Physical activity and energy balance in relation to birth outcomes during pregnancy in the Tlokwe municipality area: A longitudinal study

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Thesis submitted for the degree *Doctor of Philosophy in Human Movement Science* at the North-West University

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Graduation: May 2020
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DECLARATION

Professor SJ Moss (promoter and co-author) and Professor Y Schutz with this permit the candidate, Mr AF van Oort to include the articles as part of his doctoral thesis. The contribution of each co-author, both supervisory and supportive, was kept within reasonable limits.

Mr AF van Oort: Developed the proposal, performed data collection, drafted the manuscripts presenting the results and compiled the thesis.

Prof SJ Moss: Is the principle investigator of the Habitual Activity Patterns during PregnancY (HAPPY) study. Main contributions included coordination of the research, ethical approval of the research, data collection, guidance regarding statistical analysis, interpretation of results and critical review of the manuscripts .

Prof Y Shutz: Collaborator of the HAPPY-study. Contributed to reviewing the thesis proposal, as well as the manuscripts of Chapters 3, 4 and 5.

The thesis is in fulfilment of the requirements for a PhD degree in Human Movement Science within Physical Activity, Sport and Recreation (PhASRec) focus area in the Faculty of Health Sciences at the North-West University.

Prof SJ Moss
Promoter, co-author and HAPPY-study principle investigator

Prof Y Schutz
Co-promoter and co-author

The opinions, findings and conclusions or recommendations expressed in any publication generated by the National Research Fund (NRF) supported research is that of the authors and, the NRF accepts no liability whatsoever in this regard.

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ACKNOWLEDGEMENTS

I would like to express my heartfelt appreciation to the following persons and institutions who contributed to the completion of my thesis:

- My Lord, Jesus Christ, for the wisdom and strength to complete my studies.
- My promoter, Prof Hanlie Moss, for her diligence, patience, and encouragement throughout my postgraduate studies.
- My family, especially my mother, who herself obtained a Ph.D., and who motivated me to continue my studies.
- My friends: Jaco Brits, Manie Slabbert, Regert Coetzer and Adri Visser who helped keep me motivated when times got rough. Sometimes a friendly face to whom one could talk made a vast difference.
- My colleagues: Dr Henriette Hammill, Dr Mariette Swanepoel, Dr Terry Ellapen, Ms Tamrin Veldsman and Mr Trevor Duvenhage who helped me with my academic responsibilities, when I struggled balancing my research and academic work.
- The North-West University for affording me the opportunity to further my academic career.
- To every participant in the HAPPY-study, whose diligent long-term contributions are not typically seen in research.
- The National Research Foundation South African-Swiss Joint Programme with the project number WD 78606 and the South African Sugar Association - project number 224 - who funded this study.
- The North-West Department of Health, the nurses at the relevant clinics, and participating gynaecologists in this study, for their time and support.

ABSTRACT

Physical activity and energy balance in relation to birth outcomes during pregnancy in the Tlokwe municipality area: A longitudinal study

The high prevalence of obesity in South-African women poses a significant health risk for mother and offspring during pregnancy. Obesity and excessive gestational weight gain during pregnancy are associated with an increased risk of adverse birth outcomes. The high levels of obesity in South-African women contribute to the potential exacerbated health risk. Energy balance dictates gestational weight gain and is also associated with birth weight. Energy imbalances, such as excessive energy intake and decreased energy expenditure, may explain changes in body composition and can negatively affect birth outcomes. This study investigated the relationship between physical activity and energy balance with regards to birth outcomes during pregnancy in the Tlokwe municipal area.

A longitudinal observational cohort study design – the Habitual Activity Patterns during PregnancY (HAPPY)-study - measured 41 pregnant women in their first- (1st) (9 – 12 weeks), second- (2nd) (20 – 22 weeks) and third (3rd) trimester (28 – 32 weeks). Energy intake and macronutrient intake was determined by a semi-quantitative food frequency questionnaire while resting energy expenditure was measured applying gas exchange analyses with the Fitmate®. Active energy expenditure and diet-induced thermogenesis were objectively determined using a combined heart rate reading and accelerometer – the ActiHeart®. Body composition measurements of height, weight, and fat mass using skinfolds were taken. Birth outcomes (birth weight, gestational age at birth, abdominal and head circumference) were obtained from medical records. The study is presented in the format of three manuscripts.

Results indicated that energy intake increased slightly from the 1st trimester (8841 ± 3456 kJ/day) to the 2nd trimester (9134 ± 3046 kJ/day) and then decreased in the 3rd trimester (8171 ± 3017 kJ/day). Energy expenditure decreased from 1st trimester (10234 ± 2314 kJ/day) to the 2nd trimester (9423 ± 2732 kJ/day) and increased slightly during the 3rd trimester (9535 ± 2326 kJ/day). Energy balance was negative in the 1st trimester (- 1337 ± 4548 kJ/day), positive in the 2nd trimester (381 ± 4213 kJ/day) and negative again in the 3rd trimester (- 1331 ± 3732 kJ/day). The change in both energy intake ($p = 0.66$) and energy expenditure ($p = 0.31$) from the 1st to the 3rd trimester was not statistically significant. The change in resting energy expenditure, adjusted for body weight, was statistically significantly related to the change in body mass index ($r = 0.59$, $p = 0.02$), gestational weight gain ($r = 0.55$, $p = 0.03$) and change in fat mass ($r = 0.54$, $p = 0.03$) from the 2nd to the 3rd trimester. Consequently, changes in body composition variables significantly predicted changes in resting energy expenditure, adjusted for weight, from the 2nd to 3rd ($R^2 = 0.93$, $p < 0.01$), but not from the 1st to the 2nd trimester ($R^2 = 0.22$, $p = 0.37$). Energy intake and energy expenditure throughout all trimesters as related to birth outcomes were not statistically significant, except for energy expenditure in the 3rd trimester which was significantly negatively associated with head circumference (r = -0.94, $p = 0.02$) and birth weight (r = -0.68, $p = 0.05$).

It can be concluded that energy expenditure and energy intake did not change significantly during pregnancy. The various components of energy expenditure did, however, change to regulate overall energy balance. A decrease in physical activity throughout pregnancy led to a decrease in active energy expenditure. Resting energy expenditure was significantly associated with body composition variables in late pregnancy. A negative energy balance had a positive association with delivering an appropriate for gestational age infant.. Healthy dietary behaviours and physical activity during pregnancy can assist with the regulation of energy balance that will contribute to optimal birth outcomes.

Keywords: Body composition, energy balance, energy expenditure, energy intake, gestational weight gain, pregnancy

OPSOMMING

Fisieke aktiwiteit en energiebalans in verhouding met geboorte-uitkomste tydens swangerskap in die Tlokwe-munisipaliteit: ʼn longitudinale studie

Die hoë voorkoms van obesiteit in Suid-Afrikaanse vroue hou ʼn beduidende gesondheidsrisiko vir beide moeder en baba tydens swangerskap in. Obesiteit en oormatige gestasionele gewigstoename by swanger vroue van Suid-Afrika hou verband met ʼn verhoogde risiko vir nadelige geboorte-uitkomste. Die hoë vlakke van obesiteit by Suid-Afrikaanse vroue, dra by tot die moontlike verhoging in gesondheidsrisiko. Energiebalans bepaal gewigstoename tydens swangerskap en word ook geassosieer met geboortegewig. Energiewanbalanse, soos oormatige energie-inname en verlaagde energie-uitgawes kan veranderinge in ligaamsamestelling verklaar en die geboorte-uitkomste negatief beïnvloed. Hierdie studie het die verband tussen fisieke aktiwiteit en energiebalans met geboorte-uitkomste tydens swangerskap in die Tlokwe-munisipaliteit ondersoek.

Tydens dielongitudinale observasie studie – die *Habitual Activity Patterns during PregnancY (HAPPY)*-studie – is 41 swanger vroue in hul eerste- (9 – 12 weke), tweede- (20 – 22 weke) en derde trimester (28 – 32 weke) van swangerskap gemeet. Energie-inname en makronutriëntinname is bepaal deur ʼn semikwantitatiewe voedselfrekwensie vraelys, terwyl die rustende energie-verbruik deur middel van gasuitruilingsanalise met die Fitmate® gemeet is. Aktiewe energie-verbruik en dieet-geïnduseerde termogenese is objektief deur ʼn gekombineerde harttempo- en versnellingsmeter – die ActiHeart® – bepaal. Liggaamsamestellingmetings van lengte, gewig en vetmassa deur middel van velvoue is gemeet. Geboorte-uitkomste (geboortegewig, ouderdom by geboorte, abdominale- en kopomtrek) is uit mediese rekords verkry. Die studie word aangebied in die formaat van drie manuskripte.

Die resultate het aangedui dat die energie-inname vanaf die eerste trimester (8841 ± 3456 kJ/dag) tot die tweede trimester (9134 ± 3045 kJ/dag) effens gestyg het en daarna in die derde trimester (8171 ± 30171 kJ/dag) weer afgeneem het. Energie-verbruik het van die eerste trimester (10234 ± 2134 kJ/dag) tot die tweede trimester (9423 ± 2732 kJ/dag) gedaal en het effens in die derde trimester (9535 ± 2326 kJ/dag) verhoog. Energiebalans was negatief in die eerste trimester (- 1337 ± 4548 kJ/dag), positief in die tweede trimester (381 ± 4213 kJ/dag) en weer negatief in die derde trimester (- 1331 ± 3732 kJ/dag). Die verandering in energie-inname (p = 0.66) en energie-verbruik (p = 0.31) vanaf die eerste na die derde trimester was nie statisties betekenisvol nie. Die verandering in rustende energie-verbruik, aangepas vir liggaamsgewig, was statisties betekenisvol verwant aan die verandering in liggaamsmassa-indeks (r = 0.59, p = 0.02), swangerskap-gewigstoename (r = 0.55, p = 0.03) en verandering in vetmassa (r = 0.54, p = 0.03) vanaf die tweede tot die derde trimester. Gevolglik het veranderinge in liggaamsamestellingsveranderlikes betekenisvol die verandering in rustende energie-verbruik, aangepas vir gewig, van die tweede tot derde trimester ($R^2 = 0.93$, $p < 0.01$) voorspel, maar nie van die eerste tot die tweede trimester ($R^2 = 0.22$, $p = 0.37$) nie. Energie-inname en energie-verbruik gedurende al die trimesters van swangerskap was nie statisties betekenisvol verwant aan geboorte-uitkomste nie, behalwe vir energieverbruik in die 3de trimester wat betekenisvol, negatief geassosieer was met kopomtrek (r = -0.94, $p = 0.02$) en geboortegewig (r = -0.67, $p = 0.05$).

Daar kan tot die gevolgtrekking gekom word dat energie-verbruik en energie-inname nie betekenisvol gedurende swangerskap verander het nie. Die verskillende komponente van energie-uitgawes het wel verander om algemene energiebalans te reguleer. ʼn Afname in fisieke aktiwiteit gedurende swangerskap het gelei tot ʼn afname in energie-verbruik. Rustende energie-uitgawe was betekenisvol geassosieer met ligaamsamestellingsveranderlikes in laaste trimester van swangerskap. ʼn Negatiewe energiebalans het ʼn positiewe verwantskap getoon met die normale geboortegewig. Regulering van energiebalans deur gesonde dieetgewoontes en fisieke aktiwiteit tydens sangerskap, kan dus bydra tot die bevordering van optimale geboorte-uitkomste.

Sleutelterme: energiebalans, energie-inname, energie-uitgawe, gestasionele-gewigstoename, liggaamsamestelling, swangerskap

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LIST OF ABBREVIATIONS AND SYMBOLS

ACOG = American College of Obstetrics and Gynaecology
ACSM = American College of Sports Medicine
AEE = Active Energy Expenditure
AGA = Average-for-Gestational-Age
AIDS = Acquired Immunodeficiency Syndrome
ANOVA = Analysis of variance
beats/min = beats per minute
BMI = Body Mass Index
cm = centimetre
d = Cohen’s d
DIT = Diet-Induced Thermogenesis
E_b = Energy balance
ECG = Electrocardiogram
E_I = Energy intake
epochs = counts per minute
et al. = et alia / and others
E% = Energy percentage
F = F-statistic
FAO = Food and Agriculture Organisation
FFQ = Food Frequency Questionnaire
FL = Florida
g = gram
GWG = Gestational Weight Gain
g/day = grams per day
HAPPY = Habitual Activity Patterns during PregnancY
h = hour
HIV = Human Immunodeficiency Virus
hr:min = hour : minute
h/wk = hours per week
IBM = International Business Machines Corporation
IF = Impact Factor
IGF = Insulin-like Growth Factor
inc. = incorporated
IOM = Institute of Medicine

IPAQ = International Physical Activity Questionnaire

kcal/day = kilocalories per day

kg = kilogram

kg/m^2 = kilogram per meter squared

kJ = kilojoule

kJ/day = kilojoule per day

kJ/kg = kilojoule per kilogram

kJ/kg/day = kilojoule per kilogram per day

KPAS = Kaiser Physical Activity Survey

LGA = Large-for-Gestational-Age

Ltd. = Limited company

MCID = Minimal Clinical Important Difference

MET = Metabolic Equivalent of Task

MJ = Megajoule

ml/min = millimetre per minute

mm = millimetre

mo/y = months per year

n = total participants

NRF = National Research Fund

NWU = North-West University

NY = New York

p = Statistical significance

$PaCO_2$ = Partial pressure of carbon dioxide in the arterial blood

PAI = Physical Activity Index

PAL = Physical Activity Level

PaO_2 = Partial pressure of oxygen in the arterial blood

PPAQ = Pregnancy Physical Activity Questionnaire

R = Correlation coefficient

® = Registered Trademark

REE = Resting Energy Expenditure

RMR = Resting Metabolic Rate

SA = South Africa

SD = Standard Deviation

SGA = Small-for-Gestational-Age

SPSS = Statistical Package for the Social Sciences

TEE = Total Energy Expenditure

™ = Trademark

UK = United Kingdom

ver. = version

VO_2 = Oxygen consumption

WI = Wisconsin

1st = First

2nd = Second

3rd = Third

± = Standard Deviation

% = Percentage

Δ = Change

CHAPTER 1: INTRODUCTION

1.1. Introduction

South African women suffer disproportionately from overweight and obesity (63%) as compared to South African men (Averett *et al*., 2014:28). Overweight and obese mothers have an increased risk of adverse birth outcomes and excessive gestational weight gain (Boutall *et al*., 2014:39). Healthy dietary habits and physical activity during pregnancy have been proposed as an intervention strategy in order to prevent excessive gestational weight gain and promote a healthy birth outcome (Leite *et al*., 2016:281; Shieh *et al*., 2018:1104). Nonetheless, dietary intake tends to increase above the recommended dietary allowance (Ladyman *et al*., 2010:805) and physical activity tends to decrease during pregnancy (Van Oort, 2014:77), leading to excessive energy intake and decreased energy expenditure.

The chapter presents the problem of energy imbalance during pregnancy – excessive energy intake and decreased energy expenditure – and the consequences thereof in terms of birth outcomes. This chapter also sets out the formulation of the research question with regards to the objectives of the thesis. The structure and perspectives of the thesis is supported with a framework and outline of the thesis.

1.2. Problem statement

Pregnancy is an important period in the reproductive lives of women, influencing the immediate and long-term health of both the unborn infant and the mother (Maturi *et al.*, 2011:103; McGowan & McAuliffe, 2012:906). Imbalances in energy intake and expenditure during pregnancy could have detrimental effects on both infant and mother (Ladyman *et al.*, 2010:813). Maternal energy requirements increase during pregnancy due to the energy costs associated with the synthesis and maintenance of new tissue (Lof & Forsum, 2006:298). A pregnant woman’s daily energy intake must consistently exceed energy expenditure for normal gestational weight gain to occur, changes in physical activity levels during pregnancy, therefore, have important implications for maternal energy requirements (Byrne *et al.*, 2011:819; Clarke *et al.*, 2005:248). Van Oort (2014:77) concluded that pregnant women from South-Africa do not attain the minimum physical activity recommendations for pregnant women as stated by the American College of Sports Medicine (ACSM, 2013:197) and this could have adverse effects on both mother and infant.

The consensus from the research during pregnancy is that physical activity decreases as pregnancy progresses (Amezcua-Prieto *et al.*, 2013:632–638; Borodulin *et al.*, 2008:1907; Chasan-Taber *et al.*, 2007:136; Clarke *et al.*, 2005:247–258; Derbyshire *et al.*, 2007:24; Downs *et al.*, 2012:485; Gaston &

Vamos, 2013:482; Melzer *et al.*, 2010:266.e4; Poudevigne & Connor, 2006:28). A decrease in physical activity may, to some extent, offset reductions in maternal energy requirements (Lof & Forsum, 2006:298). However, physical inactivity during pregnancy is a contributor to excessive gestational weight gain (Brunette *et al.*, 2012:140; Stuebe *et al.*, 2009:58.e7). Excessive gestational weight gain may result in foetal and maternal complications, such as complications during pregnancy and delivery as well as obesity later in life (Linné & Neovius, 2006:1238; Stotland *et al.*, 2004:675). Risks pertaining to excessive gestational weight gain include the need for caesarean delivery, hypertension, pre-eclampsia, impaired glucose tolerance, and gestational diabetes mellitus (Adeniyi *et al.*, 2014:117). The risks associated with inadequate weight gain must, however, be balanced against the risk of excessive weight gain through examining the relationship between energy intake and expenditure during pregnancy, gestational weight gain, and pregnancy outcomes (Stotland *et al.*, 2004:675).

Energy balance dictates that body mass remains constant when total energy intake equals total energy expenditure (McArdle *et al.*, 2014:808). Conversely, during pregnancy, normal gestational weight gain must occur as it is positively correlated with birth weight (Rode *et al.*, 2007:1309). The Institute of Medicine (IOM) published gestational weight gain guidelines with a specified range for each category of pre-pregnancy body mass index (BMI), specifically citing an optimal gain of 11.5kg - 16kg for women with a normal pre-pregnancy BMI and 5kg - 9kg gain for obese women (IOM, 2009:7-12). Gestational weight gain is a significant determinant of the incremental energy needs during pregnancy because it determines not only energy deposition, but also increases in Total Energy Expenditure (TEE) resulting from the energy cost of moving a larger body mass (Butte *et al.*, 2004:1086).

Total energy expenditure (TEE) in non-pregnant, healthy individuals consists of three components: resting metabolic rate (RMR, 60 -75%), active energy expenditure (AEE, 25 - 30%) and diet-induced thermogenesis (DIT, ~ 10%) (Byrne *et al.*, 2011:819; Melzer *et al.*, 2009:1185). An increase in the TEE during pregnancy can primarily be attributed to an increase in resting energy expenditure (REE), which is partly compensated by a decrease in AEE (Melzer *et al.*, 2009:1190). Lof *et al.* (2005:684) found that weight gain during pregnancy is associated with a cumulative increase in REE. Accelerated tissue synthesis, increased active tissue mass and increased cardiovascular and respiratory work contribute to the increase in REE (FAO, 2001:55). Prentice *et al.* (1989:18) concluded that DIT is likely to remain essentially unaltered during pregnancy. A fourth energetic component, specific to pregnancy, also contributes to an increase in TEE: the energy cost of synthesising new foetoplacental tissue and the retention of fat and protein by the mother’s body (Byrne *et al.*, 2011:819).

The additional energy demands of pregnancy can be met through an increase in food intake or through the mobilisation of energy from body fat stores, particularly in well-nourished women with sufficient pre-pregnancy reserves (Melzer *et al.*, 2009:1189). Butte *et al.* (2004:1086) concluded that the incremental energy needs during pregnancy are negligible in the first trimester, but energy needs increase to 1465 kJ/day in the second trimester and 2092 kJ/day in the third trimester, over non-pregnant values. According to Blumfield *et al.* (2012:332) current energy increment recommendations during pregnancy need to be evaluated along with physical activity and dietary intake data.

The American College of Obstetricians and Gynecology recommends that pregnant women should do 30 to 40 minutes of moderate-intensity physical activity on most, preferably on all, days of the week (ACSM, 2013:196). Physical activity during pregnancy provides maternal- and foetal benefits (Downs *et al.*, 2012:494). Maternal health benefits include a reduced risk of gestational diabetes (Dempsey *et al.*, 2004:212), as well as the prevention of both excessive gestational weight gain (Brunette *et al.*, 2012:141; Stuebe *et al.*, 2009:58.e7), pre-eclampsia (Mudd *et al.*, 2013:273) and premature birth (Takito & Benício, 2010:98), improved cardiovascular fitness (Melzer *et al.*, 2010:266.e5) and a reduction in the onset of long-term diseases such as obesity, type 2 diabetes, and cardiovascular disease (Downs *et al.*, 2012:496).

Furthermore, Van Oort (2014:78) states that adhering to the recommendations for a healthy, habitual, physical activity level during pregnancy could improve foetal outcomes such as birth weight, head circumference and ponderal index. Physical activity may improve birth outcomes by limiting excessive foetal growth without reducing normal foetal growth (Mudd *et al.*, 2013:267; Watson *et al*., 2018:1198). Therefore, a U-shaped relationship has been proposed to describe the relationship between physical activity during pregnancy with birth-weight (Takito & Benício, 2010:91), where physical activity can prevent the delivery of a too large-for-gestational age infant (Mudd *et al.*, 2013:276) or too small-for-gestational-age infant (Pompeii *et al.*, 2005:1284).

Birth weight serves as an amalgam for multiple determinants (Mahmoodi *et al.*, 2013:573; Oken *et al.*, 2003:501) including maternal height (Perkins *et al.*, 2007:84), pre-pregnancy weight (Mahmoodi *et al.*, 2013:573; Takito & Benício, 2010:91), emotional stress (Takito & Benício, 2010:91), cigarette smoking (Oken & Gillman, 2003:497), socio-economic status (Oken & Gillman, 2003:497-498), gestational weight gain (Rao *et al.*, 2003:539) and physical activity (Mahmoodi *et al.*, 2013:578; Perkins *et al.*, 2007:84). The foetal origins of disease theory propose that environmental factors, as mentioned above, can have profound influences in utero on lifelong health (Oken & Gillman, 2003:496). Foetal programming occurs when alterations in foetal growth and development cause long-term or permanent effects, mediated by the prenatal environment (Sayer & Cooper, 2005:741).

High birth weight is associated with an increased risk of adiposity in childhood and adulthood (Oken & Gillman, 2003:498), while a lower birth weight is associated with central obesity and metabolic syndrome in adulthood (Oken & Gillman, 2003:500). Andersen *et al.* (2009:6) provide evidence that both a low and high birth weight (outside the normal range of birth weights) are associated with a lower probability of the mother being physically active during pregnancy.

In a South African context, Kruger *et al.* (2002:427) concluded that physical inactivity is one of the most important factors affecting obesity among black South African women. Averett *et al.* (2014:28) state that over a third of South-African women are obese, and nearly two thirds (63%) are overweight. Kruger *et al.* (2005:494) state that the barriers to physical activity in a South African context include a fear of losing weight (most South Africans perceive moderately overweight women as attractive as this is associated with dignity, respect and confidence), personal safety, and a lack of exercise. Additionally, in South Africa, there has been a large increase in the consumption of processed foods due to their increased availability and reduced prices (Averett *et al.*, 2014:26). Sartorius *et al.* (2015:14) state that a more westernised lifestyle is adopted in South Africa due to urbanisation. The result is substandard dietary habits and reduced physical activity, leading to a positive energy balance.

The South African Sports Medicine Association published a Position Statement regarding exercising during pregnancy, whereby they encourage pregnant women, in the absence of either medical or obstetric complications, to participate in aerobic- and strength-conditioning training at a moderate intensity (3-4 Metabolic Equivalent [MET]) on most or all days of the week (Barsky *et al.*, 2012:69).

Brunette *et al.* (2012:138) collected physical activity and energy expenditure data from pregnant South African women subjectively by means of questionnaires and reported a decreased level of physical activity from the second to the third trimester. In addition, a Nigerian study reported physical activity during pregnancy as lower than recommended physical activity levels. In this study, the data was also collected by means of a questionnaire and the study concluded that this decrease could lead to unfavourable health outcomes for both mother and child (Adeniyi *et al.*, 2014:125). Furthermore, Van Oort (2014:76) reported on objectively-measured habitual physical activity patterns of pregnant women in the Tlokwe municipality of South Africa and found a statistically significant decline in physical activity from pre-pregnancy to the third trimester of pregnancy ($p = 0.04$). In another South African study which measured physical activity objectively, Watson *et al.* (2018:1197) found the total volume of physical activity to decrease from second to the third trimester. However, the study could not provide sufficient evidence on the association between physical activity and birth outcomes (Watson *et al.*, 2018:1197).

Given the paucity of longitudinal research in a South African context regarding birth outcomes, energy intake and expenditure, as well as physical activity during pregnancy, the research question remains: What are the objectively determined energy expenditure and energy intake levels during pregnancy, and how do they relate to birth outcomes? The knowledge obtained from the study will be beneficial to a multitude of health practitioners with regards to the motivation of a healthy lifestyle relating to physical activity or nutritional guidelines, during pregnancy. Additionally, this information may also aid in guiding researchers in establishing gestational weight gain, nutritional and physical activity guidelines tailored to the South African pregnant population.

1.3. Objectives

The objectives of this study are to determine:

- The change in energy intake and expenditure from first to the third trimester during pregnancy in women of the Tlokwe Municipal area.
- The relationship between changes in resting energy expenditure during pregnancy and body composition from first to the third trimester in pregnant women of the Tlokwe Municipal area.
- The relationships between energy intake and expenditure during pregnancy and birth outcomes in pregnant women of the Tlokwe Municipal area.

1.4. Hypotheses

This study is based on the following hypotheses:

- Energy intake and energy expenditure will increase significantly from the first to the third trimester of pregnancy in women of the Tlokwe Municipal area.
- The resting energy expenditure of pregnant women will increase significantly from the first to the third trimester of pregnancy and present a significant positive relationship with body composition in women of the Tlokwe Municipal area.
- A moderate increase in energy intake and energy expenditure during pregnancy will have a significant positive relationship with the birth outcomes of women of the Tlokwe Municipal area.

1.5. Thesis framework

In order to address the objectives set out for this study, and to test the stated hypotheses, the data from the larger Habitual Activity Patterns during PregnancY (HAPPY)-study was analysed. The main objective of the longitudinal observational HAPPY-study was to determine the habitual activity patterns of pregnant women. Other than physical activity, maternal lifestyle habits measured included smoking-, alcohol and drug use, as well as dietary information and psychosocial factors. Maternal health measurements included anthropometrics, cardiovascular risk, and resting energy expenditure. Birth outcomes were obtained postpartum using medical records.

For the thesis, the concept of energy balance and the relationship thereof to birth outcomes was conceptualised in order to contribute to new knowledge in the field of pregnancy and childbirth. The objective measurement of energy expenditure and the longitudinal observational study design of the HAPPY-study provided a mean to explore the relationship between energy balance and birth outcomes.

Figure 1-1 provides a conceptualised framework of the HAPPY-study and how the thesis elaborates on the themes of the larger project. Dietary information, physical activity patterns and resting energy expenditure measurements were used to determine the change in energy intake and expenditure from the first to the third trimester - the first objective of the study. The second objective utilised measurements of resting energy expenditure and maternal body composition, which included body mass index, gestational weight, fat- and fat-free mass. The third objective was investigated by measurements of energy intake, energy expenditure and various birth outcomes – birth weight, birth length, abdominal circumference, and head circumference.

