 3 months</td>
<td>Yes</td>
</tr>
</tbody>
</table>
## Contra-Indications & Risk factors

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

<table>
<thead>
<tr>
<th>Body mass index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>BMI</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waist / Hip ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist circumference</td>
</tr>
<tr>
<td>Hip circumference</td>
</tr>
<tr>
<td>Waist / Hip circumference</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Skinfolds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triceps</td>
</tr>
<tr>
<td>Supra-iliac</td>
</tr>
<tr>
<td>Mid thigh</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fat percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bod-Pod Body composition</td>
</tr>
<tr>
<td>Fat percentage</td>
</tr>
<tr>
<td>Lean body mass</td>
</tr>
<tr>
<td>Fat mass</td>
</tr>
<tr>
<td>Lung volume</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bio-electrical Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Body Water</td>
</tr>
<tr>
<td>Fat percentage</td>
</tr>
</tbody>
</table>
# Blood pressure, Resting Metabolic Rate and Nutritional information

<table>
<thead>
<tr>
<th>Heart rate (beats/min)</th>
<th>Blood pressure (mm Hg)</th>
<th>/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting Metabolic Rate</td>
<td>(ml O₂ / kg)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ActiHeart</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEE</td>
</tr>
<tr>
<td>DEE</td>
</tr>
<tr>
<td>TEE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutritional calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dietary Intake</td>
</tr>
<tr>
<td>Foetal growth parameters</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>Expected birth weight (grams)</td>
</tr>
<tr>
<td>Head circumference (cm)</td>
</tr>
<tr>
<td>Abdominal circumference (cm)</td>
</tr>
<tr>
<td>Femur length (cm)</td>
</tr>
<tr>
<td>Bi-parietal diameter (cm)</td>
</tr>
<tr>
<td>Ponderal Index</td>
</tr>
</tbody>
</table>
Appendix C

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

<table>
<thead>
<tr>
<th>Ethics number:</th>
<th>NWU-2010-07-13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approval date:</td>
<td>2010-07-13</td>
</tr>
<tr>
<td>Expiry date:</td>
<td>2015-07-12</td>
</tr>
</tbody>
</table>

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 deviation 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:
  - 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.
  - request access to any information or data at any time during the course or after completion of the project.

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

[Signature]

Prof MJM Lowes
(chair NWU Ethics Committee)
Appendix D

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
ID: 8709010240081
Home/Postal Address: 37 Mackenzie Street; Brooklyn; Pretoria; South Africa; 0181
Cell: +2782 5917942
E-mail: carissam.nel@gmail.com