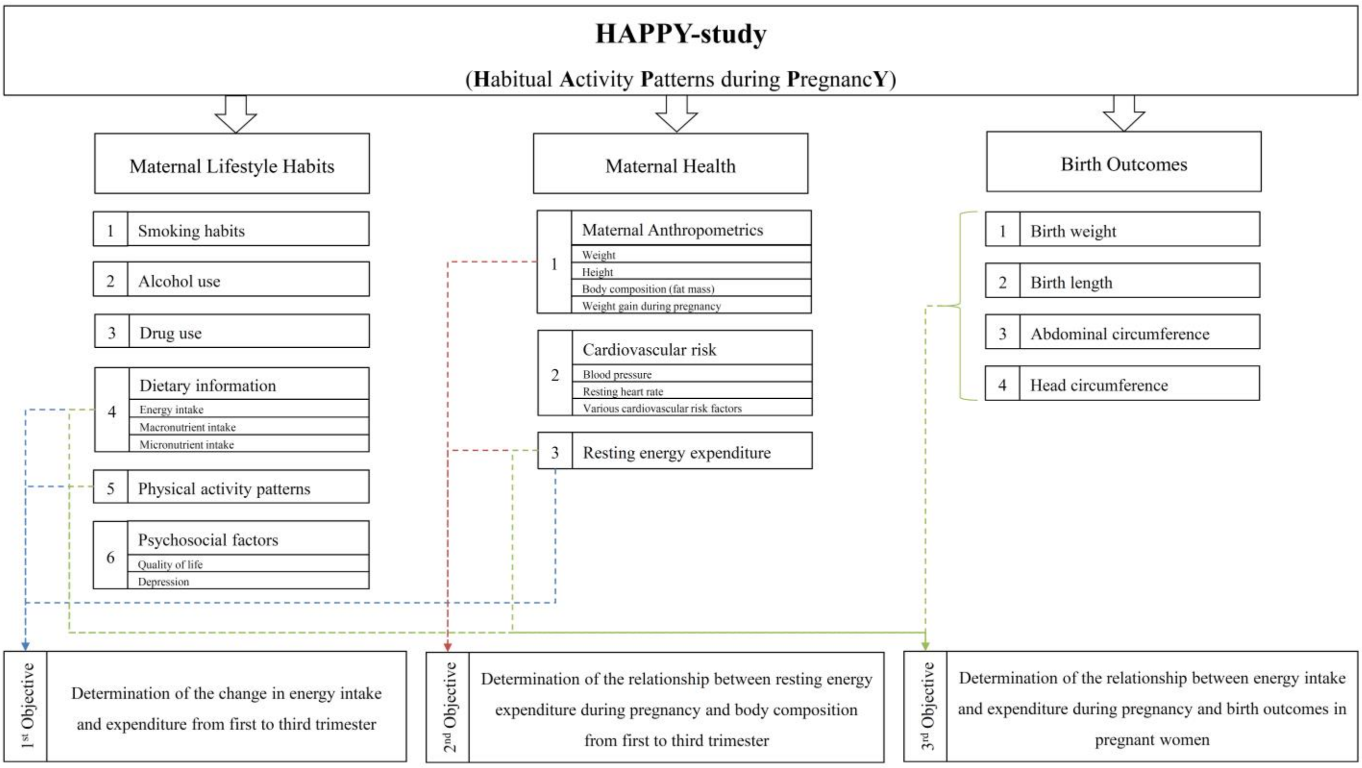

Figure 1-1: Framework of the HAPPY-study and linkages with the objectives of this thesis

1.6. Structure of the thesis

The thesis is structured in six chapters. Chapter 1 provides the introduction, problem statement, objectives, hypotheses, and conceptual framework of the thesis. References are provided at the end of the chapter in the adapted North-West University Harvard style. A literature review, Chapter 2, entitled: “Energy balance and birth outcomes during pregnancy” provides the reader with recent research related to the main themes of the thesis. As per Chapter 1, references are provided in the adapted North-West University Harvard style at the end of the chapter. Chapter 3 addresses the first objective of the study and is entitled: “Longitudinal changes in energy balance during pregnancy in South African women of the Tlokwe Municipal area.” The research manuscript was submitted for publication in the *BMC Pregnancy and Childbirth* journal. Chapter 4 explores the second objective of the thesis and is entitled: “Relationship between longitudinal changes in resting energy expenditure and body composition during pregnancy in South African women of the Tlokwe Municipal area.” The research manuscript was submitted to the journal *Scientific report* for publication. The last manuscript, Chapter 5, entitled: “Relationships between energy intake and expenditure and birth outcomes during pregnancy in a South African cohort of the Tlokwe Municipal area” will be submitted for publication in the *Journal of Pregnancy and Child Health*. References for Chapter 3 – 5 are given at the end of each chapter according to the author guidelines of the specific journal. Chapter 6 presents a summary, the conclusion, the limitations, and the recommendations of the completed thesis. To ensure uniform line spacing, font size and type were consistently applied between chapters. Tables and figures were consistently included in the text to ensure unambiguousness.

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CHAPTER 2: LITERATURE REVIEW - ENERGY BALANCE AND BIRTH OUTCOMES DURING PREGNANCY

2.1 Introduction

Pregnancy, childbirth, and the postpartum period represent critical phases in the reproductive lives of women (Maturi *et al.*, 2011:103; Reid *et al.*, 2014:1208) influencing growth in both the mother and her offspring (Leppanen *et al.*, 2014:2158; Nowicki *et al.*, 2011:560; Pearson *et al.*, 2015:93). During pregnancy, energy balance (energy intake minus energy expenditure) influences foetal growth (Kruger, 2005:44), gestational weight gain (Byrne *et al.*, 2011:819), as well as maternal- and birth outcomes (Kopp-Hoolihan *et al.*, 1999:703). High-quality longitudinal studies assessing all parameters of energy metabolism during pregnancy are recommended (Abeysekera *et al.*, 2016:44) as metabolic responses to pregnancy vary widely (Kopp-Hoolihan *et al.*, 1999:703).

Energy intake requirements are increased during pregnancy due to the energy costs associated with the synthesis and maintenance of new tissue (Lof & Forsum, 2006). Excessive energy intake, however increases the risk of excessive gestational weight gain (Stuebe *et al.*, 2009:58.e7) and gestational hypertension (Kazemian *et al.*, 2014:491). Energy requirements during pregnancy are influenced by various factors including pre-pregnancy weight or body mass index (BMI), maternal age, stage of gestation, basal metabolic rate (BMR) and physical activity levels (Blumfield *et al.*, 2012:332).

Two-thirds of South African women are inactive, with physical inactivity being a major contributing factor to the increase in overweight or obesity (Dickie *et al.*, 2014:828; Kruger *et al.*, 2001:738). The obesity epidemic is especially evident in young people, including women of reproductive age (Guelinckx *et al.*, 2008:140). The determination of altered energy balance and gestational weight gain during pregnancy should be clarified especially in overweight and obese pregnant women (Abeysekera *et al.*, 2016:43). Although weight gain is expected during pregnancy due to the development of new foetoplacental tissue and maternal protein and fat tissue to support gestation (Byrne *et al.*, 2011:826), excessive gestational weight gain is associated with various adverse maternal outcomes (IOM, 2009:5-1). Furthermore, energy balance during pregnancy should be optimised to promote the potential for a healthy gestational outcome for both mother and infant (Kopp-Hoolihan *et al.*, 1999:703).

Energy expenditure also increases during pregnancy due to tissue growth, an elevated BMR, as well as an increase in the energy cost of moving a heavier body mass (Löf, 2011:1295). From an energy balance perspective, changes that occur in physical activity during pregnancy will have important implications for maternal energy requirements (Clarke *et al.*, 2005:248). Research regarding energy intake and energy expenditure recommendations during pregnancy and optimal pregnancy outcome need to report physical activity data alongside dietary intake data in order to quantify energy balance (Abeysekera *et al.*, 2014:63; Blumfield *et al.*, 2012:322; Kruger, 2005:41; Schlaff *et al.*, 2014:21).

In this chapter, energy balance and birth outcomes during pregnancy will be critically reviewed in order to obtain a better understanding of the energy balance during pregnancy and the role that it plays regarding birth outcomes. The physiological adaptations that occur during pregnancy will be explained. Thereafter the constituent elements of energy intake and energy expenditure will be elaborated on. The implications of energy balance changes during pregnancy will also be discussed and will include changes in gestational weight gain, foetal growth, the theory of foetal origins of obesity and disease, as well as various maternal and offspring outcomes. Consequently, an elaboration on the relationship between energy balance and pregnancy follows. Finally, a summary of the literature will be provided, touching on current gaps in research with regards to energy balance during pregnancy.

2.2 Pregnancy-related physiological adaptations

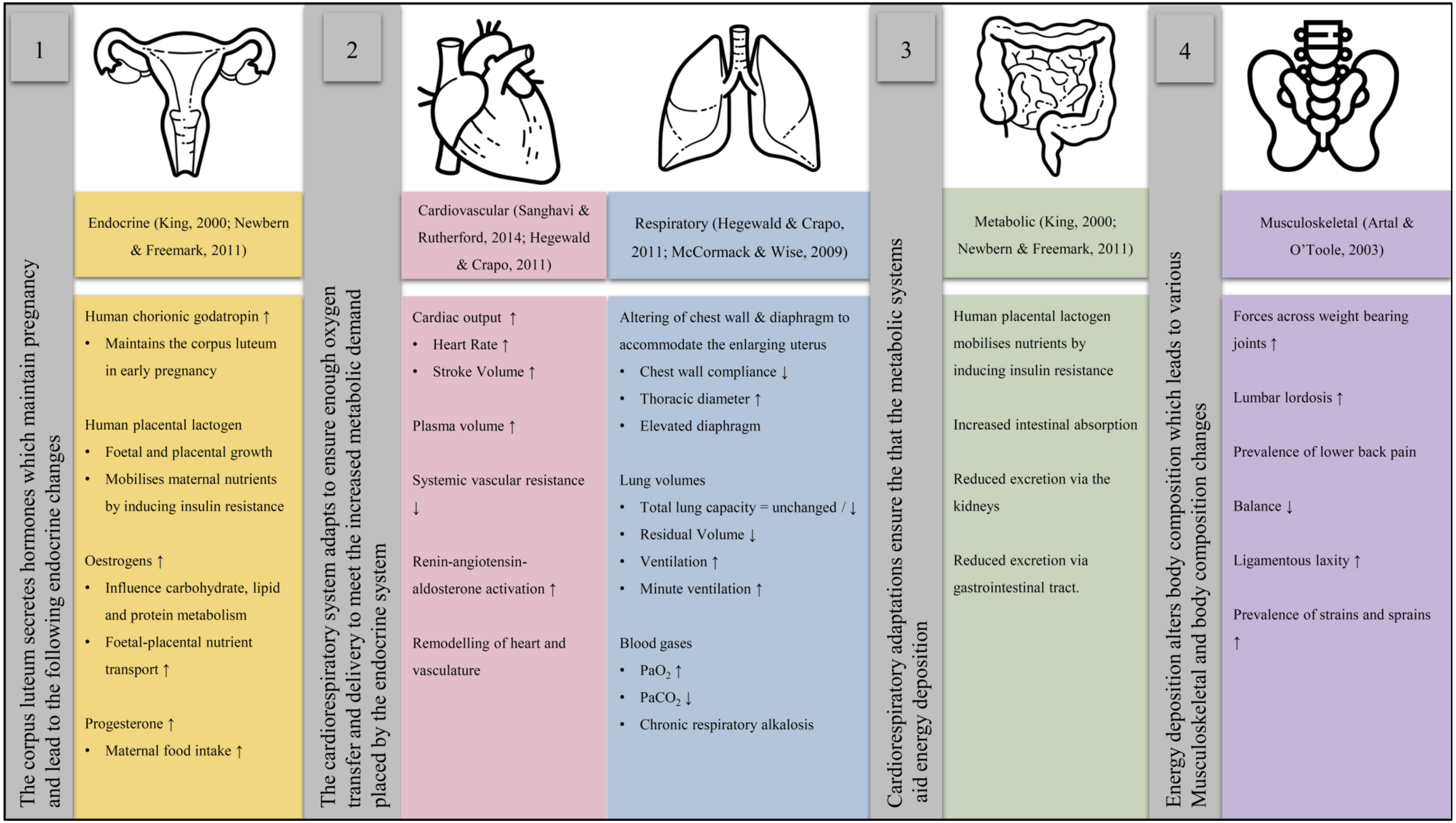
Pregnancy is a dynamic and physiologically complex period (ACOG, 2015:271; Bell & Robson, 2016:192); maternal physiological adaptation to pregnancy varies by gestational age, reflects the growth of the foetus, and changes with gestational weight gain (Newton & May, 2017:11). The aforementioned period is characterised by intense physical changes in which morphological adaptations occur in order to provide an ideal environment for the development of the foetus (da Silva *et al.*, 2017:295–296). In addition, the gestational period can be seen as an opportunity to promote positive health behaviours (da Silva *et al.*, 2017:296). Both the maternal environment and maternal lifestyle factors influence many of the maternal physiological adaptations to pregnancy which regulates foetoplacental growth (Clapp, 2006:527).

Pregnancy is divided into three trimesters (King, 2000:1218S). The onset of pregnancy is primarily a time of preparation for the demands of rapid foetal growth that occur later in pregnancy (King, 2000:1218S). Although foetal demand for nutrients primarily occurs during the last half of gestation when more than 90% of foetal growth occurs, adjustments in nutrient metabolism are apparent within the first weeks of pregnancy (King, 2000:1219S). This rapid rate of foetal growth during the last half of gestation, especially in the third trimester (Bernstein *et al.*, 1996:32), dictates changes in basal metabolism, protein, and mineral accretions (King, 2000:1219S).

The physiological changes related to pregnancy are graphically illustrated in Figure 2-1. The corpus luteum and placenta secrete hormones that maintains pregnancy by secreting hormones, including human chorionic gonadotropin, human placental lactogen, oestrogens, and progesterone (King, 2000:1218S–1219S). Human chorionic gonadotropin maintains the corpus luteum in early pregnancy (King, 2000:1218S). Human placental lactogen is biologically similar to growth hormone and correlates with placental mass which is indicative of its function in the growth of the foetus and placenta (King, 2000:1219S). Oestrogens not only influence the uterus and other reproductive organs but also influence carbohydrate, lipid, and bone metabolism (King, 2000:1219S). Specifically, oestrogens enhance Low-Density Lipoprotein cholesterol for placental steroid production, increases uteroplacental blood flow and foetoplacental angiogenesis, thus increasing foetoplacental nutrient transport (Newbern & Freemark, 2011:2). Progesterone stimulates maternal food intake (Newbern & Freemark, 2011:2) which leads to an energy-conserving state. The cardiorespiratory system adapts to ensure enough oxygen transfer and delivery so as to meet the increased metabolic demand placed by the abovementioned metabolic- and endocrine changes (Sanghavi & Rutherford, 2014:1007).

Cardiovascular changes during pregnancy include an increase in blood volume, heart rate and stroke volume, as well as cardiac output, and a decrease in systemic vascular resistance (ACOG, 2015:270; Hegewald & Crapo, 2011:10; Kader & Naim-shuchana, 2014:2; Sanghavi & Rutherford, 2014). These changes cause a low-resistance, high volume pregnant state necessary for appropriate utero-placental perfusion and effective foeto-maternal exchange (Vasapollo *et al.*, 2017:1). Additionally, the renin-angiotensin-aldosterone system is activated, and the heart and vasculature undergo remodelling (Sanghavi & Rutherford, 2014:1007). These cardiovascular adaptations allow for adequate foetal growth and development (Sanghavi & Rutherford, 2014:1007).

Profound respiratory changes during pregnancy include a 50% increase in minute ventilation, primarily as a result of the increased tidal volume (ACOG, 2015:271). The increased minute ventilation during pregnancy results in a reduction in the partial pressure of carbon dioxide ($PaCO_2$) and an increase in the partial pressure of oxygen (PaO_2) in arterial blood, which subsequently leads to respiratory alkalosis (Hegewald & Crapo, 2011:7). Mechanical alterations of the chest wall and diaphragm occur, coinciding with the enlargement of the uterus (Hegewald & Crapo, 2011:10; McCormack & Wise, 2009:23). In terms of lung volumes and capacities, Residual Volume decreases, with little or no changes in Total Lung Capacity (Hegewald & Crapo, 2011:10; McCormack & Wise, 2009:23). Pregnancy also causes an increase in oxygen consumption and a 10 – 12% increase in BMR (Artal & O’Toole, 2003:7) – which will be discussed under the Resting Energy Expenditure section in more detail. Increases in oxygen uptake of up to 10 – 20% compared with pre-pregnancy levels are illustrative of the respiratory changes during pregnancy (Kader & Naim-shuchana, 2014:2). The cardiorespiratory adaptations ensure that the metabolic system aids energy deposition.



1

The corpus luteum secretes hormones which maintain pregnancy and lead to the following endocrine changes

Endocrine (King, 2000; Newbern & Freemark, 2011)

Human chorionic godatropin ↑
- Maintains the corpus luteum in early pregnancy

Human placental lactogen
- Foetal and placental growth
- Mobilises maternal nutrients by inducing insulin resistance

Oestrogens ↑
- Influence carbohydrate, lipid and protein metabolism
- Foetal-placental nutrient transport ↑

Progesterone ↑
- Maternal food intake ↑

2

The cardiorespiratory system adapts to ensure enough oxygen transfer and delivery to meet the increased metabolic demand placed by the endocrine system

Cardiovascular (Sanghavi & Rutherford, 2014; Hegewald & Crapo, 2011)

Cardiac output ↑
- Heart Rate ↑
- Stroke Volume ↑

Plasma volume ↑

Systemic vascular resistance ↓

Renin-angiotensin-aldosterone activation ↑

Remodelling of heart and vasculature

Respiratory (Hegewald & Crapo, 2011; McCormack & Wise, 2009)

Altering of chest wall & diaphragm to accommodate the enlarging uterus
- Chest wall compliance ↓
- Thoracic diameter ↑
- Elevated diaphragm

Lung volumes
- Total lung capacity = unchanged / ↓
- Residual Volume ↓
- Ventilation ↑
- Minute ventilation ↑

Blood gases
- PaO_2 ↑
- $PaCO_2$ ↓
- Chronic respiratory alkalosis

3

Cardiorespiratory adaptations ensure the that the metabolic systems aid energy deposition

Metabolic (King, 2000; Newbern & Freemark, 2011)

Human placental lactogen mobilises nutrients by inducing insulin resistance

Increased intestinal absorption

Reduced excretion via the kidneys

Reduced excretion via gastrointestinal tract.

4

Energy deposition alters body composition which leads to various Musculoskeletal and body composition changes

Musculoskeletal (Artal & O'Toole, 2003)

Forces across weight bearing joints ↑

Lumbar lordosis ↑

Prevalence of lower back pain

Balance ↓

Ligamentous laxity ↑

Prevalence of strains and sprains ↑

Figure 2-1: Physiological changes related to pregnancy

The placenta secretes hormones that affect the metabolism of all nutrients which support foetal growth and development while maintaining maternal homeostasis and preparing for lactation (King, 2000:1218S). Metabolic homeostasis during pregnancy depends upon the precise control of maternal nutrient storage and mobilization, placental growth and nutrient transport, as well as foetal nutrient uptake and utilization (Newbern & Freemark, 2011:6). Human placental lactogen mobilizes nutrients for foetal growth by inducing maternal insulin resistance (Newbern & Freemark, 2011:3). Increasing intestinal absorption, or the reduction of excretion via the kidneys or gastrointestinal tract, adjust nutrient metabolism continuously throughout pregnancy (King, 2000:1218S). Nutrient metabolism is driven by hormonal changes, foetal demands, and maternal nutrient supply (King, 2000:1218S). Changes within the finely tuned metabolic homeostasis have important consequences for foetal growth and long-term metabolic function (Newbern & Freemark, 2011:6). Energy deposition alters the body composition of pregnant women, which leads to various musculoskeletal adaptations.

Adaptation of the musculoskeletal system includes increased forces across weight-bearing joints due to weight gain (Artal & O’Toole, 2003:6). Furthermore, changes in the centre of gravity due to weight gain during pregnancy leads to a lumbar lordosis and contributes to the high prevalence of lower back pain in pregnant women (Artal & O’Toole, 2003:6). These changes in the centre of gravity also predispose pregnant women to loss of balance and an increased risk of falling (Artal & O’Toole, 2003:6). Hormonal changes include an increased level of oestrogen and relaxin ,which in turn causes increased mobility of the joints (Kader & Naim-shuchana, 2014:2). The higher levels of oestrogen and relaxin, which increase the risk of ligamentous laxity, might predispose pregnant women to an increased incidence of strains and sprains (Artal & O’Toole, 2003:6).

Metabolic changes during pregnancy ensure energy balance in anticipation of the subsequent energy costs related to foetal development and lactation. Maternal behaviour changes – such as physical activity and nutritional habits - augment physiological adjustments, although a limit exists in the physiological capacity to adjust nutrient metabolism to meet pregnancy needs, which when exceeded impairs foetal growth and development (King, 2000:1218S).

2.3. General energy balance

The dominant theoretical framework that explains weight change and obesity is based on the concept of energy balance derived from the laws of thermodynamics – that energy can be converted among forms, but can never be destroyed and therefore must be conserved (Hand *et al.*, 2013:276). Energy balance dictates that total energy intake from food equals total energy expenditure (McArdle *et al.*, 2014:808). Total energy expenditure (TEE) includes the basal metabolic rate (BMR), diet-induced thermogenesis

(DIT) and energy expended during physical activity and daily living activities (active energy expenditure – AEE) (Butte & King, 2005:1023-1024; McArdle *et al.*, 2014:192). The constituent elements of energy balance, energy intake and energy expenditure, will be elaborated on in more detail in the following sections.

Imbalances between energy intake and expenditure result in weight change (Hand *et al.*, 2013:276). An imbalance from an excessive intake of energy will result in weight gain while excessive energy expenditure will result in weight loss (Hand *et al.*, 2013:276). Weight regulation is, however, both complicated and multifactorial with significant evidence to support the influence of genetics, environmental factors, physiology, behaviour, and the interaction of these variables (Hand *et al.*, 2013:281). A positive energy balance is required for weight gain to occur: daily energy intake must consistently exceed energy expenditure (Byrne *et al.*, 2011:819). During pregnancy, the extra physiological energy demand is estimated to be greater than 836 kJ per day in order to achieve foetal growth through positive energy balance during the third trimester of pregnancy (Melzer *et al.*, 2009:1190)

2.4. Energy intake during pregnancy

Energy is provided by macronutrients which consist of carbohydrates, lipids and fats (McArdle *et al.*, 2014:8). Energy is extracted from macronutrients by means of metabolism (McArdle *et al.*, 2014:118). The average dietary intake allowance for men of reference size (77 kg) is 2300 kcal/day and 1900 kcal/day for women (National Research Council, 1989:33). Hand *et al.* (2013:281) measured an average energy intake of 1792 ± 471 kcal/day for non-pregnant women and 2407 ± 818 kcal/day for men, where the largest component of energy intake in both groups was from carbohydrates. However, energy intake varies dramatically from person to person (Mattes, 2014:111; McCrory *et al.*, 2000:277S). Various factors such as gender, age, race, physical activity, exercise, body composition, and basal metabolic rate all influence energy intake. A South African study by Hattingh *et al.* (2008:4021) measured an average energy intake of 2743 kcal/day in a population of black women in Bloemfontein aged 25 – 44 years old. Another determinant of energy intake is pregnancy which significantly influences the nutritional habits of women. Dietary energy requirements are increased during pregnancy due to the energy costs associated with the synthesis and maintenance of new tissue (Lof & Forsum, 2006:298).

Pregnancy is a critical period where maternal nutrition is a key factor influencing the health of both mother and child (Pick *et al.*, 2005:240; Verbeke & De Bourdeaudhuij, 2007:79). A review by Wrottesley *et al*. (2016:160), confirms the importance of maternal nutrition in Africa during the first 1000 days, which includes the prenatal period, to improve foetal growth and birth outcomes. An appropriate diet will provide the necessary amounts and varieties of nutrients to ensure optimal health for both mother and offspring (Pick *et al.*, 2005:240; Verbeke & De Bourdeaudhuij, 2007:79). According to the National Research Council (1989:34) additional energy intake is not required during the first trimester unless the woman begins her pregnancy with depleted body reserves. Thereafter, an additional 300 kcal/day is recommended during the second and third trimester (National Research Council, 1989:34). However Alavi *et al.* (2013:75) in a systematic review of energy intake recommendations found that these recommendations vary substantially from country to country. Blumfield *et al.* (2012:326) systematically reviewed energy intake during pregnancy in high-income countries and reported mean energy intake during pregnancy as 2144 ± 247 kcal/day. Blumfield *et al.* (2012:326) also found daily energy intake in the third trimester (2213 ± 59 kcal/day) to be significantly higher (p = 0.019) than in the first trimester (2029 ± 209 kcal/day).

2.4.1. Macronutrient metabolism in pregnancy

While pregnancy affects the metabolism of all nutrients (King, 2000:1224S), the majority of studies regarding nutritional requirements during pregnancy concentrate exclusively on changes in total caloric intake and only a few deals with total macronutrient composition (Rad *et al.*, 2011:186). Recommendations regarding macronutrient composition are that 50 – 55% of daily calories be derived from carbohydrates, 30 – 35% from fat, and 10 – 15% from protein, similar to the standard nutritional recommendations for non-pregnant women (Rad *et al.*, 2011:186).

Rad *et al.* (2011:189) observed no change in the macronutrient composition of the diets of healthy, normal-weight pregnant women, who exhibited normal foetal growth and had average weight gain during their pregnancy. In contrast, Blumfield *et al.* (2012:331) found that, in general, the dietary intakes of pregnant women from high-income countries do not align with country-specific energy and macronutrient recommendations. Poor macronutrient quality may have an unfavourable impact on mother and offspring during pregnancy (Blumfield *et al.*, 2012:332). Blumfield *et al.* (2012:333) reported that energy and fibre intakes were consistently lower than recommended levels, total fat and saturated fat intakes were generally above recommended levels. At the same time, carbohydrate and polyunsaturated fatty acids were either lower or borderline low as compared to recommend levels (Blumfield *et al.*, 2012:333).

2.4.1.1. Carbohydrates

The dietary glycaemic load of carbohydrates modify several of the physiological adaptations to pregnancy which regulates the availability of substrate delivery and influences the variable foetoplacental growth (Clapp, 2006:532-533). Maternal hyperglycaemia induces hyperinsulinaemia, which results in accelerated foetal growth which may result in macrosomia (Daniels & Grobbelaar, 2015:21). Daniels & Grobbelaar

(2015:21) state the importance of recommending lower glycaemic index choices for their positive effect on gestational weight gain and maternal glucose intolerance. A low glycaemic diet may blunt the increase in insulin resistance and may influence normal infant birth weight and maternal weight gain (Daniels & Grobbelaar, 2015:22).

In a systematic review, Blumfield *et al.* (2012:330) the reported that carbohydrate intake during pregnancy was 269.1 ± 37.0 g/day. Women consumed 256.0 ± 31.2 g/day of carbohydrates during the first trimester and 273.8 ± 39.7 g/day of carbohydrates in the third trimester (Blumfield *et al.*, 2012:330). Another study by Rad *et al.* (2011:88) reported that carbohydrate intake remained constant during pregnancy and averaged 281 ± 58 g.

2.4.1.2. Lipids

Dietary lipid intake during pregnancy affects pregnancy outcomes and modulates the growth, development and health of the infant (Drouillet *et al.*, 2009:583; Koletzko *et al.*, 2007:873). Essential fatty acids are required for the foetal brain, nervous system, and retinal growth (Drouillet *et al.*, 2009:584). As a proportion of energy intake, dietary lipids should be the same as that recommended for the general population (Koletzko *et al.*, 2007:875)

Total lipid intake was reported as 84.7 ± 14.6 g/day during the whole pregnancy (Blumfield *et al.*, 2012:329). In the first trimester, women consumed 78.1 ± 9.6 g/day, and in the third trimester, they consumed 88.2 ± 16.5 g/day (Blumfield *et al.*, 2012:329). Rad *et al.* (2011:188) found no variation during the course pregnancy in lipid consumption ($p = 0.41$), and daily lipid intake averaged 86 ± 16 g. Blumfield *et al.*, (2012:331) indicated total fat intake and saturated fat intakes to be above the recommended dietary allowance during pregnancy.

2.4.1.3. Proteins

Protein intake during pregnancy correlated positively with neonatal head circumference, chest circumference, birth weight, whole length, and foot length by Awasthi *et al.*, (2015:490). Protein intake lower than the recommended levels is possible but is also associated with preterm birth (Awasthi *et al.*, 2015:491). In a Cochrane review (Ota *et al*., 2012:29) balanced energy/protein supplementation was associated with an increased mean birth weight, reduced risk of stillbirth, and small-for-gestational-age birth.

The reported protein intake during pregnancy averaged 82.1 ± 12.5 g/day (Blumfield *et al.*, 2012:328). There was a 5.9 g/day difference in the protein intake in the first (78.1 ± 9.6 g/day) and third (84.0 ± 13.0 g/day) trimester. Rad *et al.* (2011:88) found no change in protein consumption during their course of the study ($p = 0.36$) measuring an average daily protein intake of 75 ± 13 g.

2.4.2. Energy conservation during pregnancy

In contrast to the previously mentioned increase in energy and macronutrient intake during pregnancy, Butte and King (2005:1019) in a systematic review of high-income countries found no or only minor increases in energy intake in well-nourished women which only partially covered the energy cost of pregnancy. Similar results were found by Rad *et al.* (2011:189) who observed no clinically significant increase in energy intake in the diets of healthy, normal-weight pregnant women living in Berlin, who exhibited normal foetal growth. Jebeile *et al.* (2016:481) found, in a systematic review related to both high- and low-to-middle-income countries, no correlation between additional energy intake and gestational weight gain suggesting that factors other than additional food intake may be responsible for the physiological weight gain of pregnancy. This discrepancy between energy intake and the projected energy costs of pregnancy led to the theory of energy-conserving metabolic adaptations during pregnancy (Bronstein *et al.*, 1995:261; Kopp-Hoolihan *et al.*, 1999:703; Poppitt *et al.*, 1993:360; Prentice *et al.*, 1989:18). Abeysekera *et al.* (2016:47) concluded that pregnancy alters homeostatic mechanisms, allowing for a more efficient fat-storing state even if there are no significant changes in energy intake. Clarke *et al.* (2005:248) state that the offset in increased energy costs is attained by decreasing physical activity during the gestational period. Energy requirements during pregnancy are relatively modest after allowance for the physical and metabolic adaptations that occur during pregnancy is made (Swift *et al.*, 2017:40). The present nutritional advice to increase energy intake may thus result in an increased risk of excessive gestational weight gain (Abeysekera *et al.*, 2016:47).

These energy-conserving metabolic adaptations might primarily be related to low-to-middle-income countries. Byrne *et al.* (2011:828) stated that energy-conserving adaptations accommodate dietary insufficiencies and protect foetal growth in undernourished women. Poppitt *et al.* (1993:363) confirmed the finding of energy-sparing adaptations which occurred in rural Gambian women through a decrease in RMR. Kruger (2005:42) states that underweight women with a limited food supply and who live under the constraints of hard physical work will conserve energy primarily by means of a reduction in RMR. In particular, low-income women must often maintain a strenuous work pattern until shortly before delivery, and the Food and Agriculture Organization of the United Nations (FAO, 2001:59-60) thus does not recommend a reduction in the additional energy allowance for pregnancy.

2.4.3. Dietary behaviour during pregnancy

Being pregnant leads to different beliefs, behaviour, and dietary patterns as compared to non-pregnant women (Olson, 2005:134; Rifas-Shiman *et al.*, 2006:36; Verbeke & De Bourdeaudhuij, 2007:79). Pregnant women are more conscious about their diet, and their food choices are more strongly driven by safety concerns, as compared to non-pregnant women (Verbeke & De Bourdeaudhuij, 2007:85). Generally, the consumption frequency of fruit, vitamins and supplements, beef, milk and fat increases while a decrease in the consumption of alcohol, caffeine and smoking occurs (Olson, 2005:135; Rifas-Shiman *et al.*, 2006:40; Verbeke & De Bourdeaudhuij, 2007:84). Swift *et al.* (2017:44) demonstrated that women's dietary behaviour does not develop gradually during early pregnancy, but instead appears to be triggered by the confirmation of conception. Food cravings during pregnancy generally result in increased calcium and energy intakes, whereas food aversions cause a decrease in the intake of alcohol, caffeine, and animal protein (King, 2000:1221S). Levels of nausea and vomiting, which are reported commonly in the first trimester (Poudevigne & Connor, 2006), may also influence the dietary habits of the pregnant woman.

2.4.4. Accuracy of dietary information

Accurately measuring dietary intake is challenging as most studies typically rely on self-reported dietary assessment (Nowicki *et al.*, 2011:560). A summary of the energy and macronutrient intake during pregnancy is provided in Table 2-1. The accuracy of dietary records in pregnancy remains uncertain (McGowan & McAuliffe, 2012:906) due to significant discrepancies in dietary data collection methods and insufficient data on demographic and social factors that often confound dietary values (Blumfield *et al.*, 2012:333). However, assessing habitual dietary intake using a food frequency questionnaire (FFQ) is appropriate among pregnant women by a wide variety of epidemiological studies (Nowicki *et al.*, 2011:561; Mejía-Rodríguez *et al.*, 2012:1476). The FFQ has been validated in pregnant women in Belgium (De Vriese *et al.*, 2001:277), Japan (Ogawa *et al.*, 2017:208), Malaysia (Loy & Jan Mohamed, 2013), Mexico (Mejía-Rodríguez *et al.*, 2012:1476), Norway (Brantsaeter *et al.*, 2008:41) and the United States (Baer *et al.*, 2005:144; Brown *et al.*, 1996:266; Wei *et al.*, 1999:245). In South Africa, the FFQ has been validated in a non-pregnant cohort (MacIntyre *et al.*, 2001:49; Sheehy *et al.*, 2014:448).

2.4.5. Dietary Guidelines during pregnancy

Recommendations for nutritional intake during pregnancy are diverse and depend on the population being evaluated, making general guidelines for nutritional intake difficult (Catalano *et al.*, 2003:1679S). The nutrient intakes to support good pregnancy outcomes are not fixed as they undoubtedly vary widely from woman to woman depending on her prepregnancy nutritional status, foetal size, health and lifestyle during gestation, and genetics (King, 2000:1224S). Whitaker and Wilcox (2016:2313) indicated a general lack of detail in terms of nutritional advice given during pregnancy. In the study, nearly one-third of women simply reported that the recommendations provided were to "eat healthily".

The Food Guide Pyramid provides a baseline for dietary guidelines which is based on the premise that if the minimum number of recommended servings are met, the majority of people will take in all the nutrients required to maintain health and prevent diet-related chronic diseases (Pick *et al.*, 2005:240). However, during pregnancy goals such as preventing low birth weight and congenital disabilities as well as supporting maternal nutrition without excessive weight gain are essential and are influenced by dietary recommendations (Pick *et al.*, 2005:240–241). As such, an extra energy intake of 100 – 200 kCal/day is recommended to support foetal growth during the first-trimester, 340 kCal/day during the second trimester and 452 kCal/day during the third trimester, respectively (Most *et al*., 2018).

Most dietary guidelines provided during pregnancy are generally made regarding the aversion of specific, potentially harmful, food groups like raw meats and vegetables, the reduction of alcohol and caffeinated beverages, rather than regarding dietary improvement aimed at healthy nutrition and the control of gestational weight gain (Guelinckx *et al.*, 2008:145-147; Rifas-Shiman *et al.*, 2006:39-40; Verbeke & De Bourdeaudhuij, 2007:84-85). According to Clapp (2006:532), apart from folic acid supplementation, the most important aspect of diet prescription during pregnancy in western industrialized society is to emphasize the value of fresh fruits and vegetables and the potential deficits of most processed food.

The positive effects of intervention studies focusing on nutritional habits should be critically evaluated as pregnant women probably automatically change their nutritional behaviour through a higher consumption of vegetables and fruit, and beef and dairy products (Guelinckx *et al.*, 2008:145; Olson, 2005:135; Rifas-Shiman *et al.*, 2006:6; Verbeke & De Bourdeaudhuij, 2007:85). In a randomized controlled trial, Wolff *et al.* (2008:499) demonstrated that it is possible to restrict excessive gestational weight gain in obese women by a dietary intervention. Furthermore, by preventing excessive gestational weight gain during pregnancy, Wolff *et al.* (2008:499-500) observed no adverse effects on foetal growth and incidences of pregnancy and birth complications. Preventing excessive gestational weight gain in obese women by means of either nutritional or physical activity recommendations could play an important role in the prevention of pregnancy complications such as gestational diabetes and pregnancy-induced hypertension by reducing concentrations of glucose, insulin, and leptin (Wolff *et al.*, 2008:500).

Table 2-1: A Summary of studies reporting on energy intake during pregnancy

Authors	Title	Study Design	Methods	Energy and macronutrient intake
Ådén *et al.*, 2007)	Energy and nutrients in self-reported diet before and at week 18-22 of pregnancy	Design: Longitudinal observational study *n* = 50 pregnant women	A self-administered, validated FFQ (84-item) was retrospectively used to capture food intake in the year before pregnancy. To capture food intake at mid-gestation, two 24-hour dietary recalls were performed by telephone recorded at gestational weeks 18 – 22.	*Intake at mid-gestation:* Energy (kcal) = 2104 ± 583 (945 – 3627) Energy (MJ) = 8.81 ± 2.44 (3.96 – 15.19) Carbohydrates (*E*%): 51.1 ± 6.6 Protein (*E*%): 16.8 ± 2.4 Fat (*E*%): 32.1 ± 6.4
Brion *et al.*, 2010)	Maternal macronutrient and energy intakes in pregnancy and offspring intake at 10 y: exploring parental comparisons and prenatal effects	Design: Prospective cohort study *n* = 5717 pregnant women	Mothers completed a FFW at 32 weeks of gestation.	Energy (kJ/day) = 7506 ± 1959 (2228 – 17600) Carbohydrates (g/d): 223.0 ± 60.9 Protein (g/d): 67.8 ± 18.0 Fat (g/d): 70.5 ± 22.6
McGowan & McAuliffe, 2012	Maternal nutrient intakes and levels of energy underreporting during early pregnancy	Design: Prospective observational study *n* = 248 pregnant women of a gestational age of 14 weeks (range 12 – 20 weeks) and a mean age of 33.6 years (range 23 – 43 years)	Three-day food diaries were collected from 260 healthy pregnant women recruited from antenatal clinics at the National Maternity Hospital. Food diaries were completed 1 – 2 weeks after the first antenatal hospital visit between 12 and 20 weeks gestation. Participants recorded all food and beverages consumed over three consecutive days, including a weekend day.	Energy (MJ) = 8.0 ± 1.9 Carbohydrates (*E*%): 50 ± 6.2 Protein (*E*%): 16.7 ± 2.8 Fat (*E*%): 36.2 ± 5.6
Blumfield *et al.*, 2012	Systematic review and meta-analysis of energy and macronutrient intakes during pregnancy in developed countries	*Design:* Systematic review 90 studies *n* = 126242	FFQs were the most frequently used dietary assessment methodology (34 studies). Estimated diet records (26 studies), weighed food records (14 studies), diet history questionnaires (8 studies), and 24-hour diet recalls (8 studies).	Energy intake: 8969 ± 1034 kJ/day / 2144 ± 247 kcal/day Carbohydrate intake: 269.1 ± 37.0 g/day Protein intake: 82.1 ± 12.5 g/day Fat intake: 84.7 ± 14.6 g/day

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<table>
<tr><th>Authors</th><th>Title</th><th>Study Design</th><th>Methods</th><th>Energy and macronutrient intake</th></tr>
<tr><td>Kopp-Hoolihan <i>et al.</i>, 1999</td><td>Longitudinal assessment of energy balance in well-nourished pregnant women</td><td><i>Design</i>: Longitudinal observational study

<i>n</i> = 10 healthy, non-smoking pregnant women</td><td>Participants kept 3-day weighed food intake records at 8-10, 24-26, and 34-35 weeks of gestation. Records were analysed using NUTRITIONIST IIII software (version 7.2; N-Squared Computing, Salem, OR) and energy intake and macronutrient content were estimated at each time point from the 3-day average value.</td><td>Energy intake (1st trimester): 8488 ± 1624 kJ/day
Energy intake (2nd trimester): 8496 ± 1654 kJ/day
Energy intake (3rd trimester):9344 ± 2170 kJ/day</td></tr>
<tr><td>Bouwland-Both <i>et al.</i>, 2013</td><td>A periconceptional energy rich dietary pattern is associated with early fetal growth: The Generation R study</td><td><i>Design</i>: Population-based prospective birth cohort study in Rotterdam, the Netherlands.

<i>n</i> = 847 pregnant Dutch women in early pregnancy</td><td>A semiquantitative FFW.
Dietary patterns were extracted by principal component factor analysis.</td><td>Energy intake (kJ/day): 8847 (5564-12726)
Carbohydrate (<i>E</i>%): 48.3 (39.2 – 59.1)
Carbohydrate (g/day): 254.7 (149.6 – 397.6)
Fat (<i>E</i>%): 36.3 (27.3 – 44.3)
Fat (g/day): 83.3 (51.0 - 126.9)
Protein (<i>E</i>%): 14.9 (11.4 – 19.3)
Protein (g/day): 79.1 (47.9 – 112.0)</td></tr>
<tr><td>Abeyseker a <i>et al.</i>, 2016)</td><td>Alterations in energy homeostasis to favour adipose tissue gain: A longitudinal study in healthy pregnant women</td><td><i>Design:</i> Longitudinal study design measured at 12-14 weeks, 24-26 weeks and 34-36 weeks of gestation.

<i>n</i> = 26 women with singleton pregnancies</td><td>3-day food record.
Participants were instructed to maintain their usual diets and to record the type and quantities of all food and drink consumed over three consecutive days.
Average daily caloric, carbohydrate, fat, and protein intakes were calculated using the Foodworks program, which uses the Food Standards and New Zealand AUSNUT 2007 nutrient database (Foodworks Version 1: Xyris Software Aust. Pty Ltd. Highgate Hill, QLD, Australia).</td><td><table>
<tr><th></th><th>12 – 14 weeks</th><th>24 – 26 weeks</th><th>34 – 36 weeks</th></tr>
<tr><td>Energy intake (kJ/day)</td><td>8649 ± 1497</td><td>8171 ± 2210</td><td>8637 ± 2236</td></tr>
<tr><td>Carbohydrate intake (g/day)</td><td>231 ± 72</td><td>231 ± 66</td><td>237 ± 77</td></tr>
<tr><td>Fat intake (g/day)</td><td>76 ± 20</td><td>67 ± 26</td><td>75 ± 17</td></tr>
<tr><td>Protein (g/day)</td><td>102 ± 31</td><td>96 ± 25</td><td>99 ± 33</td></tr>
</table>
Energy intake was not significantly different in any trimester (<i>P</i> = 0.551), as well as daily carbohydrate, fat and protein intakes (<i>P</i> = 0.889, <i>P</i> = 0.183 and <i>P</i> = 0.672 respectively)</td></tr>
</table>

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<table>
<tr><th>Authors</th><th>Title</th><th>Study Design</th><th>Methods</th><th>Energy and macronutrient intake</th></tr>
<tr><td>Jebeile et al., 2016)</td><td>A systematic review and meta-analysis of energy intake and weight gain in pregnancy</td><td>Design: Systematic review and meta-analysis

n: 18 studies</td><td>Electronic databases (Ovid Medline, Cochrane Library, Excerpta Medica DataBASA (EMBASE), Cumulative Index to Nursing and Allied Health Literature, and Science Direct) were systematically searched for observational and intervention studies.</td><td>The mean reported energy intake was 8130 ± 1100 kJ/day and 8600 ± 1230 kJ/day in early and late pregnancy, respectively.</td></tr>
<tr><td>Awasthi et al., 2015</td><td>Energy and Protein Intake During Pregnancy in Relation to Preterm Birth: A Case Control Study</td><td>Design: A Case-control study in two hospitals at Lucknow in Northern India

n = 350 cases defined as mothers (age 18-40) of singleton live preterm (<37 weeks) neonates.

n = 350 controls defined as mothers who delivered a singleton neonate, after completing 37 weeks of gestation.</td><td>A predesigned questionnaire was used to obtain dietary information one week preceding the delivery.

Food frequencies for individual questions were converted into servings for a day or week, and then summed to give a total daily intake of protein and energy.</td><td><table>
<tr><th></th><th>Cases – prematurity</th><th>Controls – Full term infant</th><th>P-value</th></tr>
<tr><td>Energy intake (kCal/day)</td><td>1624 ± 249</td><td>1911 ± 341</td><td>< 0.001</td></tr>
<tr><td>Protein (g/day)</td><td>32 ± 6.0</td><td>37.2 ± 7.0</td><td>< 0.001</td></tr>
</table></td></tr>
<tr><td>Lagiou et al., 2011</td><td>Energy intake during pregnancy in relation to offspring gender by maternal height</td><td>Design: Prospective study

n = 150 Caucasian women in Boston, USA
n = 243 Asian women in Shanghai China</td><td>Semi-quantitative centre-specific FFQ was incorporated to determine energy intake in the second trimester.</td><td><table>
<tr><th></th><th>Boston USA (n = 150)</th><th>Shanghai, China (n = 243)</th></tr>
<tr><td>Energy intake (kcal/day)</td><td>2328 ± 541</td><td>3321 ± 1105</td></tr>
</table></td></tr>
</table>

Continues on following page.

Authors	Title	Study Design	Methods	Energy and macronutrient intake				
Rad *et al.*, 2011	Longitudinal analysis of changes in energy intake and macronutrient composition during pregnancy and 6 weeks post-partum	*Design*: Prospective study *n:* 32 healthy pregnant women	The women recorded the total amount of food and beverages consumed over 2-day periods during the 16th, 22nd, 30th, and 36th weeks of gestation and, in addition, 6 weeks after delivery. Food logs were distributed 1 day before each respective check-up. Participants were carefully instructed in individual sessions on how to keep food logs. The participants were instructed to not change their normal eating habits.		16th week	22nd week	30th week	36th week
				Energy intake (kJ/day)	9237 ± 1876	9496 ± 2437	9073 ± 1863	9525 ± 2135
				Energy intake (kcal/day)	2206 ± 448	2268 ± 582	2167 ± 445	2275 ± 510
Pereira-Da-Silva *et al.*, 2013	The Adjusted Effect of Maternal Body Mass Index, Energy and Macronutrient Intakes during Pregnancy, and Gestational Weight Gain on Body Composition of Full-Term Neonates	*Design*: Cross-sectional study of a systematically recruited convenience sample of mother-infant pairs *n*: 100 mother-infant pairs were included	Food intake during pregnancy was evaluated using a FFQ and its nutritional value was evaluated using the Food Processor Plus (ESHA Research Inc, Salem, OR). Women completed the questionnaire once, in the immediate postpartum period, to recall their usual dietary intake during the whole pregnancy.		Whole pregnancy			
				Energy intake (kcal/day)	2982 ± 72			
				Carbohydrate intake (*E%*)	49.90 ± 5.17			
				Fat intake (*E*%)	33.66 ± 4.03			
				Protein (*E*%)	18.06 ± 2.58			
Rifas-Shiman *et al.*, 2006	Changes in dietary intake from the first to the second trimester of pregnancy	*Design*: Prospective cohort study *n*: 1543 during their 1st and 2nd trimester of pregnancy	Self-administered validated 166-item semi-quantitative FFQ assessing the woman's diet in the 1st and 2nd trimester of pregnancy. Thereafter mean servings per day of food and food groups and mean daily nutrient intake during each of the two trimesters were calculated.		1st trimester	2nd trimester		
				Energy intake (kcal/day)	2047 ± 655	2137 ± 640		
				Protein (*E*%)	17.5 ± 3.0	17.6 ± 2.8		
				Carbohydrates (*E*%)	55.4 ± 7.3	54.5 ± 7.1		
				Trans-fatty acids (*E*%)	1.0 ± 0.3	1.0 ± 0.3		
				N-3 fatty acid (*E*%)	0.5 ± 0.2	0.5 ± 0.2		
				N-6 fatty acids (*E*%)	5.3 ± 1.4	5.5 ± 1.5		
				Saturated fat (*E*%)	10.5 ± 2.5	11.1 ± 2.6		

Continues on following page.

Authors	**Title**	**Study Design**	**Methods**	**Energy and macronutrient intake**		
Pick *et al.*, 2005	Assessment of Diet Quality in Pregnant Women Using the Healthy Eating Index	*Design:* Case-control study *n*: Pregnant (*n* = 52) and control group (*n* = 49) of healthy women of child bearing age	Dietary information was prospectively collected from nonpregnant women and pregnant women at 20 to 38 weeks' gestation using 4-day food records. Diet records were analysed for nutrient content using computer software and for overall quality using the Healthy Eating Index.		Non-pregnant (*n* = 49)	Pregnant (*n* = 52)
				Energy intake (kcal/day)	2033 ± 67.5	2309 ± 53.4
				Carbohydrates (*E*%)	56 ± 1.11	56 ± 0.74
				Protein (*E*%)	16.1 ± 0.58	15.1 ± 0.34
				Total fat (*E*%)	28.0 ± 0.85	28.9 ± 0.67
				Saturated fat (*E*%)	9.7 ± 0.36	10.2 ± 0.30

n = total participants, FFQ = Food frequency questionnaire, *E*% = Energy percentage, kcal = kilocalories, kJ/day = kilojoules per day, g/day = grams per day

Although it is difficult to set standards for energy intake, King (2000:1222S) states that for normal-weight and overweight women living in high-income countries, the additional energy need may only be 300 kcal/day, especially if activity levels decline. Energy intake above the rise in basal metabolism that occurs during pregnancy will likely cause excessive gestational weight gain (King, 2000:1222S).

2.5 Energy expenditure during pregnancy

In general, the most significant contributor to energy expenditure is resting energy expenditure, comprising 60 – 75% of total energy expenditure, whereas active energy expenditure only comprises 15 – 30% with diet-induced thermogenesis comprising 10% of total energy expenditure (McArdle *et al.*, 2014:192). Dugas *et al.* (2009:670) measured average energy expenditure in South-African women: lean black women expended 8672 kJ/day, lean white women 9761 kJ/day, obese black women 9840 kJ/day and obese white women 11132 kJ/day. Factors influencing energy expenditure are fat-free mass, physical activity participation, climate and even the type of diet (McArdle *et al.*, 2014:196). Another example of a state that influences energy expenditure is pregnancy.

The additional energy cost of pregnancy is due to the additional maternal and foetoplacental tissue accrued during pregnancy and the additional energy cost of pregnancy, for example, the increased cardiac output (Catalano *et al.*, 2003:1679S). The highest increases in maternal energy expenditure occur between 10 and 30 weeks of gestation, primarily because of the maternal accretion of adipose tissue (Catalano *et al.*, 2003:1679S) which however varies considerably among ethnic groups (Catalano *et al.*, 2003:1679S). According to Widen *et al.* (2015:1464), the low-income, the urban African American population is at high risk of obesity and excessive gestational weight gain. Excessive gestational weight gain is associated with a higher percentage of body fat in this population (Widen *et al.*, 2015:1465).

2.5.1. Resting energy expenditure during pregnancy

Basal metabolic rate (BMR) is defined as the minimum level of energy needed to sustain vital functions in the waking state (McArdle *et al.*, 2014:192). Basal metabolic rate is measured under specific conditions which include being awake in the supine position after 10 – 12 h of fasting and 8 hours of physical rest (Hronek *et al.*, 2009:947). A less stringent measurement: Resting Metabolic Rate (RMR) is measured 3 to 4 hours after a light meal without prior physical activity (McArdle *et al.*, 2014:192). In clinical practice, BMR and RMR are used interchangeable (Hronek *et al.*, 2009:948; McArdle *et al.*, 2014:192). Resting metabolic rate accounts for about 60 – 75% of Total Energy Expenditure in individuals not engaged in competitive physical activity and correlates well with total energy expenditure (Catalano *et al.*, 2003:1679S; McArdle *et al.*, 2014:192). McMurray *et al.* (2014:1356) systematically reviewed literature on RMR and determined a mean RMR of 0.89 kcal/kg/h for men and 0.84 kcal/kg/h for women. However, as stated by the author, there is considerable variability in the RMR of adults and one standard value should not reasonably be used for adults of varying age, sex, or obesity status (McMurray *et al.*, 2014:1355).

Resting metabolic rate is influenced by various factors including age, sex, body composition and ethnicity (McMurray *et al.*, 2014:1357). The difference in RMR between sexes and age groupings could be due to differences in muscle mass as RMR is primarily dependent on metabolically active muscle tissue (McMurray *et al.*, 2014:1356). Women therefore typically have lower RMR values compared to men, and this can be attributed to lower muscle mass (McMurray *et al.*, 2014:1356). Ethnicity also influences RMR as demonstrated by Adzika Nsatimba *et al.* (2016:1837) when they concluded that sub-Saharan African individuals are characterised by a lower RMR when compared to Australians of European descent. Thus, the application of a single estimated figure to an entire population subgroup is likely to misrepresent the expected energy costs of physical activity promotion intended to achieve, for example, energy balance among pregnant women (McMurray *et al.*, 2014:1358).

A significant energy requirement during pregnancy concerns the basal metabolism of newly synthesised tissue (King *et al.*, 1994:441S). Prentice and Goldberg (2000:1227S) divided the additional energy required during pregnancy into the following three main components: first, energy deposited as new tissue in the conceptus [placenta, uterus, breasts, amniotic fluid, expansion of blood volume, the foetus (minus foetal fat) – total cost approximated at about 20 MJ], second, energy deposited as fat (averaging about 150 MJ in a well-nourished pregnancy), and third, the energy required to maintain this new tissue (estimated at 150 MJ in a well-nourished pregnancy). The last component relates to the rise in a mother's basal metabolic rate above the prepregnancy baseline metabolic rate (Prentice & Goldberg, 2000:1227S).

Increases in TEE during pregnancy is primarily attributed to an increase in RMR (Abeysekera *et al.*, 2016:46). Studies investigating to changes in RMR during pregnancy are summarized in Table 2-2. Alterations in RMR are brought about by an increase in lean body mass with the extra weight of pregnancy (Yu *et al.*, 2006:1118). However, the energy cost of pregnancy is not equally distributed throughout pregnancy where increases in RMR and TEE are more pronounced in the second half of pregnancy (Butte & King, 2005:1015; FAO, 2001:56). More increases explicitly of 5, 10 and 25 percent for the first, second and third trimester, respectively have been recorded (FAO, 2001:55). The RMR required to maintain foetal metabolism in late pregnancy is significant, possibly about 33% of the total metabolic demand during gestation (King, 2000:1219S; King *et al.*, 1994:443S). King, (2000:1219S) states that about 60% of the increase in resting energy expenditure occurs during the last half of gestation when the metabolic cost of foetal tissue synthesis is the greatest.

Table 2-2: A Summary of studies reporting on resting energy expenditure during pregnancy

Authors	Title	Study Design	Methods	Results
Lof *et al.*, 2005	Changes in basal metabolic rate during pregnancy in relation to changes in body weight and composition, cardiac output, insulin-like growth factor I, and thyroid hormones and in relation to foetal growth	Design: Longitudinal observation study *n* = 22 healthy women	A ventilated hood system (Deltatrac Metabolic Monitor; Datex Instrumentarium Corp, Helsinki) was used to measure oxygen consumption during a 20-min period. For each subject, basal metabolic rate obtained at each measurement occasion was plotted against the stage of gestation. The cumulative increase in BMR was calculated as the area under the curve from the start of pregnancy until delivery.	The average BMR did not differ significantly in gestational weeks 8, 14, and 20 from that before conception, but it did increase significantly from prepregnancy values in gestational week 32 (1430 kJ/d) and gestational week 35 (1750 kJ/d). The cumulative increase in BMR (*n* = 22) was 16 ± 52 MJ (range: -69 to 122 M) for the first half of pregnancy, 177 ± 110 MJ (range: 9 – 437 MJ) for the second half of pregnancy, and 193 ± 156 MJ (range: - 60 to 525 MJ) for the entire pregnancy.
Byrne *et al.*, 2011	Changes in resting and walking energy expenditure and walking speed during pregnancy in obese women	Design: Case-control study Experimental group: *n* = 23 women aged 31 ± 4 y with a BMI of 33.5 ± 2.5 kg/m^2 at 15 and 30 weeks of gestation. Control group: RMR was also measured in 2 cohorts of nonpregnant control participants matched for the age, weight, and height of the pregnant cohort at 15 (*n* = 23) and 30 (*n* = 23) weeks.	RMR measurements were conducted under outpatient conditions via respiratory gas exchange by using a Hans Rudolph mouthpiece and nose-clip system. VO_2 and VCO_2 were obtained over a 30-min period by using a MOXUS Modular VO_2 System (AEI Technologies).	RMR increased significantly by an average of 177 ± 176 kcal/day (11 ± 12%; $p < 0.0001$); however, the within-group variability was large.

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Authors	Title	Study Design	Methods	Results
Kopp-Hoolihan *et al.*, 1999	Longitudinal assessment of energy balance in well-nourished pregnant women	*Design*: Longitudinal observational study *N* = 10 healthy, non-smoking pregnant women	Fasting RMR was measured between 08h00 and 08h30 under standard conditions after a 10-h fast by using a metabolic cart system with a ventilated canopy (Sensormedics, Inc., Yorba Linda, CA). Measurements were made every minute for 30 min while the participants were awake but at complete rest. Energy expenditure (kJ/min) was calculated from measurements of oxygen consumption and carbon dioxide production using the classic Weir equation.	The average increase in RMR by the 3rd trimester was 1578 ± 876 kJ/day, or 29% above the average RMR before pregnancy. RMR in the 1st trimester: 5459 ± 903 kJ/day RMR in the 2nd trimester: 6459 ± 818 kJ/day RMR in the 3rd trimester: 7075 ± 960 kJ/day
Löf, 2011	Physical activity pattern and activity energy expenditure in healthy pregnant and non-pregnant Swedish women	*Design*: case-control study *n* = 39 healthy, non-smoking women (21 non pregnant/non lactating and 18 pregnant).	CO_2-production and O_2-consuption were measured for 20 min after an overnight fast and 45 min of rest (Deltatrac Metabolic Monitor, Datex Instrumentarium Corp, Helsinki, Finland), and converted to BMR	Non-pregnant (*n* = 21) Pregnant (*n* = 18) BMR (kJ/day) 5910 ± 720 7000 ± 850
Melzer *et al.*, 2009	Pregnancy-related changes in activity energy expenditure and resting metabolic rate in Switzerland	*Design*: Cross-sectional observational study *n* = 27 healthy women in their third trimester of pregnancy	RMR was assessed by indirect calorimetry using a ventilated hood system (Deltatrac II Metabolic Monitor; Datex-Ohmeda, Helsinki, Finland). Oxygen consumption (VO_2) and carbon dioxide (VCO_2) production were measured for 30 min at 1 min intervals with the participants in a supine position and completely at rest in a thermoneutral environment (20-22°C).	RMR (kJ per day): 7484 ± 1112

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<table>
<tr><th>Authors</th><th>Title</th><th>Study Design</th><th>Methods</th><th>Results</th></tr>
<tr><td>Butte & King, 2005</td><td>Energy requirements during pregnancy and lactation</td><td>*Design:* Literature review

n = healthy pregnant and lactating women</td><td>A database on changes in basal metabolic rates was complied.</td><td>In healthy, well-nourished women, the cumulative increase in BMR ranged from 124 to 210 MJ, with an average increase of 157 MJ for the entire pregnancy.

The average increases in BMR over prepregnancy values were 4.5, 10.8 and 24.0% for the first, second and third trimesters, respectively</td></tr>
<tr><td>Highman *et al.*, 1998</td><td>Longitudinal changes in maternal serum leptin concentrations, body composition, and resting metabolic rate in pregnancy</td><td>*Design:* Longitudinal study

n = 10 women evalueated before pregnancy, in early pregnancy (12 to 14 weeks), and in late pregnancy (34 to 36 weeks).</td><td>Metabolic rate was determined by indirect calorimetry. Participants expired air was collected by a ventilated hood system for 45 minutes, dried in a condenser, and delivered to an oxygen analyser (Magnos 4G, Hartmann & Braun, Frankfurt), a carbon dioxide analyser (Uras 3G, Hartmann & Braun), and a flow meter (Interface Associates, Irvine, California). Integrated results of VO_2 were averaged and recorded every 5 minutes. The highest and lowest readings were eliminated before determining the average.</td><td>
<table>
<tr><th></th><th>Pregravid</th><th>Early (12 – 14 weeks)</th><th>Late (34 – 36 weeks)</th><th>*P-value*</th></tr>
<tr><td>RMR (ml/min)</td><td>221.1 ± 29.5</td><td>230.4 ± 42.9</td><td>285.3 ± 51.9</td><td>$p < 0.0001$</td></tr>
<tr><td>RMR (ml/kg/min)</td><td>3.02 ± 0.43</td><td>3.05 ± 0.30</td><td>3.31 ± 0.37</td><td>$p = 0.002$</td></tr>
</table>

A 27% increase in BMR with advancing gestation was found. When adjusted for weight, there was a 9% increase in BMR from before pregnancy to late pregnancy.</td></tr>
</table>

n = amount of participants, RMR = Resting metabolic rate, kJ/min = kilojoule per minute, BMR = Basal Metabolic Rate, MJ = Megajoule

Nonetheless, the FAO (2001:55) found high variability between women and demonstrated that the application of mean population requirements to specific individuals might lead to significant errors. Due to wide variations in the changes in the maternal accretion of adipose tissue, there are wide variations in the change in maternal basal metabolic rate during gestation (Catalano *et al.*, 2003:1679S; Prentice & Goldberg, 2000:1228S).

The metabolic response to pregnancy varies widely among women (IOM, 2009). The increase in RMR during pregnancy differs dramatically in women from high and low-to-middle-income countries (Butte & King, 2005:1018). The observed variation in resting energy expenditure during pregnancy may be influenced by maternal energy status, before and during pregnancy (King *et al.*, 1994:442S). Poppitt *et al.* (1993:363) and Prentice *et al.* (1989:20) confirmed substantial energy-sparing adaptations that occur in rural Gambian women, predominantly manifested as a decline in RMR. These women gained very little weight during pregnancy, probably as a consequence of energy insufficiency (Poppitt *et al.*, 1993:363). On the other hand, an increase in RMR occurs in overweight pregnant women (King, 2000:1221S; King *et al.*, 1994:443S). Thus, weight gain during pregnancy is correlated with the cumulative increase in BMR (Lof *et al.*, 2005:684; Prentice & Goldberg, 2000:1228S). The total costs of pregnancy are strongly correlated to a women's pregnancy weight gain ($r = 0.94$, $P < 0.001$) (Prentice & Goldberg, 2000:1228S). Berggren *et al.* (2016:S317) recommend that the measurement of RMR, and body composition, are essential considerations in developing and evaluating interventions to optimise weight gain in pregnancy. King *et al.* (1994:443S) state that the metabolic cost of pregnancy is extremely flexible, influenced by maternal prepregnancy energy status, energy intake during pregnancy, and foetal growth.

2.5.2. Diet-induced thermogenesis

Diet-induced thermogenesis (DIT) consists of two components namely obligatory thermogenesis, which results from the energy required to digest, absorb, and assimilate food nutrients, as well as facultative thermogenesis which relates to the activation of the sympathetic nervous system and its stimulating influence on metabolic rate (McArdle *et al.*, 2014:197). Generally, this component of energy metabolism is considered to be small (about 5 – 10% of TEE) (Lof & Forsum, 2006:300).

As previously mentioned, pregnancy leads to energy-conservation mechanisms. A decrease in energy expended through DIT can occur during pregnancy by a reduction in energy spent digesting and assimilating food (Bronstein *et al.*, 1995:262). However, this has not been extensively studied in pregnancy (Bronstein *et al.*, 1995:262). Changes in hormones may enable pregnant women to reduce DIT and offset, at least in part, the increased energy requirements for RMR and tissue deposition (Bronstein *et al.*, 1995:271; Kopp-Hoolihan *et al.*, 1999:703). Conflicting results were obtained by Prentice *et al.*

(1989:20) where changes in the cost of DIT were minimal during pregnancy. The conflicting results may be due to the variance of metabolic adjustments seen in high- and low-to-middle-income countries during pregnancy (Butte & King, 2005:1018).

2.5.3. Active Energy Expenditure

Physical activity exerts by far the most profound effect on human energy expenditure (McArdle *et al.*, 2014:196). Active Energy Expenditure (AEE) - the amount of energy expended in physical activity of daily living and structured physical activity, known as exercise (Butte *et al.*, 2004:1085) generally accounts for between 15 – 30% of TEE (McArdle *et al.*, 2014:196).

Physical activity is defined as “bodily movement produced by skeletal muscles that result in energy expenditure” (Caspersen *et al.*, 1985:126). In contrast, exercise is defined as a “subset of physical activity that is planned, structured, and repetitive and has a final or an intermediate objective to improve or maintain physical fitness” (Caspersen *et al.*, 1985:126).

The caloric contribution of each category of physical activity can be defined in the following formula, as stated by Caspersen *et al.* (1985:127):

$$\text{kcal}_{\text{total daily physical activity}} = \text{kcal}_{\text{sleep}} + \text{kcal}_{\text{occupation}} + \text{kcal}_{\text{leisure}}$$

This categorisation identifies the physical activity that occurs while sleeping, at work and leisure (Caspersen *et al.*, 1985:127). Leisure-time physical activity can be further categorized into sports, conditioning exercises, and household tasks. Another classification of physical activity is by categorising physical activities in terms of intensity as light, moderate, or vigorous physical activity (Caspersen *et al.*, 1985:127). The Metabolic Equivalent of Task (METs) is a widely used physiological concept representing a simple procedure for expressing the energy cost of physical activities as multiples of Resting Metabolic Rate (Ainsworth *et al.*, 2000:S498). The American College of Sports Medicine (ACSM, 2018:3) defines light physical activity as requiring < 3 METs, moderate as 3 - 6 METs, and vigorous as ≥6 METs.

2.5.3.1. Measuring Active Energy Expenditure

A wide variety of methods have been used to measure physical activity (Dickie *et al.*, 2014:813). In order to measure physical activity, objective methods of assessing energy expenditure and physical activity are recommended, as these methods are not subject to many of the sources of error associated with self-report measures (Berntsen *et al.*, 2011:906; Gaston & Vamos, 2013:483). More specifically relating to pregnancy, valid assessment of pregnancy physical activity is essential when assessing the relationship between physical activity and maternal and foetal health outcomes (Berntsen *et al.*, 2014:594; Chasan-Taber *et al.*, 2007:133; Downs *et al.*, 2012:485-486; Melzer *et al.*, 2012:e5). An important step in assessing the dose-response relationship between physical activity and health outcomes is a critical analysis of the measurement of physical activity during pregnancy (Chandonnet *et al.*, 2012:1; Chasan-Taber *et al.*, 2007:87; Downs *et al.*, 2012:489; Perkins *et al.*, 2007:81). As stated by Chasan-Taber *et al.* (2007:85–104) measurement of physical activity needs to be highly accurate to minimise the possibility that an effect will not be observed due to a measurement error. There is a need for well-designed longitudinal studies that document pregnancy-related changes in physical activity at frequent intervals during pregnancy using validated and more precise measures of physical activity (Chandonnet *et al.*, 2012:1; Chasan-Taber *et al.*, 2007:102; Poudevigne & Connor, 2006:29).

Moreover, it is challenging to assess free-living physical activity accurately, both in general and during pregnancy (Melzer *et al.*, 2012:e5; Melzer *et al.*, 2010:266.e1). A primary weakness of most studies on pregnant women related to physical activity measures was the lack of published evidence regarding their reliability or validity (Chandonnet *et al.*, 2012:1; Poudevigne & Connor, 2006:28). Most studies used a subjective method of measuring physical activity – physical activity recall (Poudevigne & Connor, 2006:28; Schlaff *et al.*, 2014:10). Additionally, very few studies reported all the significant dimensions of physical activity (i.e. frequency, intensity, duration and mode) (Poudevigne & Connor, 2006:28).

Questionnaires capturing self-recall physical activity are relatively inexpensive and can be self-administered, which makes them the most suitable method for epidemiologic studies (Abeysekera *et al.*, 2014:62; Chasan-Taber *et al.*, 2007:103). Be that as it may, the inherent subjectivity of questionnaires may hamper the establishment of a precise dose-response relationship between physical activity and birth outcomes (Abbasi & van den Akker, 2015:352; Chasan-Taber *et al.*, 2007:103). Other limitations to questionnaires are that these instruments are influenced by recall bias, cultural adaptation, and literacy issues (Downs *et al.*, 2012:495). Questionnaires that have been validated for use in determining physical activity during pregnancy include the Pregnancy Physical Activity Questionnaire (PPAQ) and the Kaiser Physical Activity Survey (KPAS) (Chasan-Taber *et al.*, 2007:103). Based on high quality evidence, the PPAQ is indicated as a valid and reliable measure instrument to use during pregnancy (Sattler *et al.* 2018:2343) to assess total physical activity and vigorous physical activity. The PPAQ provides a quantitative measure of a wide range of physical activity types and intensities, including sedentariness (Chandonnet *et al.*, 2012:2).

Objective measurements of physical activity during pregnancy include the use of portable activity monitors such as accelerometers, heart rate monitors and pedometers (Abbasi & van den Akker, 2015:352; Chandonnet *et al.*, 2012:2; Chasan-Taber *et al.*, 2007:103-104). Portable activity monitors do however have several limitations, including the inability to discriminate between different types of activity (Chasan-Taber *et al.*, 2007:104), as well as dependency on participants concerning the wearing of the monitor and difficulty in the assessment of long-term physical activity patterns (e.g., most monitors store data for limited periods) (Downs *et al.*, 2012:488). Furthermore, objectively measured physical activity has generally been limited to the assessment of activity among pregnant women residing in high-income countries; studies examining physical activity and making use of these devices in low-to-middle-income countries are recommended (Downs *et al.*, 2012:495).

Heart rate monitors estimate AEE through the relatively linear relationship between heart rate and oxygen consumption (Abeysekera *et al.*, 2014:62). Limitations to heart rate monitors in determining physical activity include external factors that affect the calculation such as physical fitness, emotion and ambient temperature (Abeysekera *et al.*, 2014:62). Furthermore, physiological variables such as heart rate and stroke volume change as pregnancy advances and this result in energy expenditure being overestimated at rest and underestimated during activity (Abeysekera *et al.*, 2014:62).

Motion sensors refer to devices which detect motion or acceleration and are therefore classified into two main types of sensors: pedometers and accelerometers (Abeysekera *et al.*, 2014:62). Pedometers quantify the number of steps taken by responding to vertical acceleration, while accelerometers record motion in various planes and integrate this information to determine the frequency, duration and intensity of AEE (Abeysekera *et al.*, 2014:60).

The limitations of pedometers include insensitivities to differences in gait, not recording horizontal or upper body movements, as well as the quantification of distances travelled and TEE (Abeysekera *et al.*, 2014:62). Pregnancy-related limitations include the design thereof in so far as they are designed to be attached to a waist belt, which becomes problematic as pregnancy advances (Abeysekera *et al.*, 2014:62). The underlying principle of accelerometers relates to acceleration being directly proportional to muscular forces and the measurements taken by accelerometers, therefore, relate well to AEE (Abeysekera *et al.*, 2014:62). The advantages of the use of accelerometers compared to other techniques is that TEE is objectively divided into time spent at various intensity levels, differentiating between sedentary, light, moderate and vigorous activity (Abeysekera *et al.*, 2014:62). The limitations of accelerometers include under- and overestimation of energy expenditure for various activities, as well as the lack of pregnancy-specific algorithms for analysis (Abeysekera *et al.*, 2014:62). A common problem in the validation of accelerometers is the different cut-points used to define participation in moderate- and vigorous-intensity physical activity (Watson *et al.*, 2014:669). Accelerometers that have been used to measure physical activity during pregnancy include the Actigraph™ (Chandonnet *et al.*, 2012:2), the ActiHeart™ (Van Oort, 2014:44-45) and the Caltrac accelerometer (Hemokinetics, Madison, WI) (Perkins *et al.*, 2007:82).

Heart rate monitors and motion sensors can be combined to improve accuracy when estimating AEE by confirming changes in heart rate and accelerometer data (Abeysekera *et al.*, 2014:62). Melzer *et al.* (2012:e7) assessed the validity of the ActiHeart™ (CamNtech Ltd., Cambridge, UK) (Figure 2-2) – a combined heart rate and accelerometer – and concluded the device to be reliable in determining AEE after individual calibration of the device. The study found that the ActiHeart™ AEE estimates of walking, cycling and stepping during pregnancy in relation to indirect calorimetry have excellent reliability (p = 0.9). Melzer *et al.* (2012:e9) further stated that the reliability of the ActiHeart™ could provide valuable information, improving the assessment of AEE in pregnancy.

Figure 2-2: The ActiHeart® (CamNtech) accelerometer and heart rate device

Some authors have found correlations between subjective and objective measurements of physical activity during pregnancy (Chandonnet *et al.*, 2012:6; Kwak *et al.*, 2011:26). Chandonnet *et al.* (2012:6) found a correlation between data from the PPAQ and the Actigraph® (ActiGraph, Pensacola, FL) (Figure 2-3). Furthermore, it confirmed the moderate but acceptable accuracy (r = 0.58, p < 0.01) of the questionnaire in a French population. However, Sanda *et al.* (2017:9) found limited validity (r = 0.14, p = 0.280 for moderate to vigorous physical activity) with the International Physical Activity Questionnaire (IPAQ) short form when compared to a sensory-based physical activity monitor in pregnant women. Chasan-Taber *et al.* (2007:104) recommend that future epidemiologic studies supplement questionnaire-based data with accelerometer-based measures in order to improve the assessment of dose-response relationships with birth outcomes.

Figure 2-3: The Actigraph® accelerometer and heart rate device

2.5.3.2. Physical activity during pregnancy

Recently, the perception regarding physical activity during pregnancy has dramatically changed (Kader & Naim-shuchana, 2014:3). A review from Kader and Naim-shuchana (2014:8) provided evidence-based recommendations that all pregnant women without medical risk can be physically active in order to achieve substantial health benefits. Previously, physical exercise was thought to increase the risk of adverse pregnancy and birth outcomes (Connelly, 1989:364).

2.5.3.3. Benefits of physical activity during pregnancy

When not contraindicated by disease or a high-risk obstetrics pregnancy, regular physical activity provides a pregnancy with better overall fitness, improves cardiovascular health and muscle performance, prevents excessive weight gain, improves blood pressure, protects against gestational diabetes mellitus and enhances psychological well-being (ACOG, 2015:268; Cid & González, 2016:58).

Adequate levels of physical activity during pregnancy can have long-term, positive impacts on women’s health (Thompson *et al.*, 2017:198). Physical activity during pregnancy has been shown to improve pregnancy outcomes, reduce gestational weight gain, resulting in fewer caesarean deliveries, a shorter duration of labour, and reduce the risk of both gestational diabetes mellitus and preeclampsia (Clapp, 2006:531-532; da Silva *et al.*, 2017:310; Newton & May, 2017:11; Tinius *et al.*, 2017:5). Meeting physical activity guidelines during pregnancy is associated with a better health-related quality of life (Kolu *et al.*, 2014:2104).

Different modes of physical activity throughout pregnancy are safe and efficacious for mother and child (ACOG, 2015:268; Kader & Naim-shuchana, 2014:7; May *et al.*, 2016:51). The foetus is not at an increased risk of distress or adverse health outcomes in response to acute maternal exercise, regardless of the type and intensity (May *et al.*, 2016:51). For example, cardiovascular adaptations prevent excessive increases in foetal heart rate when exercise ends (Roldan *et al.*, 2015:772).

Physical activity can affect the maternal organism, despite results from interventional trials or even from secondary studies that can be conflicting for methodological reasons, mainly related to the inclusion of distinct subgroups of pregnant women, or even by the non-standardization of the gestational period in which physical activity is performed (Leite *et al.*, 2016:276). Rogozinska *et al.* (2017:1109) found that the overall reporting quality of clinically relevant outcomes of physical activity-based interventions was unusually low. Furthermore, Rogozinska *et al.* (2017:1109) recommended the standardisation of measurements in order to improve robust evidence synthesis. Unfortunately, methodological issues and bias in clinical studies preclude conclusive evidence regarding physical activity and favourable outcomes for the mother and foetus (Leite *et al.*, 2016:277). Considerable difficulties arise when interpreting the results of different studies regarding the measurement of physical activity during pregnancy due to the variety of measurement points, scales, and instruments (Lindqvist *et al.*, 2016:19).

2.5.3.4. Physical activity recommendations during pregnancy

Despite the apparent dose-response effect, even minimal physical activity reduces risk, improves physiological adaptations to pregnancy and a woman’s quality of life (Clapp, 2006:532). The American College of Obstetricians and Gynecologists (ACOG, 2015:269) physical activity guidelines recommend healthy pregnant and postpartum women to obtain at least 150 minutes of moderate-intensity aerobic activity (i.e., equivalent to brisk walking) spread throughout the week and adjusted as medically indicated. More recently, the 2019 Canadian guidelines stipulated similar physical activity guidelines during pregnancy but provided more details in terms of frequency and type of physical activity (Mottola *et al*., 2018:1434). They found moderate-quality evidence that physical activity should be accumulated over a minimum of 3 days per week; however, being active every day was also encouraged. Furthermore, they advised pregnant women to incorporate a variety of aerobic exercise and resistance training activities to achieve more significant benefits.

However, it was noted by Whitaker and Wilcox (2016:2313) that less-educated women have a lower-income, are non-White, multiparous and who reported poorer perceived health were less likely to receive physical activity recommendations from primary health care workers. Additionally, Whitaker & Wilcox (2016:2314) stated that few women recall provider advice describing the duration, frequency, and intensity required to meet current physical activity recommendations.

The intensity of physical activity can be monitored through Ratings of Perceived Exertion (RPE) rather than heart rate during pregnancy given the variability of maternal heart rate responses to exercise (Artal & O'Toole, 2003:9). Evidence of the efficacy of this approach is that, when exercise is self-paced, most pregnant women will voluntarily reduce their exercise intensity as the pregnancy progresses (McMurray *et al.*, 1993:1318). According to Artal & O'Toole (2003:9), two concerns should be taken into consideration when prescribing the duration of physical activity during pregnancy. Firstly, thermoregulation – long-duration physical exertion can lead to fluid loss due to excessive evaporative cooling (Artal & O'Toole, 2003:9). Secondly, energy balance – energy expenditure should be balanced by appropriate energy intake (Artal & O'Toole, 2003:9).

2.5.3.5. Risks associated with physical activity during pregnancy

Some pregnant women, and even some health care providers, are concerned that regular physical activity during pregnancy may cause miscarriage, poor foetal growth, musculoskeletal injury, or premature delivery (ACOG, 2015:269). According to the American College of Obstetricians and Gynecologists (ACOG, 2015:268) health care providers should carefully evaluate women with medical or obstetric complications before making recommendations on physical activity participation during pregnancy. However, physical activity has few risks and many benefits for newborns and mothers alike (Newton & May, 2017:9). Bed rest, although frequently prescribed, is only rarely indicated and, in most cases, allowing ambulation should be considered (ACOG, 2015:268).

The absence of scientific evidence regarding the safety of high-intensity physical activity during pregnancy prevents definite conclusions and recommendations for switching or reducing the intensity of these activities (Leite *et al.*, 2016:277). Considerations regarding maternal and foetal outcomes took into account moderate-intensity maternal physical activity (Leite *et al.*, 2016:277).

Artal & O'Toole (2003:8) evaluated epidemiological studies which suggested that a link exists between strenuous physical activity, deficient diet, and the development of intrauterine growth restriction. The association appears to be primarily related to mothers engaged in physical work, which includes occupations that require standing, trunk bending or repetitive, strenuous, physical work such as lifting (Artal & O'Toole, 2003:8; Bonzini *et al.*, 2014:689; El-Metwalli *et al.*, 2001:44). Bonzini *et al.*, (2014:689) found that the risk of preterm delivery was three-fold higher in women whose work at 34 weeks entailed trunk bending for more than one hour per day. Bonzini *et al.*, (2014:689) also found small head circumference to be more common in babies born to women who worked for more than 40 hours per week, but other findings were broadly reassuring. Some authors, however, contradicted the link between physical activity and intra-uterine growth restriction (Leite *et al.*, 2016:280; Magann *et al.*, 2002:471; Rêgo *et al.*, 2016:7).

Previously the main concerns of physical activity and exercise in pregnancy were focused on the foetus (Artal & O'Toole, 2003:7). The potential foetal risks are hypothetical in so far as foetal injuries during uncomplicated pregnancies are highly unlikely (Artal & O'Toole, 2003:7). Does physical activity during pregnancy impede transplacental transport of oxygen, carbon dioxide, and nutrients, and, if it does, what are the lasting effects thereof? Artal & O'Toole (2003:8) state that indirect evidence shows no lasting adverse effects.

Exercise challenges maternal physiology in terms of oxygen delivery, glucose and substrate delivery, heat dispersal, and metabolic by-product disposal (Newton & May, 2017:2). Hemodynamic changes during exercise are the basis for theories which allege that physical activity during pregnancy can cause decreased oxygen delivery to the foetus and the potential foetal growth restriction (Cid & González, 2016:59). However, maternal physiology responds differently to exercise and, in numerous conditions, makes use of compensating physiological mechanisms (Leite *et al.*, 2016:276). These physiological changes which compensate for exercise include an increased maternal haematocrit and oxygen transport in the blood, an inverse relationship between blood flow and the tissue extraction of oxygen, as well as a redistribution of blood flow to the placenta rather than to the uterus (Artal & O'Toole, 2003:7; Cid & González, 2016:59). Cid & González, (2016:61) state that moderate physical activity improves the antioxidant capacity of the placenta, restoring nitric oxide signalling and reducing the probability of foetoplacental blood flow dysfunction.

Foetal heart rate responses to maternal exercise have been comprehensively researched (Artal & O'Toole, 2003:8). Increases in foetal heart rate by 10-30 beats/min over baseline occur during or after maternal exercise (Artal & O'Toole, 2003:8). Foetal bradycardia has been reported during maternal exercise but these have been speculated to be attributable to vagal reflex, cord compression, or foetal head malposition (Artal & O'Toole, 2003:8); no associated lasting effects on the foetus have been reported (Artal & O'Toole, 2003:8).

Weight and growth patterns indicate that the greatest need for maternal adaption to exercise is at 20 weeks of gestation (Newton & May, 2017:2). The oxygen and or substrate challenges posed by exercise in the late third trimester might manifest in a decrease in the weight-to-length ratio, as measured by head circumference/abdominal circumference at higher than the 95th percentile for gestational age, and asymmetric foetal growth restriction (Newton & May, 2017:2). Nonetheless, it appears that birth weight is not affected by exercise in women who have adequate energy intake (Artal & O'Toole, 2003:8).

Pregnant women should not engage in activities that may cause abdominal trauma, scuba diving or engage in physical activity in overheated environments (ACOG, 2015:270). Warning signs for the discontinuation of physical activity include dyspnoea before exertion, dizziness, headache, chest pain, weakness affecting balance, vaginal bleeding, painful contractions, amniotic fluid leakage, as well as calf pain or swelling (ACOG, 2015:272).

Absolute contra-indications that preclude physical activity during pregnancy include hemodynamically significant heart disease, restrictive lung disease, incompetent cervix or cerclage, multiple gestations at risk of premature labour, persistent second- or third trimester bleeding, placenta previa after 26 weeks of gestation, premature labour during the current pregnancy, ruptured membranes, preeclampsia or pregnancy-induced hypertension and severe anaemia (ACOG, 2015:269). Relative contraindications include anaemia, unevaluated maternal cardiac arrhythmia, chronic bronchitis, poorly controlled type 1 diabetes, extreme morbid obesity, extreme underweight (BMI less than 12 kg/m^2), a history of an extremely sedentary lifestyle, intrauterine growth restriction in the current pregnancy, poorly controlled hypertension, orthopaedic limitations, poorly controlled seizure disorder, poorly controlled hyperthyroidism and heavy smoking (ACOG, 2015:269).

2.5.3.6. Risks related to physical inactivity during pregnancy

A sedentary lifestyle is the fourth most crucial risk factor for mortality worldwide (Cid & González, 2016:58). Sedentary behaviour is associated with severe short and long term risks for mothers and babies (Garland, 2017:55). Adverse health outcomes related to physical inactivity during pregnancy include gestational diabetes, large and small for gestational age infants (Huberty *et al.*, 2016:358). According to the ACOG (2015:272), there is no credible evidence to prescribe bed rest in pregnancy, which is most commonly prescribed for the prevention of preterm labour. In contrast the risks of prolonged bed rest include venous thromboembolism, bone demineralization, and deconditioning (ACOG, 2015:272).

Excessive gestational weight gain is significantly associated with a decline in physical activity during pregnancy (Merkx *et al.*, 2015:698). Merkx *et al.* (2015:698) found that women whose physical activity decreased during pregnancy had a twofold risk of gaining weight above the Institute of Medicine guidelines (IOM, 2009:7-12). However, Ruifrok *et al.* (2014:2092) found neither physical activity nor sedentary behaviour had an association with gestational weight gain. Reducing unhealthy gestational weight gain requires a better understanding of the decline in physical activity during pregnancy, as well as of the determinants of the decline (Merkx *et al.*, 2015:698).

2.5.3.7. Physical activity patterns during pregnancy

In general, as the pregnancy progresses physical activity during pregnancy decreases (Cid & González, 2016:58; Huberty *et al.*, 2016:357; King, 2000:1223S; Lindqvist *et al.*, 2016:19; Merkx *et al.*, 2017:22; Pearson *et al.*, 2015:95). A summary of physical activity patterns during pregnancy is provided in Table 2-3. Due to the increased cost of weight-bearing activity resulting from the proportional increase in body weight, a reduction in activity during gestation is expected (King, 2000:1223S). Huberty *et al.* (2016:357) however measured physical activity as the pregnancy progressed and found an inverse U-shaped curve, where women increased their physical activity in the first and second trimesters, spending more time sedentary and less time being active by the third trimester they.

A small proportion of pregnant women do not meet the physical activity guidelines, especially in terms of moderate-to-vigorous physical activity (Ruifrok *et al.*, 2014:2094). Lack of adequate physical activity in pregnancy remains a significant public health concern especially given the known health benefits of physical activity during gestation (Thomson *et al.*, 2016:694).

2.5.3.8. Physical activity during pregnancy in South Africa

Despite the abundance of evidence encouraging physical activity as a means for the prevention and management of chronic diseases, minimal research exists with regards to physical activity in the pregnant population, specifically in low-to-middle-income countries (King, 2000:1223S; Pearson *et al.*, 2015:93). Pearson *et al.* (2015:95) articulated that most literature examining physical activity trends during pregnancy comes from international studies, with limited data on South African women. Due to the difference in the social and environmental context of South Africa, factors which influence physical activity participation are also likely to be different in South African women (Pearson *et al.*, 2015:95). Dickie *et al.* (2014:813) stated that black urban South African women are a particularly vulnerable group for low levels of habitual physical activity.

In rural areas, women’s physical activity involves bending, walking, and carrying loads; all of these activities are difficult for pregnant women to engage in (King, 2000:1223S). On the other hand, low-income women living in urban areas in are often as active as those living in rural areas (King, 2000:1223S). However, the activities may not be as energy-intensive (King, 2000:1223S). Determinants of physical activity during pregnancy in the Western world are not necessarily correlated to physical activity in other ethnic groups (Berntsen *et al.*, 2014:599). A higher level of education among Western women is positively associated with physical activity, while among South Asian women, higher education levels and physical activity are inversely related (Berntsen *et al.*, 2014:599).

In a longitudinal observational study, Van Oort (2014:76) found that South African women's habitual physical activity patterns were lower than the prescribed American College of Sports Medicine recommendations (ACSM, 2016:197). The participants accumulated 103 min/week in the first trimester, 63 min/week in the second trimester and 55 min/week in the third trimester of moderate-intensity physical activity (Van Oort, 2014:76). Van Oort (2014:76) also found a statistically significant ($p = 0.04$) decline in Active Energy Expenditure from pre-pregnancy to the third trimester of pregnancy. In another South-African study, Watson *et al*. (2017:334), also found low and declining levels of physical activity during pregnancy in a population where the majority were either overweight or obese at the start of pregnancy. Mukona *et al*. (2016:33) systematically reviewed studies related to physical activity in pregnant women in Africa and also concluded physical activity to be generally low. Physical activity in low-income countries is done during household activities which have an intensity below the recommended guidelines (Mukona *et al*., 2016:33).

Muzigaba *et al.* (2014:1281) found that although South African women considered physical activity as important for themselves and the baby, they also stated barriers to physical activity including the lack of a supportive environment, a fear of hurting oneself and the growing baby, a lack of time due to work and family responsibilities, and a lack of knowledge regarding safe levels of physical activity. Muzigaba *et al.* (2014:1281) stated that in so far as some of the women reported concerns regarding the safety of themselves and their unborn baby, physical education and promotion program should be implemented in order to bridge the gaps in pregnant women's behavioural beliefs and attitudes toward physical activity during pregnancy. Healthcare providers at clinics generally do not offer physical activity related advice and information to pregnant women (Muzigaba *et al.*, 2014:1281). Watson *et al.* (2016:8), in a qualitative study, highlighted beliefs regarding physical activity in pregnant black South African women that show the need for proper culturally sensitive physical activity education as well as for social support for physical activity behaviour within this community. Implementing such an intervention may diminish perceived barriers to physical activity during pregnancy in the South African black community.

Physical activity levels, as well as the beliefs, barriers and facilitators of physical activity during pregnancy, must be better understood in a South African context (Dickie *et al.*, 2014); Pearson *et al.*, 2015:95). Muzigaba *et al.* (2014:1282) stated the need to design a physical activity intervention for pregnant women that is context-specific and sensitive toward individual experiences and circumstances in the communities that were studied.

Table 2-3: A summary of studies reporting physical activity during pregnancy

Authors	Title	Study Design & Participants	Methods	Results		
Lof & Forsum, 2006	Activity pattern and energy expenditure due to physical activity before and during pregnancy in healthy Swedish women	Cross-sectional study design *n* = 23	Activity pattern was assessed using a questionnaire and heart rate recordings.	PAL at gestational week 14: 1.89 ± 0.20	PAL at gestational week 32: 1.72 ± 0.17	
				Amount of minutes spent in different activity categories in gestational week 14:	Amount of minutes spent in different activity categories in gestational week 32:	
				Very light = 447 ± 198	Very light = 491 ± 191	
				Light = 296 ± 173	Light = 320 ± 168	
				Moderate = 149 ± 131	Moderate = 142 ± 118	
				Vigorous = 43 ± 63	Vigorous = 14 ±23	
				Very vigorous = 2 ± 5	Very vigorous = 0 ±	
				When compared to the pre-pregnant value, there was little change in physical activity level in gestational week 14 but it was significantly reduced in gestational week 32.		
Kopp-Hoolihan *et al.*, 1999	Longitudinal assessment of energy balance in well-nourished pregnant women	*Design*: Longitudinal observational study *n* = 10 healthy, non-smoking pregnant women	AEE was estimated as the difference between TEE and RMR before pregnancy, at 8-10, 24-26, and 34-36 weeks gestation. TEE was estimated at each time point by using the doubly labelled water methods.	AEE before pregnancy: 3728 ± 969 kJ/day		
				AEE at 8-10 weeks of gestation: 3115 ± 1416 kJ/day		
				AEE at 24-26 weeks of gestation: 3625 ± 1174 kJ/day		
				AEE at 34-36 weeks of gestation: 4338 ± 1336 kJ/day		
				AEE increased by an average of 610 kJ/day by 34-36 weeks of gestation, 23% higher than the mean AEE before pregnancy.		
Löf, 2011	Physical activity pattern and activity energy expenditure in healthy pregnant and non-pregnant Swedish women	*Design*: case-control study *n* = 39 healthy, non-smoking women	The women's reference TEE was calculated by means of the doubly labelled water method. Thereafter reference AEE was calculated by subtracting BMR from TEE.		Non-pregnant (*n* = 21)	Pregnant (*n* = 18)
				TEE (kJ/day)	10990 ± 1400	11150 ± 1580
				AEE (kJ/day)	5080 ± 940	4150 ± 1000
				PAL	1.86 ± 0.16	1.59 ± 0.14
				Minutes spent being sedentary (MET < 1.5)	1038 ± 113	1130 ± 123
				Minutes spent in moderate activity (MET = 3 – 6)	84 ± 34	63 ± 33

Continues on following page.

<table>
<tr><th>Authors</th><th>Title</th><th>Study Design & Participants</th><th>Methods</th><th colspan="2">Results</th></tr>
<tr><td>Melzer *et al.*, 2009</td><td>Pregnancy-related changes in activity energy expenditure and resting metabolic rate in Switzerland</td><td>*Design*: case-control study

n = 27 healthy women in their third trimester of pregnancy</td><td>TEE and AEE were estimated analysing 3 full (24 h) day recordings of heart rate and body movement with a 30 second movement averaging epoch setting.

ActiHeart®; Cambridge Neurotechnology Ltd., Papworth, UK</td><td>*Participants RMR, TEE, PAL and activity (counts per minute) of women at 38.2 ± 1.5 weeks of pregnancy*
TEE (kJ/day) = 11560 ± 2284
AEE (kJ/day) = 2918 ± 1150
PAL = 1.54 ± 0.13
Activity (counts per min): 21.4 ± 10.0</td><td>METs < 1.5: 1066.8 ± 106.4
1.5 ≤ METs < 2.0: 155.7 ± 46.2
2.0 ≤ METs < 2.5: 102.5 ± 38.9
2.5 ≤ METs < 3.0: 58.0 ± 30.5
3.0 ≤ METs < 6.0: 55.7 ± 34.3
METs ≥ 6: 1.3 ± 3.5</td></tr>
<tr><td>Clarke *et al.*, 2005</td><td>Activity patterns and time allocation during pregnancy: A Longitudinal study of British women</td><td>*Design:* A prospective, longitudinal study

n = 57 healthy nulliparous pregnant women</td><td>The time allocation patterns of pregnant women were assessed at 16, 25, 34 and 38 weeks gestation by semi-structured interview.

Mean total daily activity levels were estimated according to the intensity and duration of each activity reported.

Self-reported activity (Baecke questionnaire) was sub-divided into occupational, recreational, domestic and nocturnal activity ratios.</td><td colspan="2">Maternal daily activity level (METS) as assessed by self-report:
Gestational week 16: 1.54 ± 0.18
Gestational week 25: 1.51 ± 0.26
Gestational week 34: 1.40 ± 0.20
Gestational week 38: 1.31 ± 0.14

<table>
<tr><th></th><th colspan="4">Gestational stage (weeks)</th></tr>
<tr><th>Activity ratio</th><th>16</th><th>25</th><th>34</th><th>38</th></tr>
<tr><td>Occupational</td><td>2.27 ± 0.69</td><td>2.20 ± 0.54</td><td>2.05 ± 0.43</td><td>-</td></tr>
<tr><td>Domestic</td><td>2.45 ± 0.36</td><td>2.45 ± 0.40</td><td>2.44 ± 0.45</td><td>2.46 ± 0.33</td></tr>
<tr><td>Recreational</td><td>1.50 ± 0.23</td><td>1.55 ± 0.29</td><td>1.47 ± 0.23</td><td>1.43 ± 0.19</td></tr>
<tr><td>Nocturnal</td><td>1.91 ± 0.46</td><td>0.29 ± 0.26</td><td>0.93 ± 0.41</td><td>0.93 ± 0.28</td></tr>
</table>
In the different activity domains, mean occupational activity ratio decreased ($p < 0.002$) from 16 to 34 weeks. Nocturnal activity ratio increased ($p < 0.002$) from 16 to 34 weeks. Mean recreational activity ratio decreased significantly between 25 and 38 weeks ($p < 0.001$) but no significant changes were observed in mean domestic activity ratio.</td></tr>
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Authors	Title	Study Design & Participants	Methods	Results
Brunette *et al.*, 2012	An epidemiological study of physical activity patterns and weight gain in physically active and sedentary pregnant women in Tshwane, South Africa	*Design*: Epidemiological cross-sectional study *n* = 78 pregnant women in their second (*n* = 31) and third trimester (*n* = 47)	A modified physical activity questionnaire called the EPAQ-2 (Epic Physical Activity Questionnaire; Medical Research Council, Copyright 2003-2008) was used to assess the physical activity patterns.	Relatively active: 29% Relatively active: 53.9% Very active: 17% No significantly relationship was found in the sample between the trimester of pregnancy and a woman's physical activity level.
Amezcua-Prieto *et al.*, 2013	Changes in Leisure Time Physical Activity During Pregnancy Compared to the Prior Year	*Design:* Cross-sectional study in Granada, Spain. *n:* 1175 healthy pregnant women	Leisure time physical activity 1 year before and during pregnancy (type, frequency and duration) was obtained through the Paffenbarger Physical Activity Questionnaire.	Only 27.5% of the participants met the ACSM recommendations prior to pregnancy. This figure further decreased during pregnancy to 19.4%. The study found a general reduction in the frequency, intensity, and duration of all leisure time physical activities during pregnancy.
Adeniyi *et al.*, 2014	Physical Activity and Energy Expenditure: Findings from the Ibadan Pregnant Women's Survey	*Design* = cross-sectional study of pregnant women attending antenatal clinics in Ibadan, Oyo State of Nigeria. *n* = 453 Pregnant Nigerian women	The Pregnancy Physical Activity Questionnaire was used to assess the physical activity of the participants. The questionnaire was translated into the Yoruba language and culturally adapted. The compendium-based MET values were used to estimate the intensity of the physical activity.	49% (*n* = 222) of participants were sedentary, only 46 participants (10.2%) were moderately active and the remaining 40.8% presented with a light physical activity level. Most of the pregnant women recorded physical activity at levels lower than recommended.

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<table>
<tr><th>Authors</th><th>Title</th><th>Study Design & Participants</th><th>Methods</th><th>Results</th></tr>
<tr>
<td>Kruger et al., 2002</td>
<td>Physical inactivity is the Major Determinant of Obesity in Black Women in the North West Province, South Africa: The THUSA Study</td>
<td>Design: Cross sectional study of adult black women in the North West Province, South Africa.

n = 1040</td>
<td>A physical activity questionnaire was specifically developed for the THUSA study population.

The PAI, calculated from the questionnaire data, was validated against calculated energy expenditure during physical activity over a 24-h period. Participants were categorized into three tertile groups of PAI</td>
<td>The Physical Activity Questionnaire ranged from 1.14 to 9.17, with a mean and standard deviation of 2.75 ± 1.03.

Distribution of a participants in tertile groups of PAI
<table>
<tr><th>Tertile of physical activity</th><th>n</th><th>%</th><th>Explanation of PAI</th></tr>
<tr><td>Lowest third (PAI 1.14 – 2.249)</td><td>179</td><td>33.8</td><td></td></tr>
<tr><td>Middle third (PAI 2.25 – 2.806)</td><td>177</td><td>33.4</td><td>Middle-level occupations, e.g., Cleaning service, commuting by taxi, no sports participation, and some standing or walking leisure time activities.</td></tr>
<tr><td>Highest third (PAI 2.807 – 9.17)</td><td>174</td><td>32.8</td><td>Middle-level activity occupations, e.g., cleaning services, but also walking at a moderate pace to work for 31 to 60 min each day and spending most leisure time standing, walking, or at low-level sports activities (2 to 3 h/wk, 7 to 9 mo/y)</td></tr>
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<tr>
<td>Abeysekera et al., 2016</td>
<td>Alterations in energy homeostasis to favour adipose tissue gain: A longitudinal study in healthy pregnant women</td>
<td>Design: Longitudinal study design measured at 12-14 weeks, 24-26 weeks and 34-36 weeks of gestation.

n = 26 women</td>
<td>Energy expenditure was measured using the Sensewear Armband (model: MF-SW; Body Media, Pittsburgh, PA, USA), which combined information on motion from triaxial accelerometer measurements.</td>
<td>
<table>
<tr><th></th><th>12 – 14 weeks</th><th>24 – 26 weeks</th><th>34 – 36 weeks</th></tr>
<tr><td>Total energy expenditure (kJ/24 hour)</td><td>9514 ± 1497</td><td>10240 ± 1872</td><td>10263 ± 1296</td></tr>
<tr><td>Active energy expenditure (kJ/24 hours)</td><td>1546 ± 1128</td><td>1970 ± 1475</td><td>1348 ± 864</td></tr>
<tr><td>Physical activity duration per 24 hours (hr:min)</td><td>1:35 ± 1:22</td><td>1:49 ± 1:33</td><td>1:08 ± 0:47</td></tr>
</table>
TEE increased significantly between first and third trimester (p = 0.026).
AEE increased from first to second trimester, before decreasing in the third trimester, but these changes were not significant (p = 0.891).
</td>
</tr>
</table>

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<table>
<tr><th>Authors</th><th>Title</th><th>Study Design & Participants</th><th>Methods</th><th>Results</th></tr>
<tr><td>Reid et al., 2014</td><td>Physical activity, sedentary behaviour and fetal macrosomia in uncomplicated pregnancies: A prospective cohort study</td><td>Design: Prospective cohort study

n = 100 in healthy pregnant women predicted to deliver infants weighting ≥ 4000 g (study group) (n = 50) or ≤ 4000 g (control group) (n = 50)</td><td>SenseWear® Body Media Pro3 physical activity armband was worn for four consecutive days in the third trimester.

Physical activity was measured in METs.</td><td><table>
<tr><th></th><th>Study (n = 50)</th><th>Controls (n = 50)</th></tr>
<tr><td>TEE (kcal/day)</td><td>2418 ± 426</td><td>1977 ± 361</td></tr>
<tr><td>Moderate-to-vigorous Physical Activity (min)</td><td>48.6 ± 26.1</td><td>62.1 ± 41.9</td></tr>
<tr><td>Average METs (kcal/kg bodyweight)</td><td>1.22 ± 0.17</td><td>1.31 ± 0.20</td></tr>
<tr><td>AEE (kcal/day)</td><td>254 ± 134</td><td>287 ± 182</td></tr>
<tr><td>Steps/day</td><td>7190 ± 1861</td><td>7795 ± 3055</td></tr>
<tr><td>Sedentary time ≤ 1 METs</td><td>14.7 ± 3.2</td><td>12.8 ± 4.3</td></tr>
</table>
Women predicted to deliver macrosomic infants are more likely to exhibit increased sedentary behaviour and reduced physical activity intensity in the third trimester of pregnancy.</td></tr>
<tr><td>Richardsen et al., 2016</td><td>Predicting who fails to meet the physical activity guideline in pregnancy: a prospective study of objectively recorded physical activity in a population-based multi-ethnic cohort</td><td>Design: Multi-ethnic population-based cohort

n: 555 women in gestational week 28</td><td>Moderate-to-vigorous physical activity was recorded with the monitor SenseWear® Pro3 Armband.</td><td>Overall, the mean length of moderate-to-vigorous intensity physical activity was 64.4 min/week. 25% of women complied with the PA guideline, but the proportion was lower in South Asian (14%) and Middle Eastern (16%) as compared with Western women (35%).</td></tr>
</table>

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Authors	**Title**	**Study Design & Participants**	**Methods**	**Results**
Huberty *et al.*, 2016	Trajectories of objectively-measured physical activity and sedentary time over the course of pregnancy in women self-identified as inactive	*Design:* Cross-sectional study *n*: 80 inactive pregnant women (8-16 weeks) were recruited	Physical activity was measured until the end of the pregnancy, by means of a Fitbit and which provides estimates of sedentary, light, fairly active and very active minutes as daily accumulated totals. Fairly active represents activities occurring at > 3.0 METS and very active at > 6.0 METs. Sedentary behaviour is defined as seated activities at < 1.5 METs	Monitoring period (days): 100.73 ± 51.71 Sedentary behaviour (min/day): 979.23 ± 176.49 Light activity (min/day): 113.18 ± 43.81 Fairly active (min/day): 51.12 ± 24.03 Very active (min/day): 4.82 ± 4.49 Steps/day: 4138.15 ± 1713.52 Women spend more time being sedentary than physically active as pregnancy progresses. A pronounced decline in physical activity was observed in the third trimester.
Ruifrok *et al.*, 2014	The relationship of Objectively Measured Physical Activity and Sedentary Behaviour with Gestational Weight Gain and Birth Weight	*Design:* Secondary analysis of data from two prospective studies (one cohort) *n:* 111 healthy pregnant women between 15 and 32 weeks of gestation.	Daily physical activity and sedentary behaviour were measured with an accelerometer (ActiTrainer accelerometer; Actigraph, Pensacola, FL< USA). Total counts per minute were converted into light (100 – 2019 counts/min), moderate (2020 – 5998 counts/min) and vigorous PA (≥ 5999 counts/min)	15 weeks pregnant / 32 – 35 weeks pregnant Time spent being physically active (min/day): 286 ± 103 / 273 ± 103 Time spent in moderate-to-vigorous physical activity (min/day): 24 ± 16 / 18 ± 22 Time spend in sedentary behaviour (min/day): 530 ± 170 / 505 ± 173 A small proportion of pregnant women met the ACOG guidelines for sufficient moderate-to-vigorous physical activity in pregnancy.

Continues on following page.

Watson *et al*., 2017	Are South African Mothers Moving? Patterns and Correlates of Physical Activity and Sedentary Behavior in Pregnant Black South African Women	*Design:* Longitudinal cohort study *n:* 322 singleton, pregnant in their first trimester	Physical activity was measured using the Global Physical Activity Questionnaire		2nd trimester	3rd trimester
				Total moderate-vigorous physical activity (MET min/week)	600	480
				Total work (moderate-vigorous physical activity) (min/week)	0	0
				Total transport (moderate-vigorous physical activity) (min/week)	120	90
				Total recreation (moderate-vigorous physical activity) (min/week)	0	0
				Sitting time (min/day)	330	300
				Moderate-vigorous physical activity decreased significantly from the second- to the third trimester ($p = 0.01$).		
Watson *et al*., 2018	The influence of objectively measured physical activity during pregnancy on maternal and birth outcomes in urban black South African women	*Design:* Observational, longitudinal study. *n*: 120 women in the second trimester and 90 women in their third trimester.	Physical activity was expressed as gravity–based acceleration units using a hip-mounted triaxial accelerometer.		2nd trimester (14 – 18 weeks gestation)	3rd trimester (29 – 33 weeks gestation)
				Physical activity in gravity-based acceleration units	12.8 ± 4.1	9.7 ± 3.6
				Total volume of physical activity significantly decreased from the second to the third trimester.		

PAL = Physical Activity Level, AEE = Active Energy Expenditure, TEE = Total Energy Expenditure, RMR = Resting Metabolic Rate; epoch = counts per minute, METS = Metabolic Equivalent of Task, ACSM = American College of Sports Medicine, PAI = Physical Activity Index, h/wk = hours per week, mo/y = months per year, kJ/24 = kilojoule per 24 hours, hr:min = hour:minute, *P* = significance level, counts/min = counts per minute, min/day = minute per day, min/week = minutes per week, ± = standard deviation

2.5.3.9. Determinants of physical activity during pregnancy

Factors correlating with physical activity during pregnancy are not well understood (Jukic *et al.*, 2012:325). Pregnancy is a period of significant and heterogeneous behaviour change concerning physical activity (Swift *et al.*, 2017:45). Multiparous women and older women are more likely to reduce their physical activity during pregnancy (Merkx *et al.*, 2017:20). However, in a study from Berntsen *et al.* (2014:599), parity was positively associated with moderate-to-vigorous physical activity levels during pregnancy among South Asian women, while the opposite effect was seen among Western women. Age and educational status may also affect physical activity during pregnancy (Kader & Naim-shuchana, 2014:7; Maputle *et al.*, 2014:59). The strongest predictors of physical activity during pregnancy include education level, working part-time, and having a physically active spouse (Leppanen *et al.*, 2014:2163).

Barriers pertaining to physical activity during pregnancy can be classified as intra- and interpersonal factors. Interpersonal barriers to physical activity during pregnancy include (1) Pregnancy-related symptoms and limitations; (2) time constraints; (3) perceptions of already being active, (4) lack of motivation and (5) mother-child safety concerns, while interpersonal barriers include (1) Lack of advice and information and (2) lack of social support (Coll *et al.*, 2017:21-22). Pregnancy-related symptoms and limitations impeding physical activity during pregnancy include tiredness, pain, and a growing belly (Merkx *et al.*, 2017:20). Women with children cite childcare constraints and lack of time or fatigue related to household/childcare responsibilities as barriers to physical activity (Garland, 2017:56).

Designing and targeting interventions in order to maintain or increase physical activity during pregnancy mandates an understanding of the factors correlated with physical activity during pregnancy (Downs *et al.*, 2012:489; Evenson & Wen, 2010:125; Jukic *et al.*, 2012:325). Factors positively correlated to physical activity during pregnancy include a higher education level, Caucasian race, enjoyment of physical activity, previous physical activity participation, single marital status and the reception of health professional advice (Evenson & Wen, 2010:125-126; Gaston & Vamos, 2013:482; Jukic *et al.*, 2012:331; Merkx *et al.*, 2017:19). Antagonistically, factors negatively correlated to physical activity during pregnancy is primarily intrapersonal, including time constraints and lack of energy or tiredness (Jukic *et al.*, 2012:331). Other barriers to physical activity include maternal age greater than 35 years, being employed, a history of miscarriage, women receiving fertility treatments, and multiparous women (Gaston & Vamos, 2013:482; Jukic *et al.*, 2012:331).

How pregnancy-related physiological and behavioural changes influence AEE is not well understood (Marshall & Pivarnik, 2015:1039). Reported changes in AEE during pregnancy are inconsistent across studies (Byrne *et al.*, 2011:820). Krkeljas and Moss (2015:304) stated that relative to mass, AEE remained unchanged throughout pregnancy. Löf (2011:1298) measured through the Intelligent Device for Energy Expenditure and Physical Activity (IDEEA), a multiple accelerometer-based system and found pregnant women's AEE was 18% lower compared with non-pregnant controls, which was achieved by spending less time (1.5h/24 h) on standing and moderate activities and more time (1.5h/24 h) on sedentary activities (Löf, 2011:1295–1301). The decline in AEE escalates at the end of pregnancy, where most pregnant women shift toward less intense, more comfortable modes of activity as a means to avoid any risk of maternal or foetal injury, and to accommodate the increase in body mass (Melzer *et al.*, 2009:1189).

Changes in absolute AEE can either be modified through metabolic (changes to the economy of movement) or behavioural (volume of movement) changes (Byrne *et al.*, 2011:820). From a behavioural perspective, a consensus exists that physical activity levels decrease over pregnancy due to discomfort or increased fatigue of moving when pregnant (Byrne *et al.*, 2011:828; Melzer *et al.*, 2009:1189). Adversely, from a metabolic perspective, this decrease can be ascribed to the offset of the energy cost of pregnancy which ensures adequate fuel to support the conceptus (Byrne *et al.*, 2011:828). The most significant energy conservation through AEE can be seen in extremely active women or those with heavy physical workloads (Kopp-Hoolihan *et al.*, 1999:702).

Richardsen *et al.* (2016:185) developed a theoretical model to estimate factors related to physical activity non-compliance during pregnancy. They found the most critical predictors thereof were an ethnic minority background, multiparity, few physically active friends, and a high body fat percentage (Richardsen *et al.*, 2016:185). Barriers to physical activity include tiredness, nausea, health-related issues, work, and lack of time (Leppanen *et al.*, 2014:2163). Obese women spend less time being active as compared to normal-weight women (Huberty *et al.*, 2016:357). Misconceptions regarding physical activity during pregnancy include beliefs that physical activity may cause miscarriage, restrict foetal growth, cause preterm birth, and lead to musculoskeletal injury (Garland, 2017:55). Given the numerous barriers to physical activity during pregnancy, expectant mothers, particularly those with little exercise history, may have little motivation to perform moderate physical activity if they do not perceive there to be a protective benefit for their babies, especially if they must simultaneously cope with other pregnancy-related difficulties (Connolly *et al.*, 2016:500-501). Additionally, the energy requirements of undernourished women from low-to-middle-income countries may differ from those of overweight and obese women, and physical activity patterns may change during pregnancy to an extent determined by socio-economic and cultural factors (FAO, 2001:53).

2.5.3.10. Promoting physical activity during pregnancy

Pregnant women should be encouraged to be physically active as physical activity is a modifiable lifestyle factor and pregnancy is seen as a window of opportunity for the improvement of women's health (ACOG, 2015:269; Merkx *et al.*, 2017:22). In support of this notion, da Silva *et al.* (2017:314) emphasise the promotion of physical activity in pregnancy as a strategy to improve maternal and child health.

In light of the obesity epidemic and the high prevalence of women with excessive pregnancy weight gain, health care providers should be better equipped to discuss weight gain, physical activity and nutrition (Whitaker *et al.*, 2016:121). The current high prevalence of maternal overweightness and obesity, insulin resistance, and gestational diabetes mellitus, necessitates the establishment of public policies that support gestational and leisure-time physical activity (Cid & González, 2016:61).

In promoting physical activity during pregnancy, special attention must be paid to overcome specific barriers related to pregnancy, such as pregnancy-related symptoms and limitations, and mother-child safety concerns (Coll *et al.*, 2017:23). Health care providers should encourage physical activity among healthy pregnant women, increasing women's knowledge about the mother-child benefits of physical activity during pregnancy as well as of the physical activity guidelines for pregnant women (Coll *et al.*, 2017:24).

Garland (2017:57) states that emphasising goals, dispelling myths, and providing educational materials about the benefits and importance of achieving at least 150 minutes per week of moderate-intensity physical activity for maternal and foetal health will encourage women to remain active during pregnancy.

Reid *et al.* (2014:1207) made the following achievable health promotion recommendations during pregnancy: increase the intensity of free-living physical activity, by walking at a brisker pace, climbing stairs instead of taking a lift, walking instead of sitting in transport and spending less time sitting or watching television.

Support and encouragement in maintaining the recommended levels of physical activity during pregnancy are especially crucial as Reid *et al.* (2014:1207) stated that women predicted to deliver macrosomic infants exhibit high levels of sedentary behaviour when compared to women predicted to deliver average-sized infants. Given the physiological effects of diet and physical activity prescription, it would be beneficial to incorporate these concepts into antenatal care for all low-risk women (Clapp, 2006:532). A study by Most *et al.* (2018:6) found energy intake recommendations may significantly overestimate the energy requirements during pregnancy in African-American women due to their lower energy expenditure, which may contribute to adverse pregnancy outcomes.

2.6. Maternal and offspring outcomes

Clinically relevant pregnancy outcomes include the prevalence of gestational diabetes, prematurity and caesarean section, delivery complications, gestational weight gain and birth weight (Hoque & Hoque, 2010:4; Rogozinska *et al.*, 2017:1107). Rogozinska *et al.* (2017:1109) emphasised the wide variation and limited reporting of clinically essential outcomes in studies related to diet and physical activity in pregnancy. In utero foetal exposure to maternal obesity, excessive gestational weight gain, and abnormal glucose tolerance can influence the risk of ensuing overweight or obesity in the offspring (Downs *et al.*, 2012:487).

2.6.1. Theory of foetal origins of obesity and disease

Many epidemiological studies have demonstrated the association between low birth weight and the subsequent development of hypertension, insulin resistance, type 2 diabetes and cardiovascular disease (Barker *et al.*, 1993:425). Foetal programming was proposed by Barker *et al.* (1993:425) as the mechanism underlying the association between low birth weight, childhood growth and subsequent disease. The theory developed by Barker *et al.* (1993:425) has been named the “foetal origin hypothesis,” “early life programming,” and “thrifty phenotype hypothesis” (Newton & May, 2017:10). The foetal programming hypothesis proposes that a stimulus which acts during critical periods of growth and development – such as during pregnancy – may permanently alter tissue structure and function (Drake & Walker, 2004:1). Exposure of the foetus to an adverse environment *in utero* may lead to permanent alterations in physiology influencing the adulthood of the infant (Drake & Walker, 2004:7). The relative importance of genetic and environmental factors remains unknown, however, as with most nature vs nurture arguments, the answer is probably a mixture of the two (Drake & Walker, 2004:1).

The metabolic dysfunction associated with foetal programming crosses generations, perhaps via an epigenetic mechanism (Drake & Walker, 2004:1–2; Newton & May, 2017:10). As suggested by Drake & Walker (2004:11), intergenerational effects may occur as a result of genetic attributes, adverse extrinsic environmental conditions persisting from one generation to the next, or adverse intrauterine conditions resulting in an altered maternal metabolism, which in turn provides an adverse environment for the foetus. As an example: if low birth weight is associated with increased cardiovascular risk, then this could lead to the ‘inheritance’ of a predisposition to low birth weight and adverse cardiovascular risk across several generations (Drake & Walker, 2004:2). Growing evidence supporting the association of foetal programming by *in utero* events suggests that the focus of disease prevention or research interventions should begin in gestation (May *et al.*, 2016:50).

A high pre-pregnancy body mass index (BMI) and low insulin sensitivity are strong predictors of increased foetal growth, possibly due to maternal insulin resistance resulting in the greater availability of nutrients to the foetus (Downs *et al.*, 2012:492). Pre-pregnancy BMI and gestational weight gain have been found to predict birth weight (Galtier-Dereure *et al.*, 2000:1245S) whereas higher BMI was associated with delivering large for gestational age infants (Guelinckx *et al.*, 2008:144). In turn, this puts the child at an increased risk of future overweight and obesity, developing further complications associated with obesity such as type 2 diabetes and cardiovascular disease later in life (Catalano *et al.*, 2003:1681S).

The scarce findings available in the literature about the changes evoked by maternal physical activity as measured by later outcomes in the offspring are positive, whether permanent or temporary (Leite *et al.*, 2016:279). Until now, many of these investigations have not clarified the triggering mechanisms of change, making it impossible to make clear associations between maternal physical activity and the outcome in the offspring (Leite *et al.*, 2016:279). Maternal nutrition is a significant factor proposed as an explanation for foetal programming, especially in low-to-middle-income countries where maternal diet affects birth-weight (Drake & Walker, 2004:7). Barker *et al.* (1993:425) proposed that maternal undernutrition, by constraining foetal growth may programme cardiovascular disease.

Physiological adaptations due to foetal programming prepare the foetus for the same extra-uterine conditions as were experienced during the gestational period (Drake & Walker, 2004:10). As foetal programming influences generations, transitional populations such as South Africa, which experienced rapid urbanisation leading to an increase in the prevalence of type 2 diabetes and other cardiovascular risk factors, is of particular importance (Drake & Walker, 2004:10). Foetal programming has major public health implications for low-to-middle-income countries and thus policies which are aimed at improving the health of one generation, in particular those directed at improving maternal, foetal and infant health, may have essential benefits on several succeeding generations (Drake & Walker, 2004:11). Findings relating sedentary behaviour in pregnancy to macrosomia may have long term implications for infancy and childhood and interventions to reduce sedentary behaviour during pregnancy have the potential to impact the health of future generations (Cid & González, 2016:58; Reid *et al.*, 2014:1208; Richardsen *et al.*, 2016:187).

2.6.2. Gestational weight gain

Pregnant women with a normal pre-pregnancy BMI of 20 to 26 kg/m^2, gain about one-third of the weight (4.5 kg) in the first 20 weeks of gestation and two-thirds (9 kg) of the total weight is gained in the last 20 weeks (Newton & May, 2017:2). However, weight gain varies dramatically among women with normal birth outcomes (King *et al.*, 1994:439S). Prentice & Goldberg (2000:1229S) found that gestational weight gain ranged from 10% to 30% of pre-pregnancy weight. More specifically, Van Oort (2014:55) found a gestational weight gain of 4.5 kg, 4.5 kg and 4.07 kg in the first, second and third trimester respectively and total weight retention from pre-pregnancy to three months postpartum of 7.21 kg.

The weight of the foetus, supportive tissue such as the uterus, placenta and amniotic fluid as well as tissue for the preparation for lactation add up to about 6.5 kg for full-term infants weighing 3 – 4 kg (King *et al.*, 1994:439S). However, normal-weight women gain weight from 10.0 to 16.7 kg (IOM, 2009:3-24). To account for the variation in total weight gain among women – maternal extracellular fluid and maternal fat tissue vary greatly (King *et al.*, 1994:439S). Women gaining less than the weight of the components of pregnancy (6.5 kg) lose maternal tissue, whereas those who are gaining more accumulate water and fat in their tissue (King *et al.*, 1994:439S). In low-to-middle-income countries, foetal weight represents up to 60% of total pregnancy weight gain in many pregnancies (compared with a well-nourished norm of 25%) which indicates that the foetus is developing under suboptimal nutritional and physiological conditions (Prentice & Goldberg, 2000:1230S). The observed variability in gestational weight gain indicates a wide variation in fat gain and, therefore, in the energy requirements for pregnancy (King *et al.*, 1994:439S).

Maternal fat gain correlates with gestational weight gain, implying that women with greater weight gains gain more fat (King *et al.*, 1994:440S). Fat gain during pregnancy is influenced by maternal energy status, which in turn, is influenced by nutritional- and physical activity status (King *et al.*, 1994:441S). Fat is gained primarily between the 10th and 30th week of gestation before foetal energy demands are at their peak (King, 2000:1219S). Approximately 3.3 kg fat is deposited in maternal stores, providing an energy reserve of about 30 000 kcal (129 MJ) (King, 2000:1219S).

The absence of a relationship between birth weight and maternal fat gain in normal-weight women suggests that fat gain is not essential for optimal foetal growth, although early fat deposition will protect a foetus during harsh conditions in the last trimester (King *et al.*, 1994:441S). Excess gestational weight gains during pregnancy, however, increase the risk of excess fat deposition and for obesity after delivery (King *et al.*, 1994:441S).

Table 2-4 summarises the gestational weight gain guidelines from the Institute of Medicine (IOM, 2009) for attaining normal birth outcomes.

Table 2-4: Gestational weight gain guidelines of the Institute of Medicine (IOM, 2009:7-12)

Classification	Body Mass Index before pregnancy (kg/m^2)	Total weight gain (kg)	GWG range for first 13 weeks	GWG range per week in second and third trimester (kg)
Underweight	< 18.5	12.5-18	0.5-2	0.44-0.58
Normal weight	18.5-24.9	11.5-16	0.5-2	0.35-0.50
Overweight	25.0-29.9	7-11.5	0.5-2	0.23-0.33
Obese	≥ 30.0	5-9	0.5-2	0.17-0.27

GWG: Gestational Weight Gain, kg: kilogram

Excessive gestational weight gain is associated with many adverse health outcomes for both mother and child (Whitaker & Wilcox, 2016:2310), including an increased risk of caesarean delivery, post-partum weight retention, and future overweight and obesity in the child (DeVader *et al.*, 2007:750). Understanding the risks of both insufficient and excessive weight gain during pregnancy is critical and mandates that health care providers clearly communicate these risks to their patients (Whitaker & Wilcox, 2016:2314).

Physically active women have lower weight gain during pregnancy (da Silva *et al.*, 2017:210). Another determinant of excessive gestational weight gain is related to a race where Merkx *et al.* (2015:699) found Non-Caucasian women to have a fivefold increased risk of gaining weight at levels above the IOM guidelines as compared to Caucasian participants. Merkx *et al.* (2015:699) also recommended the need to identify cut-off points in terms of gestational weight gain for different ethnic minorities.

2.6.3. Foetal growth

The transition from foetal to newborn life requires numerous anatomical and physiologic adjustments (May *et al.*, 2016:51). Growth rate relative to body weight during foetal development exceeds any other time in human life (Newton & May, 2017:2). Foetal weight change (as illustrated in Figure 2-4) during gestation equates 5 grams per day (g/d) at 15 weeks, 10 g/d at 20 weeks, 25 g/d at 30 weeks, 35 g/d at 35 weeks, and 15 g/d at 40 weeks (Newton & May, 2017:2). The highest velocity of linear growth occurs at 22 to 25 weeks, whereas the highest velocity of overall weight occurs at 32 to 35 weeks (Newton & May, 2017:2).

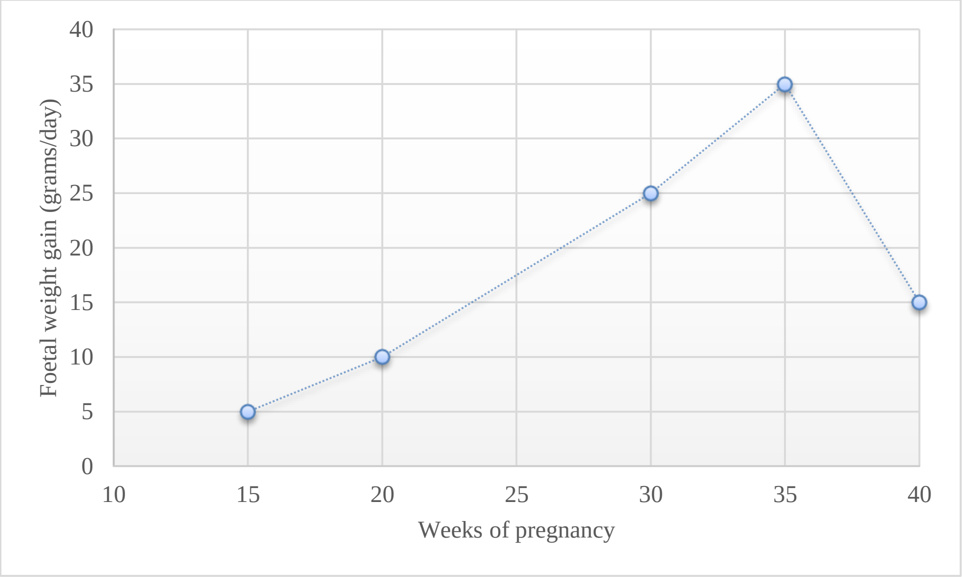

Figure 2-4: Foetal weight gain during gestation (Newton & May, 2017:2)

The availability and rate of delivery of oxygen and nutrients to the foetus are significant regulators of foeto-placental growth (Clapp, 2006:527–528). Basic physiological determinants that affect the availability or rate of delivery of oxygen and substrate between maternal- and foetal physiology include the rate of placental bed blood flow, haemoglobin content, the partial pressure of oxygen and the concentration of nutrients in maternal arterial blood (Clapp, 2006:528). Factors which alter substrate delivery regulate foeto-placental growth rate by initiating a change in the synthesis and tonic release of placental growth suppressive peptides into the foetal circulation (Clapp, 2002:45–46)

The proposed mechanism of foetoplacental growth appears to be a classic stimulus-negative feedback system where trophoblast serves as both the receptor and effector (Clapp, 2006:528). The trophoblast senses substrate and oxygen availability, which alters local gene expression and the subsequent production of multiple growth-suppressive and growth stimulatory peptides (Clapp, 2006:528). These peptides are then released into the foetal circulation where they either suppress or stimulate the production of IGFs (insulin-like growth factors) to either up- or down-regulate foetoplacental growth in a tissue-specific fashion (Clapp, 2006:528). The effect of this stimulus-negative feedback system on size at birth depends on the period in pregnancy when the intermittent stimulus is experienced as well as changes in both the stimulus intensity and duration (Clapp, 2006:528). Nutrient availability mainly affects IGFs, while oxygen tension affects the Hypoxia-inducible factor and vascular endothelial growth factors (Clapp, 2006:528). As these mechanisms are sensitive, tissue-specific, rapidly responsive and locally regulated, it explains why many maternal lifestyle factors, such as physical activity and nutrition, influence foetoplacental growth and size at birth (Clapp, 2002:46).

Clapp (2006:529-530) found that regular moderate-intensity physical activity during early pregnancy and continuing throughout pregnancy stimulates the rate of mid-trimester growth in placental volume and functional placental volume. In a case-control study, Clapp *et al.* (2000:1488) found that beginning a moderate-intensity, weight-bearing exercise regimen in early pregnancy was associated with a significant, balanced increase in foetoplacental growth in normal pregnancy.

Diet-induced differences in glucose and insulin levels have direct metabolic effects on energy balance via effects on absorption, basal metabolic rate and energy substrate utilisation (Clapp, 2002:46). High-glycaemic carbohydrate intake in mid and late pregnancy markedly increases foetoplacental growth rate, while low-glycaemic carbohydrates result in an average rate of foetoplacental growth (Clapp, 2002:48). Carbohydrate composition during pregnancy also influences maternal fat deposition and retention, probably by influencing metabolic efficiency and insulin resistance and sensitivity (Clapp, 2002:48). Increased availability of high-glycaemic carbohydrate sources in industrialised Western societies and urbanisation in low-to-middle-income countries may explain the gradual increase in both birth weight and pregnancy weight gain (Clapp, 2002:48). Changes in the rate of foetal somatic growth (a curvilinear pattern) reflect changes in gestational weight gain (Newton & May, 2017:2).

Primary immediate neonatal outcomes of concern are miscarriage, congenital disabilities, preterm delivery, and birth weight extremes, i.e., small for gestational age (SGA) or large for gestational age (LGA) (Newton & May, 2017:9).

Birth weight is the most easily measured outcome as an indicator of intrauterine environment impact on foetal development (Leite *et al.*, 2016:276). Although wide ranges in normal birth weight are standard, Catalano *et al.* (1992:46) state that 2500 grams have been used as the lower limit and 4000 g as the upper limit of normal term growth. Another biological norm for birth weight is about 25% of total weight gain (Prentice & Goldberg, 2000:1230S). As this percentage differs according to energy balance during pregnancy Prentice & Goldberg (2000:1230S) state, it may be a useful index of nutritional adequacy in pregnancy. Population-specific normative weight percentiles for gestational age criteria exist as well and classify birth weight into small for gestational age (SGA; less than the tenth percentile), appropriate for gestational age (AGA; tenth to 90th percentile), and large for gestational age (LGA; above the 90th percentile) (Catalano *et al.*, 1992:46).

2.6.4. Birth outcomes

Maternal anthropometrics are an essential factor related to birth weight (Catalano *et al.*, 2003:1677S). Maternal weight before pregnancy, as well as maternal height, is associated with an increase in birth weight (Catalano *et al.*, 2003:1678S). Relative to maternal anthropometrics, paternal anthropometric factors have a limited effect on foetal birth weight (Catalano *et al.*, 2003:1678S). Paternal birth weight, adult height and adult weight explain about 3% of the variance in infant birth weight as compared to 9% for the corresponding maternal factors (Klebanoff *et al.*, 1998:1025).

Genetic factors may have a stronger relationship with fat-free body mass, whereas the *in-utero* environment may better correlate to foetal fat mass (Barker *et al.*, 1993:425). According to Catalano *et al.* (1992:49) fat-free mass, which comprises 86% of mean birth weight, accounts for 83% of the variance in birth weight, while fat mass, which comprises only 14% of birth weight, accounted for 46% of the variance in birth weight.

Small head circumference – similar to low birth weight – is associated with a higher rate of cardiovascular death, according to the theory of foetal origins of disease (Barker *et al.*, 1993:424-425).

The ponderal index is used to estimate the state of nutrition and growth in the young child though an anthropometric measure – weight x 100 / length^3 (Catalano *et al.*, 1992:46). The ponderal index provides a better estimate of foetal nutritional abnormality than birth weight percentile as it is relatively independent of race, sex and gestational age (Catalano *et al.*, 1992:46; Walther & Ramaekers, 1982:46).

The rise in NCDs, coupled with maternal and infant mortality rates, form two of the four main threats to the health of South Africans (Baleta & Mitchell, 2014:687). Non-communicable diseases affect almost 40% of adult women who are overweight or obese in South Africa (Baleta & Mitchell, 2014:687). The American College of Obstetricians and Gynecologists (ACOG, 2015:269) states that future research is needed regarding physical activity and pregnancy-specific outcomes.

2.7. Energy balance and birth outcomes

Weight gain, physical activity, and dietary intake all directly influence pregnancy outcomes and the health of the mother and child (Whitaker & Wilcox, 2016:2309). Physical activity and diet are two easily modifiable lifestyle variables which influence various aspects of foetoplacental growth (Clapp, 2006:531; Clapp, 2002:48). These factors, if properly implemented, can provide maternal benefits and either neutral or positive effects on neurodevelopment and growth in infancy and childhood (Clapp, 2006:531; Clapp *et al.*, 2000:1488). Modifications in energy intake and energy expenditure during pregnancy could have a preventative or therapeutic value in improving pregnancy outcomes in a variety of high- and low-risk obstetrical populaces (Clapp, 2006:532). As South African women of childbearing age are particularly vulnerable to physical inactivity, malnutrition and obesity, interventions aimed in addressing both energy intake and energy expenditure during pregnancy might especially be relevant in this population (Prioreschi *et al*., 2017).

To attain energy balance during pregnancy, the following physiological and behavioural changes occur 1) a decrease in RMR, 2) mobilisation of maternal fat reserves, 3) reduction in physical activity or 4) an increase in energy intake (King *et al.*, 1994:443S). For example, underweight women living with a limited food supply and who engages in hard physical work will have no maternal fat reserves to mobilise in order to support foetal growth and her RMR will, therefore, decrease to attain an energy balance which will provide sufficient energy to deliver a viable infant (King *et al.*, 1994:443S). Another example is a normal-weight woman in a high-income country with abundant food sources – to promote energy balance, she will become more sedentary and increase energy intake to conserve energy. However, as there is no restriction in energy intake, she will gain additional fat stores (King *et al.*, 1994:444S). In a more extreme situation, an overweight woman in a high-income country with free access to food will have ample fat reserves at conception to protect foetal growth in late pregnancy (King *et al.*, 1994:444S). As she has enough energy reserves, there would be no need to accumulate more; however, this is typically not the case. A means to attain energy balance is by increasing the basal metabolic rate of overweight pregnant women during late pregnancy – 20% above that of non-pregnant overweight women (King *et al.*, 1994:444S). This increase in basal metabolic rate is to offset the potential for fat deposition in these women who already have ample energy stores (King *et al.*, 1994:444S). Further fat deposition – and the subsequent disturbance of the energy balance – may be detrimental to the health of the mother and infant (King *et al.*, 1994:444S). When assessing energy balance, estimated energy intake remains significantly lower than the estimates of total energy expenditure (Catalano *et al.*, 2003:1679S). The discrepancy can be explained by factors such as increased metabolic efficiency during gestation, decreased maternal activity and unreliable assessment of energy intake (De Groot *et al.*, 1994:830; Prentice *et al.*, 1989:19).

Contrary to the previously mentioned research, a study by De Groot *et al.* (1994:830) evaluated energy balances in healthy Dutch women. De Groot *et al.* (1994:830) kept energy intake and expenditure constant using a strict study design in order to explore the potential impact of energy-saving during pregnancy on total energy metabolism. The study clearly showed that where the energy balance becomes negative, the possibility of saving energy through a higher digestibility and metabolism of the dietary energy intake is limited. However, this study concerned healthy women in a high-income country where the possibility of energy available for the foetus will not likely be restricted by prepregnancy energy reserves.

The abovementioned research depicts a coordinated biological system in which energy-sensitive modulations in the metabolism help to sustain human pregnancy under highly limited environmental circumstances (Prentice & Goldberg, 2000:1229S). While this metabolic plasticity represents a powerful mechanism for sustaining pregnancy and birth outcomes, it must not be construed as a perfect mechanism that obviates the need for optimal nutritional and physical activity care of pregnant women (King, 2000:1224S; Prentice & Goldberg, 2000:1230-1231S). Both a positive and negative balance of energy may have public health implications during pregnancy (King *et al.*, 1994:444S). Increased perinatal mortality is an immediate consequence which indicates that the foetus is developing under suboptimal nutritional and physiological conditions (Prentice & Goldberg, 2000:1229S). The resulting energy imbalance is reflected in low weight gain, impaired foetal growth, and a decreased ability to sustain milk production (King, 2000:1224S). Both excessive leanness and overweight lead to a higher frequency of preterm birth (Galtier-Dereure *et al.*, 2000:1244S). Long-term defects in terms of adult susceptibility to non-communicable diseases reinforce the importance of energy balance during pregnancy, the most sensitive period of the life cycle in which nutritional and physical activity intervention may reap the most significant benefits (Prentice & Goldberg, 2000:1230S).

Food intake and physical activity behaviour during pregnancy affect the amount of energy and nutrients available for foetal growth. Ruifrok *et al.* (2014:2093) recommended that future studies take both sides of energy balance into account concerning gestational weight gain and birth outcomes. Pregnancy might provide an opportune time for successful lifestyle interventions, as women are highly motivated due to the possible positive impact on their child (Wolff *et al.*, 2008:500).

2.7.1. Relationship between diet and birth outcomes

Maternal nutrition is an essential factor in determining foetal growth (Catalano *et al.*, 2003:1677S). The level of energy intake associated with nutritional deprivation and impaired foetal growth is approximately < 1500 kcal/day (Stein & Susser, 1975:75). According to Stein & Susser (1975:75), nutritional deprivation early in gestation is associated with a higher rate of prematurity, deficient birth weight and smaller head circumferences whereas deprivation in late gestation is associated with 9% lower birth weight but not length. Nutritional supplementation can help to improve birth weight, mainly when food shortages and increased work-load resulted in a negative energy balance (Catalano *et al.*, 2003:1677S). Wrottesley *et al*. (2016:160) motivated that appropriate nutritional interventions during pregnancy to be prioritised in African setting, where maternal obesity, coupled with poor micronutrient status and diet quality, continues to increase.

Eriksson *et al.* (2010:56) speculated that offspring size is regulated in response to the availability of dietary energy in the environment in which the mother is living. Energy intake recommendations should be derived from healthy populations with favourable pregnancy outcomes (Butte *et al.*, 2004:1086). Not only energy intake but also the macronutrient composition consumed during pregnancy influences birth size and even adult health (Blumfield *et al.*, 2012:323). Maternal macronutrient (carbohydrate, fat and protein) energy intakes potentially influence foetal growth, birth size, and program future appetite (Blumfield *et al.*, 2012:323; Brion *et al.*, 2010:748). Future research should compare maternal diet to short- and long-term health outcomes (Blumfield *et al.*, 2012:333). King (2000:1221S) suggests that foetal size and therefore, energy demand, influences the adjustments in energy metabolism made by the mother during gestation.

The relationship between diet as a tool to improve foetal growth and decrease the incidence of low birth weight has been extensively studied (Clapp, 2006:532). While low energy reserves before pregnancy and marginal caloric intake are associated with metabolic and behavioural adaptations which act to maintain growth, there is nonetheless an increased incidence of low birth weight (King *et al.*, 2015:444S; King, 2000:1224S; Prentice & Goldberg, 2000:1230S–1231S). Stein & Susser (1975:74-75) examined the effect of the 1944-1945 Dutch famine on birth outcomes and concluded that third-trimester nutritional deprivation affected birth weight, placental weight, maternal weight at the end of pregnancy, infant length, and head circumference.

Physiological mechanisms of how maternal dietary intake affects birth outcomes might in a similar manner to physical activity be attributed to placental bed blood flow. Although unstudied, Clapp (2006:529) states that placental bed blood flow may change the absorptive state. Food intake temporarily elevates blood glucose and insulin levels, which in turn increases nutrient delivery to the placental site, whereas fasting decreases nutrient delivery (Clapp, 2006:529).

Clapp (2006:531) draws a clear link between maternal blood glucose levels and size at birth. They reasoned that post-prandial differences in blood glucose might make a significant difference in the 24-hour availability of glucose to the placental site that could easily influence the foetal growth rate (Clapp, 2006:531). To conclude, they found that those having the lightest infants ate low-glycaemic types of carbohydrate predominantly while those with large offspring ate primarily from high-glycaemic sources (Clapp, 2006:531).

Wolff *et al.* (2008:499) demonstrated the possibility of restricting excessive gestational weight gain in obese women by a dietary intervention aimed at restricting energy intake. The energy restriction led to no adverse effects on foetal growth and incidences of pregnancy and birth complications (Wolff *et al.*, 2008:499). Numerous physical activity variables interact with dietary habits and influence the availability of oxygen and substrate to the foetus, which, in turn, regulates the first placental and then foetal growth (Clapp, 2006:529).

2.7.2. Relationship between physical activity and birth outcomes

Physical activity levels before and during pregnancy modify placental growth, anatomic indices of function and size at term (Clapp, 2006:530). The influence of physical activity on offspring parameters, such as weight, height and body fat percentage is not linear (Leite *et al.*, 2016:276). Notwithstanding, evidence regarding any possible association between foetal-maternal health outcomes and physical activity is mixed and limited (ACOG, 2015:272).

Numerous benefits of physical activity and birth outcomes have however, been confirmed. Pearson *et al.* (2015:95) have shown physical activity to be an essential factor which may help to improve pregnancy outcomes. To substantiate this claim, Newton & May (2017:11) suggested that a monitored, stepwise increase in physical activity during pregnancy will decrease adverse pregnancy outcomes. Rêgo *et al.* (2016:7) concluded that physical activity is not associated with adverse perinatal outcomes such as low birth weight, premature birth, or intrauterine growth restriction. Physical activity is significantly associated with a BMI < 30 kg/m^2 and should be seen as beneficial due to the decreased risk of adverse pregnancy outcomes (Lindqvist *et al.*, 2016:19).

Van Oort (2014:77) found negative, non-statistically significant correlations between average AEE during pregnancy and birth weight, birth length and Ponderal Index, while a positive, non-statistically significant correlation was found between average AEE during pregnancy and head circumference. Similarly, Ruifrok *et al.* (2014:2092) failed to find an association between physical activity and gestational weight gain. Ruifrok *et al.* (2014:2092) accredited their finding to small sample size, not having women participating in regular vigorous-intensity physical activity as well as not taking the nutritional intake of the participants into account.

Contrary to traditional beliefs, physical activity during pregnancy is not associated with prematurity (Cid & González, 2016:59). Jayakody & Senanayake (2015:79) found no significant relationship ($p = 0.149$) between prematurity and physical activity during pregnancy. Wen *et al.* (2017:11) have shown, in a meta-analysis, the beneficial effects of leisure-time physical activity during pregnancy in reducing the risk of prematurity. Another meta-analysis by Aune *et al*. (2017:1816) also demonstrated a beneficial association between higher leisure-time physical activity and the reduced risk of premature births. Rêgo *et al.* (2016:6) found no association between women’s level of physical activity during the second trimester of pregnancy and adverse perinatal outcomes such as Low-Birth-Weight, Prematurity and Intra-Uterine Growth Retardation.

Jayakody & Senanayake (2015:80) also found a statistically significant ($p = 0.015$) relationship between physical activity during pregnancy and mode of delivery, wherein the incidence of emergency caesarean births are significantly increased among less active women.

In a systematic review and meta-analysis, Da Silva *et al.* (2017:307) concluded that associations between Leisure-Time Physical Activity during pregnancy and weight gain, gestational diabetes mellitus, prematurity and foetal growth exist. Collectively (da Silva *et al.*, 2017:314) the researchers support the promotion of Leisure-Time Physical Activity during pregnancy as a strategy to improve maternal and child health.

Physically active women were less like to deliver a Large of Gestational Age baby (da Silva *et al.*, 2017:307). Reid *et al.* (2014:1207) found an inverse association between intensity of physical activity and predicted birth weight. Reid *et al.* (2014:1207) also found that women who spent more time doing moderate- to vigorous physical activity deliver infants < 4000 g, suggesting that increasing time spend in moderate-to-vigorous physical activity may be related to reduced birth weight. Women who spent significantly less time in moderate- to vigorous physical activity and spent more time in sedentary behaviour (≤ 1 MET) were more likely to deliver macrosomic infants. However, the findings of Jayakody & Senanayake (2015:80) contradict this in so far as they found no relationship between physical activity and infant birth weight.

Madsen *et al.* (2007:1422) suggested, in findings that run contrary to several studies, as mentioned earlier, that exercise in early pregnancy was associated with an increased risk of miscarriage. However, they recommended caution when interpreting their results as potential bias arising from retrospective data collection may partly explain this association (Madsen *et al.*, 2007:1422).

Tinius *et al.* (2017:657) demonstrated the benefits of maternal physical activity during pregnancy, specifically as regards birth outcomes in obese women. Tinius *et al.* (2017:657) found that physically active pregnant obese women were less likely to exceed IOM gestational weight gain guidelines and less likely to require a caesarean delivery; however, these results did not achieve statistical significance. Tinius *et al.* (2017:658) also found a positive association between physical activity and neonatal birth weight in their cohort of obese women.

Lindqvist *et al.* (2016:19) failed to demonstrate associations between physical activity levels and birth weight due to insufficient sample size. Pathirathna *et al.* (2019:6) also concluded no significant association between physical activity, measured by the Pregnancy physical activity questionnaire, and birth weight. The reason for divergent results regarding the influence of maternal physical activity on birth weight is related to a sum of variables and also to the way that the maternal physical state is accessed, which are essential obstacles faced by researchers (Leite *et al.*, 2016:276).

Physiological mechanisms show how physical influence birth outcomes may be related to the rate of placental bed blood flow. Placental effects alter nutrient transfer, and thus foetal growth rate, which ultimately influences size at birth and neonatal morphometrics (Clapp, 2006:530). During acute exercise, the rate of placental bed blood flow decreases (Clapp, 2006:529). However, while being physically active may blunt the magnitude of this acute decrease in blood flow in late pregnancy there always will be an associated acute decrease in the delivery of oxygen and nutrients to the placental site (Clapp, 2006:529). Beginning or continuing regular physical activity throughout pregnancy may nevertheless increase placental bed blood flow at rest and will increase the delivery of nutrients and oxygen. Normalised birth weight outcomes may be the result of higher blood volume, which can increase nutrient delivery seen in active pregnant women as compared to sedentary pregnant women (Newton & May, 2017:10).

2.7.3. Relationship between obesity and birth outcomes

The prevalence of obesity during pregnancy is rapidly increasing worldwide (Kader & Naim-shuchana, 2014:3). It is estimated that in 2020 2/3 people will be overweight or obese, with the majority being women (Cid & González, 2016:59). Averett *et al*. (2014:39) found that women suffer disproportionately more from obesity (more than 30%) compared to men in a South-African cohort).

Obesity during pregnancy is associated with elevated risks of complications during pregnancy and in connection with childbirth (Kader & Naim-shuchana, 2014:3; Pearson *et al.*, 2015:94). Additionally, pregravid overweight is one of the most frequent high-risk obstetric situations, leading to increased maternal and foetal morbidity (Galtier-Dereure *et al.*, 2000:1242S; Guelinckx *et al.*, 2008:140). Complications resulting from obesity during pregnancy include adverse pregnancy outcomes, such as hypertension, pre-eclampsia, gestational diabetes mellitus, perinatal mortality, macrosomia, complicated deliveries and an increased risk of Caesarean section delivery (Galtier-dereure *et al.*, 2000:1246S; Guelinckx *et al.*, 2008:141-142; Pearson *et al.*, 2015:94). Childbearing age in women may be the perfect window of opportunity to intervene in the obesity epidemic, not only to optimise the health of the mother but also of her offspring (Pearson *et al.*, 2015:93).

Obesity during pregnancy poses various risks for adverse birth outcomes (Galtier-Dereure *et al.*, 2000:1244S; Guelinckx *et al.*, 2008:143). Low Apgar scores are slightly more prevalent in infants of obese mothers than in infants of normal-weight mothers (Mancuso *et al.*, 1991:85). Obese mothers deliver large-for-gestational-age infants 1.4 to 1.8 times more frequently than do lean mothers (Mancuso *et al.*, 1991:85). The risk of birth complications such as shoulder dystocia, birth injury, caesarean delivery and perinatal death increase with macrosomia (Spellacy *et al.*, 1985:160). Maternal obesity is also associated with increased subcutaneous fat in the new-born, suggesting that the excess weight of the new-born is due to a larger fat mass (Whitelaw, 1976:986). Gestational diabetes – one of the risks of obesity during pregnancy – influences foetal growth (Spellacy *et al.*, 1985:160). Another factor influencing foetal growth is the location of body fat stores in the mother (Brown *et al.*, 1996:64; Galtier-Dereure *et al.*, 2000:1244S). According to Brown *et al.* (1996:64), each 0.1-unit increase in pregravid waist-to-hip ratio predicated a 120 g greater birth weight, a 0.51 cm greater length, and a 0.3 cm greater head circumference. Congenital abnormalities may also be attributed to maternal obesity (Galtier-Dereure *et al.*, 2000:1244S). Maternal complications and prematurity largely contribute to the high prevalence of infant mortality seen in overweight and obese pregnant women (Galtier-Dereure *et al.*, 2000:1245S). Excessive weight gain during pregnancy worsens maternal obesity and is a strong predictor for sustained weight retention (Galtier-Dereure *et al.*, 2000:1245S; Yu *et al.*, 2006:1123).

The decreased maternal insulin sensitivity observed in obese women is associated with foetal overgrowth, in particular of adipose tissue, leading to an increased birth weight, which may be a long-term risk factor for obesity and glucose intolerance in these children (Catalano *et al.*, 2003:1679S). Relating this to energy balance, women with decreased insulin sensitivity have decreased energy expenditure, while women who were more insulin sensitive had higher increases in energy expenditure in early pregnancy (Catalano *et al.*, 2003:1679S), differences which eventually lead to different birth outcomes. Decreased maternal insulin sensitivity in an environment where food is plentiful, and a sedentary lifestyle is typical and may increase the long-term risk for both diabetes and obesity in the woman and her offspring (Catalano *et al.*, 2003:1679S).

Just as favourable modulations in the foetal environment during pregnancy evoke positive consequences that can be temporarily or permanently measured in the offspring, negative modulations in the foetal environment also have the potential to evoke adverse epigenetic changes (Leite *et al.*, 2016:279). Infants of obese mothers have a higher risk of being overweight at 12 months of age when compared to infants of normal-weight mothers (IOM, 2009:6-16). However, it is essential to note that genetic factors are also involved in the relation between maternal obesity and childhood obesity in the offspring (Galtier-Dereure *et al.*, 2000).

The consequences of obesity on maternal and foetal morbidity and mortality should be addressed through appropriate multidisciplinary management (Galtier-Dereure *et al.*, 2000:1246S), providing guidelines for pregnant women aimed at attaining energy balance by monitoring energy expenditure and energy intake. The origin of the obesity epidemic relates to an unhealthy lifestyle – high energy intake and physical inactivity (Guelinckx *et al.*, 2008:140). During pregnancy, energy balance is especially important as it may considerably influence the pregnancy, the delivery, and the health of the mother and the infant in the long term (Guelinckx *et al.*, 2008:140).

2.8. Summary

Energy balance dictates that total energy intake from food equals total energy expenditure as determined by resting metabolic rate, diet-induced thermogenesis, and physical activity. In research, the determination of both energy intake and energy expenditure is hampered by methodological difficulties, especially during pregnancy.

Pregnancy is a dynamic, physiologically complex period where energy intake and energy expenditure differ dramatically from the non-pregnant state. Energy intake tends to increase in order to prevent a negative energy balance due to the increase in energy expenditure during pregnancy. Energy conservation takes place through a decrease in habitual physical activity as pregnancy progresses. The increase in energy intake and a decrease in energy expenditure can lead to detrimental effects such as excessive gestational weight gain. Therefore, various institutions have provided guidelines in terms of physical activity, nutritional habits and weight gain guidelines to optimise health during pregnancy, for both mother and infant.

Birth outcomes include birth weight, birth length, gestational age, head circumference, hip circumference, Apgar score and ponderal index. Although maternal and parental factors influence birth outcomes, physical activity and nutrition during pregnancy can have profound effects. Pregnancy is a complex metabolic interplay between the competing needs of the foetus and those of the mother. Under disturbed energy balance conditions, the outcome will always represent a compromise. This compromise can have long-term effects as underlined by the “foetal origins of adult disease” hypothesis.

As indicated in the chapter, further research is needed with regards to energy balance, body composition and birth outcomes. Research investigating free-living objective measurements of energy expenditure, in conjunction with energy intake during pregnancy is necessary to elucidate on the relationship between energy balance and birth outcomes. However, longitudinal studies incorporating multiple measurement periods and objective measurements of energy expenditure during pregnancy are limited. Understanding how energy balance relates to body compositional changes during pregnancy and birth outcomes will assist in low-to-middle-income country-specific guidelines for gestational weight gain, recommendations for dietary intake, as well as physical activity guidelines.

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CHAPTER 3: LONGITUDINAL CHANGES IN ENERGY BALANCE DURING PREGNANCY IN SOUTH AFRICAN WOMEN FROM THE TLOKWE MUNICIPAL AREA

Title page:

Title:

Longitudinal changes in energy balance during pregnancy in South African women from the Tlokwe Municipal area

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Keywords:

Energy intake, energy expenditure, energy balance, pregnancy, gestational weight gain

Manuscript submitted to *BMC Pregnancy and Childbirth* [Impact factor: 2.413]

LONGITUDINAL CHANGES IN ENERGY BALANCE DURING PREGNANCY IN SOUTH AFRICAN WOMEN FROM THE TLOKWE MUNICIPAL AREA

Abstract

Background: Energy balance in the era of obesity contributes to challenges in healthy weight maintenance. This study aims to determine the changes in energy intake and expenditure from the first to the third trimester of pregnancy in women from the Tlokwe Municipal area.

Methods: We followed a longitudinal observational design to measure healthy pregnant women in the first (9–12 weeks), second (20–22 weeks), and third trimester (28–32 weeks). A validated, semi-quantitative food frequency questionnaire determined energy and macronutrient intakes. Energy expenditure was calculated from resting energy expenditure, as measured by indirect calorimetry (FitMate®), whereas activity energy expenditure was measured by combining heart rate and accelerometry (ActiHeart®). Energy balance was calculated as the difference between energy expenditure and energy intake. A mixed-model analysis was performed to determine significant differences between energy expenditure and intake during pregnancy.

Results: Energy intake increased from the first (8841 ± 3456 kJ/day) to the second trimester (9134 ± 3046 kJ/day) and declined in the third trimester of pregnancy (8171 ± 3017 kJ/day). A negative energy balance was found during the first (-1374 ± 4548 kJ/day) and third trimesters (-1331 ± 3734 kJ/day), whereas a minor positive energy balance was observed in the second trimester (380 ± 14212 kJ/day). Significant differences in resting energy expenditure between the second and third, as well as the first and third trimesters, were shown. Changes in activity energy expenditure throughout pregnancy showed practical significance between the first and third trimesters.

Conclusions: Energy intake and expenditure during pregnancy did not differ. The additional energy expenditure in the third trimester could be attributed to resting energy expenditure and a decrease in activity energy expenditure.

Keywords: Energy intake, energy expenditure, energy balance, pregnancy, gestational weight gain

LONGITUDINAL CHANGES IN ENERGY BALANCE DURING PREGNANCY IN SOUTH AFRICAN WOMEN FROM THE TLOKWE MUNICIPAL AREA

Background

Energy requirements during pregnancy are equal to the energy intake from food that counterbalances energy expenditure when the woman has a body composition and physical activity level consistent with good health [1, 2]. The primary energy requirements of pregnancy provide a means for adequate maternal weight gain in order to ensure the growth of the fetus, placenta, and associated maternal tissues [2, 3]. Secondary energy requirements must allow for increased metabolic demands in addition to the energy necessary to maintain adequate maternal weight, body composition, and physical activity throughout gestation, as well as providing energy stores to assist in lactation after delivery [2, 3]. The additional energy required for pregnancy is estimated to be negligible during the first trimester, 1646 kJ/day in the second trimester, and 2092 kJ/day in the third trimester [4]. By balancing energy intake with energy requirements for fetal growth and activity, energy balance will be reached where energy intake equals energy expenditure [2]. Energy balance during pregnancy can be achieved by various methods, including decreasing resting energy expenditure, mobilizing maternal fat stores, decreasing physical activity, or increasing energy intake by increasing food intake [3, 5–8].

From a systematic review, it was found that in low-to-middle-income countries, energy intake during pregnancy was 8971 ± 1034 kJ/day, with the authors reporting a significantly higher energy intake in the third trimester compared to the first trimester [3]. However, in another study, it was found that healthy pregnancies can be achieved without significant increases in energy intake [9]. Women eat significantly more than is required to meet the energy requirements for a healthy pregnancy and therefore gain, on average, excess weight of more than 12 kg [10]. Excessive energy intake that contributes to excessive weight gain may increase the risk of developing pregnancy-induced hypertension [11] and increase the risk of cesarean birth, macrosomia [12], postpartum weight retention and gestational diabetes [13]. Therefore, the belief that increasing dietary energy intake will lead to an improved pregnancy outcome has no evidence-base [3, 14]. Energy intake guidelines should, therefore, be individually adjusted to meet variations in basal metabolic rate, body composition before and during pregnancy, gestational weight gain, and physical activity [15].

In conjunction with energy intake, maternal macronutrients (carbohydrates, fat, and protein) influence fetal growth [3,16,17]. The recommended percentage energy distribution of macronutrients during pregnancy is similar to that for healthy women, with the assumption that dietary energy intake is sufficient to maintain current body weight [3, 18]. Besides, the dietary intake of pregnant women does not align with country-specific energy and macronutrient recommendations [3]. More specifically, total fat and saturated fat intake were generally higher than the recommended guidelines, while carbohydrate and poly-unsaturated fatty acid intake were lower than recommended [3].

During pregnancy, total energy expenditure increases due to the energy required for fetal growth, development of the placenta, and various maternal tissues, as well as changes in maternal metabolism and the increase of energy expended during movement and activities of daily living resulting from weight gain (1,2,9,19)]. Total energy expenditure consists of basal metabolic rate, dietary-induced thermogenesis, and energy expended during daily living activities and physical activity [2].

Basal metabolic rate – the primary component (60%) of total energy expenditure – refers to the lowest level of energy expended at rest [20]. Basal metabolic rate tends to increase during pregnancy due to increased tissue mass, and thus increased energy cost for maintenance [1, 9, 21]. Increases in both total energy expenditure and resting energy expenditure are more pronounced in the second and third trimesters [1, 21]. According to Butte & King [1], there is, on average, an increase in the basal metabolic rate of 4.5% for the first, 10.8% for the second and 24.0% for the third trimesters, respectively.

Diet-induced thermogenesis is the energy required to digest and assimilate food and is considered to be small – about 5–10% of total energy expenditure [8]. However, while little scope exists for energy savings concerning diet-induced thermogenesis during pregnancy, there is considerable scope for adaptations in basal metabolism [22].

Any changes that occur in physical activity levels during pregnancy will have important implications for maternal energy requirements [23]. Energy expended during physical activity or activity energy expenditure refers to any energy expended above resting the level due to bodily movement [24]. Activity energy expenditure contributes to about 25–30% of total energy expenditure [25] in a developed world context. Energy expended during physical activity tends to decline during pregnancy due to decreases in habitual physical activity [1, 26–28], which are likely due to minor discomforts such as leg cramps, swelling, fatigue, shortness of breath, difficulties in movement due to weight gain, and perceptions that physical activity might pose risks for the fetus [29, 30]. Physical activity may be reduced during pregnancy by selecting less demanding activities or decreasing the pace of activities [19].

Broad variations in energy requirements during pregnancy exist between well-nourished women in high-income countries and women from low-to-middle-income societies, where the availability of nutritious foods is limited [1, 2, 6, 13]. Special consideration should be given to women with low and high Body

Mass Index (BMI) as energy adaptations or responses to pregnancy may not reflect optimal nutritional conditions [4].

Underweight (BMI < 18.8 kg/m^2) Gambian women living under limited food supply constraints and who perform obligatory intense physical activity reduced their resting energy expenditure to allow the delivery of a viable infant who may or may not be small for gestational age, depending on the severity of the energy imbalance [5]. Normal-weight women in low-to-middle-income countries with unlimited food availability tend to conserve energy by reducing physical activity [5, 28]. However, this is not always the case, since hormonal changes facilitate fat deposition, and due to the non-restrictive energy supply, these women tend to gain additional fat stores [5]. With regards to overweight women (BMI > 25 kg/m^2) in high-income countries with free access to food, ample energy reserves are present at conception to protect fetal growth. There is, therefore, no need to accumulate fat [5, 19].

The possibility to offset the potential for further increases in energy-storing means that the basal metabolic rate in overweight and obese women increases [5, 31]. However, if excessive energy storage occurs, despite increases in the basal metabolic rate,excessive weight gain can be detrimental for both mother and infant [5, 17]. Promoting methods to increase energy expenditure in overweight pregnant women can be extremely valuable in the promotion of energy balance and good pregnancy outcomes by reducing excessive weight gain [17, 32].

In South Africa, the prevalence of obesity, especially among women, has increased due to urbanization, increased wealth, increased dietary intake, and decreased physical activity [33]. Furthermore, cultural factors shape South African (SA) women’s eating habits, such as overeating at social gatherings where food is abundant, associating particular foods with social status, being more accepting of being overweight, and relating thinness to illness and HIV/AIDS [34]. It was found that black women living in urban towns in South Africa have a diverse eating pattern, which leads to the consumption of an energy-dense diet that is high in protein and fat [35]. Another study from non-pregnant SA women found total energy expenditure to be lower in black than in white women, due to the lower measured activity energy expenditure and smaller fat-free mass in black women [36]. Preventing excessive weight gain and treating obesity in young black women by propagating a healthy lifestyle [37] is essential during the reproductive period.

Energy requirements during pregnancy should be derived based on healthy populations with favorable outcomes [1, 4]. As stated by Löf [19], if the energy expended on physical activity is unknown, pregnant women may be encouraged to increase their energy intake above the required levels, potentially leading to an increased risk of excessive weight gain. Both sides of the energy balance equation – energy intake and expenditure – should be accounted for in relation to gestational weight gain and birth weight [3,38]. This paper, therefore, aims to determine the changes that occur in energy intake and expenditure from the first to the third trimester of pregnancy in women from the Tlokwe Municipal area of South Africa. It was hypothesized that both energy intake and energy expenditure would increase significantly from the first to the third trimester of pregnancy in women from the Tlokwe Municipal area of South Africa.

The benefits of the study include objective measurements of energy expenditure in combination with energy intake, which would lead to a more accurate determination of energy balance. If energy imbalances occur, corrective measurements can be taken through nutritional and physical activity guidelines during pregnancy.

Methods

Research design

A longitudinal observational cohort study design was followed within the longitudinal Habitual Activity Patterns during PregnancY (HAPPY)-study. The study aimed to determine the longitudinal changes in energy intake and energy expenditure from the first to the third trimester of pregnancy. Women were measured in their first (9-14 weeks), second (20-22 weeks) and third trimesters (28-32 weeks) of pregnancy. These measurements were purposefully aligned to the recommended sonar measurements that are routinely performed by gynecologists. The setting for the study was in the Tlokwe Municipality of the North-West Province, South Africa.

Participants

The study recruited 41 pregnant women. Participants were recruited using advertisements placed in the local press and the consulting rooms of local gynecologists and clinics in the Tlokwe Municipality of Potchefstroom, North West Province, South Africa. Participants were included in the study based on the following criteria: healthy pregnant women from any ethnic background, over 18 years of age, and in their first trimester of pregnancy (9-14 weeks of gestation). Participants were excluded from the survey if they were mentally disabled or had physical limitations. A health screen was performed about risk factors for physical activity during pregnancy and for cardiovascular disease to determine whether participants were included or excluded in the study, as indicated by the American College of Sports Medicine (39). The participants who indicated an interest in the study were asked to give their informed consent to participate in the study by signing an informed consent form. Ethical approval, complying with the Declaration of Helsinki, was obtained from the Ethics Committee of the North-West University (NWU-00044-10-A1).

Demographic and pregnancy-related information

During the first measurement, a demographic questionnaire was used to obtain information regarding participants' ethnicity and age. This questionnaire was compiled specifically for the current study. Additional questions on the questionnaire concerning pregnancy-related data were collected, which included the following: recall pre-pregnancy weight (kg), weeks of pregnancy, type of pregnancy (single, twin or triplets), expected date of birth, and the number of previous pregnancies.

Energy intake measurements

At every measurement point, each participant's dietary intake was measured using a semi-quantitative food frequency questionnaire, which determined the nutrient intake of the participant in every trimester [40]. The data was analyzed using the Food-Finder 4 program (Medical Research Council, Tygerberg, South Africa). Energy intake (kJ/day), as well as carbohydrate, fat, and protein intake (g/day), was calculated. Fat intake was further divided into saturated-, mono-, and poly-unsaturated fatty acids (g/day) intake.

Energy expenditure measurements

Total energy expenditure was calculated as the sum of resting energy expenditure, diet-induced thermogenesis, and activity energy expenditure.

Resting energy expenditure

Resting energy expenditure was determined by employing indirect calorimetry with the FitMate^{TM} (Cosmed, Italy). The FitMate^{TM} is a metabolic analyzer designed for the measurement of oxygen consumption and energy expenditure during rest and exercise [41]. The FitMate^{TM} gives accurate and reproducible oxygen consumption and resting energy expenditure measurements for female adults ($r = 0.97$, $p = 0.066$) [41]. With the FitMate analyzer, ventilation is measured by a turbine flow meter, and analyses of the fraction of oxygen in expired gases are measured through a galvanic fuel cell oxygen sensor [41]. The FitMate^{TM} uses standard metabolic formulas to calculate oxygen consumption (measured in ml/min), while energy expenditure (measured in kJ/day) is calculated using a fixed respiratory quotient of 0.85 [41].

Participants were requested not to perform any exercise during the 24 hours preceding the resting energy expenditure measurement. They were also requested to be fasting for at least 10 hours before the last-mentioned measurement. The FitMate^{TM} was calibrated before each participant was subjected to the measurement. During the test, participants were requested to remain awake for the entire testing period while they breathed through an anti-bacterial filter for 15 minutes after a 10-minute resting period. During that time, the fraction of oxygen in expired gases was quantified in order to determine resting energy expenditure. The first minute of the measurement was discarded as it was considered to be the stabilization period for breathing. Resting energy expenditure was then divided by weight and presented in kJ/kg.

Activity energy expenditure

Activity energy expenditure was determined using an objective assessment based on combined accelerometry (movement counts) and heart rate response (ActiHeart®, CamNtech Ltd., Cambridge, UK). The device is a waterproof, self-contained logging device that allows physical activity to be measured synchronously with the heart rate [42]. The ActiHeart® reports a simulated heart rate within a beat per minute and above 30 beats per minute, which is comparable to heart rate monitors [42, 43]. 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 device to measure physical activity were scientifically validated ($p = 0.9$) in healthy pregnant women in Switzerland [44].

At every measurement interval in the study, activity energy expenditure was measured for seven days. The following parameters were extracted from the data: activity energy expenditure, diet-induced thermogenesis, and total energy expenditure. The activity energy expenditure, diet-induced thermogenesis, and total energy expenditure measurements were all expressed in kJ/kg/day.

For the ActiHeart® to calculate the most accurate activity energy expenditure, resting energy expenditure, was determined and an eight-minute calibration step test with a ramp protocol on a step box (21.5 cm in height) was conducted. The resting energy expenditure measurement and the step test were administered at every measurement interval. This individual calibration step test develops a heart rate and a VO_2 regression line specifically for pregnant women and takes into account the physiological changes that the women experience during pregnancy [44].

Before the measurements, ECG pads were placed on the chest, forming an arc across the heart. Fifteen minutes were given to determine a good signal, ensuring accurate measurement of the heart rate for the following seven consecutive days. When a sound signal was established, the eight-minute calibration step test with the ActiHeart® for activity energy expenditure calculation was performed. Participants were able to stop at any time during the step test if they experienced any discomfort or fatigue. Two minutes of quiet sitting was required after the step test to determine the participants' recovery heart rates.

As soon as the step test information was downloaded using the accompanying software, the ActiHeart® was set to the "Advanced Energy Expenditure" mode. Participants wore the device for seven consecutive days. The ActiHeart® was programmed to measure energy expenditure using 30-second epochs (counts per minute). The women were advised to take the monitor off when they were bathing or showering and to put it on again immediately afterward. The device was removed after seven days, and the data captured was downloaded using the accompanying software (Version 2.132, Cambridge Neurotechnology Ltd., Cambridge, UK). Participants were encouraged to wear the ActiHeart® for seven days. If the participants did not adhere to this recommendation, the data were trimmed, and only the days on which measurements were taken were included. For accurate results, participants should have worn the ActiHeart® for at least four days, of which one of the days should have been a day over a weekend [45].

Diet-induced thermogenesis

Diet-induced thermogenesis was estimated by the ActiHeart® device, which is factored in as a constant of 10% of the total energy expenditure [45].

Energy balance

In the study, energy balance was determined by applying the following equation:

$$\text{Energy Balance} = \text{Total Energy Intake} - \text{Total Energy Expenditure}$$

$$\mathbf{E_B = E_I - (REE + DIT + AEE)}$$

E_B = Energy balance

E_I = Energy intake *as measured via a semi-quantitative food frequency questionnaire (kJ/day)*

REE *= Resting energy expenditure as determined by the Fitmate® (kJ/day)*

DIT *= Diet-induced thermogenesis as estimated by the ActiHeart® (kJ/day)*

AEE *= Activity energy expenditure as determined by the ActiHeart® (kJ/day)*

Gestational weight gain

Gestational weight gain, measured by an electronic Scale (Beurer, Germany), was computed for each trimester by subtracting the measured weight of the previous trimester from the weight measured in the specific trimester. Gestational weight gain (kg) in the first trimester was calculated by subtracting self-reported pre-pregnancy weight from the measured weight in the first trimester.

Statistical analysis of data

Statistical analyses were performed with the SPSS software package, SPSS version 25 (IBM Corp, NY). The descriptive statistics of the baseline characteristics were determined while reporting means and standard deviations. Descriptive statistics were also performed on energy intake and energy expenditure variables. Body Mass Index (BMI) was categorized into underweight, normal, overweight, and obese classifications according to the ACSM scale [24].

Changes within energy intake and expenditure throughout pregnancy were analyzed using mixed-model analysis, a Bonferroni posthoc test, and an unstructured covariance structure. The dependent variables, energy intake (kJ) and energy expenditure (kJ), from first to the third trimester of pregnancy were included in the analysis. For it to be statistically significant, the change between energy intake and energy expenditure from pre-pregnancy to three months postpartum was determined by setting the p-value lower than 0.05. For practical significance (Cohen's d), 0.2 can be considered as a 'small' effect size, 0.5 representing a 'medium' effect size and 0.8 a 'large' effect size.

Results

The demographic information of the participants is presented in Table 1. The average age of the participants was approximately 28 (± 5) years. There was an equal distribution in the ethnicity of the participants. Gestational weight equated 3.23 ± 3.61 kg in the first trimester, 5.18 ± 5.37 kg in the second trimester, and 4.90 ± 3.10 kg in the third trimester.

Energy intake and expenditure variables are presented in Table 2. Energy intake throughout pregnancy did not differ significantly. There was a small increase in energy intake from the first trimester (8841 ± 3456 kJ/day) to the second trimester (9134 ± 3046 kJ/day), whereas energy intake declined in the third trimester of pregnancy (8171 ± 3017 kJ/day). Macronutrient intake is also presented in Table 2. Carbohydrate intake was calculated as 256.4 ± 99.9 g/day, 264.7 ± 86.2 g/day, and 244.5 ± 137.7 g/day in the first, second, and third trimesters of pregnancy, respectively. Similar to the reported trends regarding energy and carbohydrate intake, fat intake increased from the first trimester (71.5 ± 33.0 g/day) to the second trimester (77.9 ± 34.6 g/day) and declined in the third trimester (67.6 ± 24.0 g/day). Protein intake decreased throughout pregnancy, from 81.7 ± 44.1 g/day in the first trimester, to 79.2 ± 32.8 g/day in the second trimester and 67.7 ± 20.8 g/day in the third trimester.

Table 1: Demographic and anthropometric information of pregnant women in their first trimester as well as pregnancy-related information

	N	Mean	SD
Age (years)	72	28	5
Pre-pregnancy weight (kg)	72	63	13
BMI (kg/m^2)	41	25.48	5.10
Total weight gain over pregnancy (kg)*	12	13.50	5.59
Underweight / Normal / Overweight and Obese (%)**			
Underweight (BMI < 18.5 kg/m^2)	2	5	
Normal (BMI = 18.5–24.9)	20	49	
Overweight and Obese (BMI ≥ 25.0)	19	46	
Ethnicity (%)			
White	29	40	
Black	23	32	
Mixed race	20	28	
Number of previous pregnancies (%)			
0	29	40	
1	29	40	
2	12	17	
3	2	3	
Type of pregnancy (%)			
Single	46	98	
Twin	1	2	

N = sample size, SD = Standard deviation, kg = kilogram, BMI = Body Mass Index, kg/m^2 = kilogram per meter squared, % = percentage,

***** Calculated as weight (3rd trimester) - pre-pregnancy weight (self-reported)

** Categorized according to ACSM (2018)

Results from the mixed-model analysis are presented in Table 2. No statistically significant changes were observed in any of the variables. However, a medium practical significant difference (effect size of Cohen's d) was observed in the change of resting energy expenditure from the first to the third trimester (d = 0.44) and the second to the third trimester (d = 0.45). A medium practical significant (effect size of Cohen's d) difference was observed in the change of activity energy expenditure from the first to the third trimesters (d = 0.47).

Table 2: Energy intake, energy expenditure and gestational weight gain of pregnant women in each trimester

Variable	1st trimester		2nd trimester		3rd trimester		Mixed-model analysis	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**F-value**	***p***
Energy intake (kJ/day)	8841	3456	9134	3046	8171	8171	0.420	0.661
Carbohydrate intake (g/day)	256.4	99.9	264.7	86.2	244.5	137.7	0.173	0.8452
Fat intake (g/day)	71.5	33.0	77.9	34.6	67.6	24.0	0.684	0.512
Saturated fatty acids (g/day)	26.9	13.1	32.2	7.1	24.3	7.1	2.995	0.098
Mono-unsaturated fatty acids (g/day)	27.5	16.2	30.6	13.3	26.4	9.3	0.281	0.762
Poly-unsaturated fatty acids (g/day)	18.2	12.3	19.1	8.3	17.5	11.4	0.190	0.883
Protein intake (g/day)	81.7	44.1	79.2	32.8	67.7	20.8	0.607	0.552
Energy expenditure (kJ/day)	10234	2314	9523	2732	9535	2326	0.184	0.314
Resting energy expenditure (kJ/day)	5552	1259	5502	1456	6012	1845	2.829	0.066
Activity energy expenditure (kJ/day)	3519	1967	2941	1958	2423	1573	2.360	0.104
Diet-induced thermogenesis (kJ/day)	1059	234	1021	285	987	193	0.928	0.402
Energy balance (kJ/day)	-1377	4548	381	4213	-1331	3732	1.665	0.205
Gestational weight gain (kg)	3.23	3.61	5.18	5.37	4.90	3.10		

SD = Standard deviation, F = F statistic, *p* = statistical significance, kJ/day = kilojoule per day, g/day = gram per day, kg = kilogram.

Changes in energy expenditure, according to BMI classifications per trimester of pregnancy, are presented as a graph in Figure 1. It was found that overweight women's total energy expenditure exceeded that of normal-weight women in all three trimesters. Resting energy expenditure increased from the first trimester (6116 kJ/day) to the third trimester (7669 kJ/day) in overweight women, while normal-weight women's resting energy expenditure decreased slightly from the first trimester (5019 kJ/day) to the second trimester (4991 kJ/day), while increasing in the third trimester (6779 kJ/day). Activity energy expenditure decreased considerably in overweight women from the first trimester (3929 kJ/day) to the third trimester (2056 kJ/day), while normal-weight women's activity energy expenditure increased from the first trimester (2965 kJ/day) to the second trimester (3362 kJ/day). After that it decreased to the third trimester (2056 kJ/day).

The energy balance during the first (-1375 ± 4548 kJ/day) and the third trimesters (-1331 ± 3734 kJ/day) were negative, while a minor positive energy balance was observed in the second trimester (380 ± 4212 kJ/day).

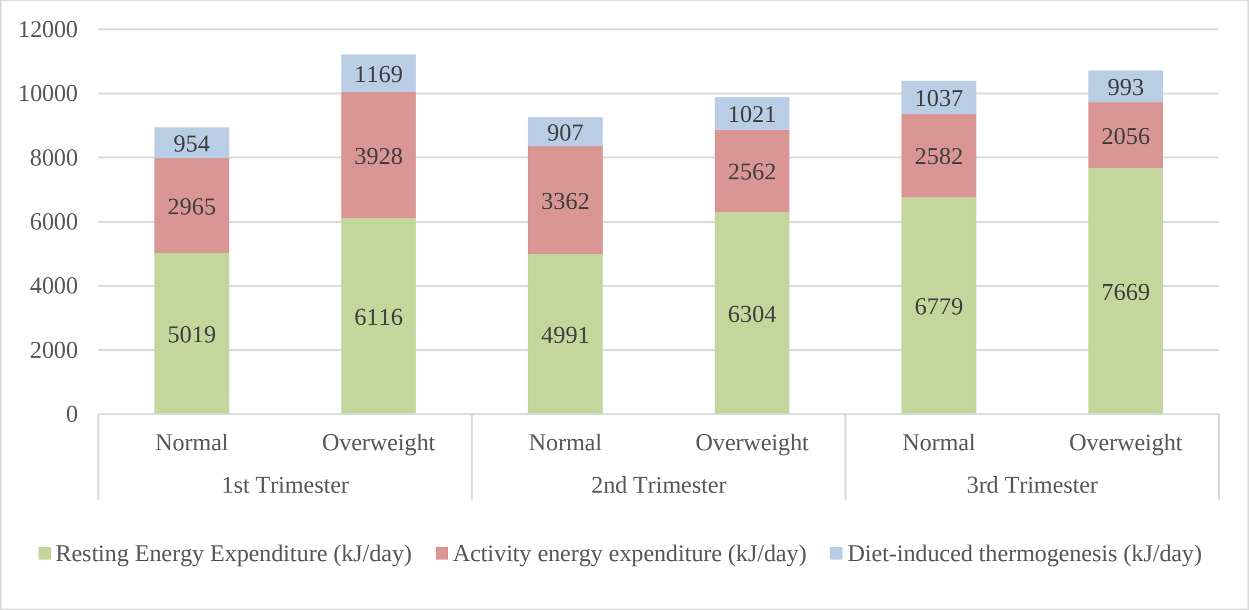

Figure 1: Change in energy expenditure from the first to the third trimester of pregnancy categorized in normal and overweight pregnant women

Discussion

The aim was to determine the longitudinal changes that occur in energy intake and expenditure throughout a pregnancy. As a characteristic of pregnant women, high variability is seen in energy intake and energy expenditure, and thus, in pregnant women's energy costs [4]. As such, recommendations in terms of energy intake and habitual physical activity patterns should be population-specific and determined by socio-economic and cultural factors that are specific to the given population [4]. The participants in the current study were representative of the South African population in terms of ethnicity.

Energy intake

In this study, no significant changes were observed relating to energy intake throughout pregnancy. Similarly, other studies reported non-significant increases in energy intake [1, 3, 46]. As per this study, the participants presented with a negative energy balance in the first and third trimesters of their pregnancies, which corresponds to previous studies [3, 46]. Despite the negative energy balance, an increase in weight was still observed. The findings are similar to those reported by a systematic review that found that both women from high- and low-to-middle-income countries appear to only consume a quarter of the theoretical requirement for additional energy, despite experiencing uniquely rapid weight gain [3].

Macronutrient intake

No statistically significant changes in macronutrient intake per trimester of pregnancy were observed in this study. However, in a systematic review of high-income countries, it was found that macronutrient intake increased during each trimester of pregnancy [47]. In contrast, carbohydrate intake increased from the first to the second trimester even though a decrease was found from the second to the third trimester of pregnancy in this cohort. Similar to carbohydrate intake, this cohort’s fat intake increased from the first to the second trimester and decreased from the second to the third trimester of pregnancy. Protein intake decreased from the first to the third trimester in this cohort. The difference in macronutrient intake could be attributed to the differences in high- and low-to-middle-income countries, wherein low-to-middle-income countries the availability of additional food outside the average intake is hampered by poverty.

Resting energy expenditure

Dietary insufficiencies in undernourished women might nonetheless be diminished by energy-sparing strategies to protect fetal growth [31]. One of the energy-sparing adaptations that occur is a decrease in resting energy expenditure, which is also known as metabolic “flexibility” in the resting energy expenditure during pregnancy [31]. In this cohort, resting energy expenditure declined from the first to the second trimester, yet increased in the third trimester. It was also found that the increase in resting energy expenditure in the third trimester is significantly correlated with higher body mass during pregnancy [25]. Although no statistically significant changes were observed in the change of resting energy expenditure throughout each trimester of pregnancy, a medium practically significant difference was observed between the first and third trimester, as well as the second and third trimester. Again, this medium practical significant difference emphasizes the contribution of resting energy expenditure to total energy expenditure. In contrast, the contribution of activity energy expenditure tends to be relatively small and constant from one person to another [25].

Activity energy expenditure

Another energy-sparing adaptation is a decrease in energy expenditure through physical activity [23, 25]. Despite non-statistically significant differences between activity energy expenditure throughout pregnancy, a practically significant decline of activity energy expenditure was observed from the first to the third trimester. A non-significant decrease in activity energy expenditure during pregnancy was also found, which, by other studies, proves that physical activity declines during pregnancy [25, 26, 48–53]. A decline in activity energy expenditure can be accounted for in so far as women shift toward less intense and more comfortable modes of activity, probably in order to avoid the risk of maternal and fetal injuries as well as to accommodate an increase in body weight.

Energy expenditure of normal versus overweight/obese women

Differences relating to energy expenditure variables in normal versus overweight or obese women vary [4]. In agreement with previous findings [4], the total energy expenditure of this study's overweight or obese cohort was higher than that of the normal-weight women. The increase in total energy expenditure can primarily be ascribed to the higher increase in resting energy expenditure in overweight or obese women as compared to the normal-weight women [4, 25, 54]. Furthermore, activity energy expenditure decreased more noticeably in overweight or obese women from the first to the third trimester, when compared to normal-weight women. Finally, it was found that sedentary SA women tended to be above the recommended weight-gain ranges; however, the study found physical activity to increase as the pregnancy progressed [55].

Strengths and limitations of the study

The strengths of the study include the measurement of both dietary energy and macronutrient intake in conjunction with energy expenditure data that has been captured by an objectively measured heart rate accelerometer (ActiHeart®). When examining energy balance, data should include both energy intake and energy expenditure data [3, 38].

The findings of this study should, however, be interpreted with some limitations in mind, such as the reliance on self-reported data given the use of the semi-quantitative Food Frequency Questionnaire. Energy intake underreporting amongst pregnant women should be acknowledged in dietary research [56]. Furthermore, due to the convenience sampling method applied, more active women might have been more interested in participating in the study. Activity energy expenditure data was captured during a five-day period, which could have led to changes in the participants' normal behavior during the study period. Another limitation was the use of estimates of body composition. Lastly, compliance with the longitudinal design in the study was weak, especially of women from low socio-economic areas, which limited the sample size of the study.

Conclusion

In conclusion, no statistically significant changes were observed in energy intake and expenditure during pregnancy in women from the Tlokwe Municipality area. The additional energy expenditure in the third trimester, mostly attributed to resting energy expenditure, was partly compensated for by the decrease in activity energy expenditure. Energy-sparing adaptations may be more critical in balancing the energy budget of pregnant women in populations where restricted food intakes and demands of physical activity are higher compared to pregnant women form high-income countries. It was found that overweight and obese pregnant women had higher energy expenditure compared to normal-weight pregnant women, primarily due to their higher resting energy expenditure. However, their activity energy expenditure decreased more prominently when compared to normal-weight women. Variability in responses to the energy requirements of pregnancy is essential in providing a healthy pregnancy outcome for both mother and infant. Recommendations for future research include the study of how variations in energy balance influence gestational weight gain and fetal growth.

List of abbreviations

ACSM = American College of Sports Medicine
AEE = Active Energy Expenditure
BMI = Body Mass Index
cm = centimeter
DIT = Diet-Induced Thermogenesis
E_B = Energy balance
E_I = Energy intake
g/day = gram per day
HAPPY = Habitual Activity Patterns during PregnancY
kg = kilogram
kg/m^2 = kilogram per square meter
kJ/day = kilojoule per day
kJ/kg/day = kilojoule per kilogram per day
N = sample size
p = significance level
r = correlation coefficient
REE = Resting Energy Expenditure
SA = South Africa
SD = Standard Deviation
VO_2 = oxygen consumption

Declaration

Ethics approval and consent to participate

The participants who indicated an interest in the study were asked to give their informed consent to participate in the study by signing an informed consent form. Ethical approval, complying with the Declaration of Helsinki, was obtained from the Ethics Committee of the North-West University (NWU-00044-10-A1).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

Financial funding from the SA Sugar Association has not resulted in a conflict of interest. The views and opinions expressed are those of the authors and do not necessarily reflect the official policy or position of the SA Sugar Association. Therefore, the authors declare no competing interest.

Funding

The research was funded by the National Research Foundation South African-Swiss Joint Programme, award number UID 78606, and the South African Sugar Association, project no 224. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors, and therefore the NRF does not accept liability regarding it.

Authors' contributions

SJ and YS conceived and designed the study. AF is a Ph.D. candidate and, together with SJ, collected the data and performed the analysis. AF drafted the manuscript. SJ and YS critically reviewed the manuscript. All authors read and approved the final manuscript.

Acknowledgments

The authors would like to acknowledge the North-West Department of Health, the nurses at the relevant clinics, participating gynecologists’ and participants in this study for their time and support.

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CHAPTER 4: LONGITUDINAL CHANGES IN RESTING ENERGY EXPENDITURE DURING PREGNANCY ASSOCIATED WITH CHANGES IN BODY COMPOSITION

Title page

Running head:

Resting energy expenditure and body composition during pregnancy

Manuscript Title:

Longitudinal changes in resting energy expenditure during pregnancy associated with changes in body composition

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Keywords:

Body composition, energy intake and energy expenditure, gestational weight gain, pregnancy, resting energy rate

Manuscript submitted to *Scientific reports* [Impact factor: 4.011]

LONGITUDINAL CHANGES IN RESTING ENERGY EXPENDITURE DURING PREGNANCY ASSOCIATED WITH CHANGES IN BODY COMPOSITION

Abstract

Introduction: Resting energy expenditure (REE) may be essential in addressing obesity during pregnancy. This study aims to examine the relationship between changes in REE and changes in body composition during pregnancy.

Methods: Data from a longitudinal observational study-design - the Habitual Activity Patterns during PregnancY (HAPPY) study was used. Height, weight, and fat mass, calculated from skinfolds, from 41 women were measured in the first, second, and third trimester of pregnancy. REE was measured using indirect calorimetry (Fitmate^{TM}). We determined the relationship between longitudinal changes in REE and changes in body composition with regression analysis.

Results: Fat mass increased from the first- (18.6 ± 8.8 kg), to the second- (20.7 ± 9.3 kg) and third trimester (22.36 ±8.38 kg). Weight gain in the first trimester was 3.2 ± 3.6 kg, 5.2 ± 5.4 kg in the second trimester, and 4.9 ± 3.1 kg in the third trimester. When adjusted for weight, REE equated 82.2 kJ/kg/day in the first trimester, 74.2 kJ/kg/day in the second trimester, and 77.7 kJ/kg/day in the third trimester. Change in body composition variables significantly predicted the change in adjusted REE from the second to the third trimester ($R^2 = 0.930$, $p = 0.000$), but not from the first to second trimester ($R^2 = 0.222$, $p = 0.373$).

Conclusion: Changes in body composition variables explain the variability of REE during late pregnancy. Future studies are needed in order to estimate the minimal clinically important differences in REE for the trimesters of pregnancy in order to tailor total energy intake and physical activity level recommendations accordingly.

Keywords: Resting energy expenditure, body composition, pregnancy, energy intake, energy expenditure

Significance: The high prevalence of obesity in pregnant women is associated with many adverse pregnancy outcomes. This study explores the relationship between changes in body composition and resting energy expenditure during pregnancy. The quantification could improve individualized recommendations related to dietary intake and physical activity during pregnancy, which can mitigate excess gestational weight gain and provide benefits to pregnancy outcome.

Introduction

With the growing prevalence of obesity in pregnant women and associated adverse pregnancy outcomes, changes in body composition represent essentially modifiable risk factors[1,2,3,4,5]. A healthy lifestyle during pregnancy, incorporating the limitation of excess energy intake and the augmentation of energy expenditure using physical activity, has been proposed to mitigate excess gestational weight gain and provide benefits in terms of pregnancy outcomes[6]. However, energy expenditure is not only composed of physical activity (about 20% in sedentary women) but also of resting energy expenditure (REE), which amounts to about 60% of total energy expenditure during pregnancy[7]. Several researchers recommend that further research should be conducted regarding REE in order to develop an effective means of limiting excessive weight gain and fat mass accrual during pregnancy[3,8,9]. Resting energy expenditure is defined as the minimum level of energy required in order to sustain vital functions in the waking state[10]. Resting energy expenditure is an important variable related to changes in gestational weight gain and fat mass accrual during pregnancy[3].

Resting energy expenditure increases as pregnancy progress in a non-linear fashion[3,8,11–13]. Gestational weight gain is a principal determinant of incremental energy needs during pregnancy since it determines not only energy storage but also the increase in REE and total energy expenditure, representing the energy costs of moving a larger, heavier body[13,14]. Melzer *et al.*[15] found REE to be significantly correlated with body weight ($r = 0.84$, $p < 0.001$). In addition to weight gain during pregnancy, REE also shows a relationship with other body composition variables such as fat mass and fat-free mass[9,16].

The increased total energy expenditure during pregnancy is associated with a cumulative rise in body weight, fat mass, fat-free mass, and REE[17]. Wide variations in total energy expenditure throughout pregnancy lead to a change in gestational weight gain[3]. The Institute of Medicine provides guidelines for gestational weight gain categories according to pre-pregnancy body mass index for optimal pregnancy outcome, the lower the BMI, the higher the weight gain that can be afforded and vice versa[18]. In a Gambian cohort, gestational weight gain was lower than the average weight gain among well-nourished Western women, probably explained by the energy deficit due to low energy intake together with high energy expenditure in this specific cohort[19]. Excessive gestational weight gain above the Institute of Medicine Guidelines may lead to many adverse short and long-term health outcomes for both mother and offspring, such as preeclampsia, a large-for-gestational-age infant, fetal distress, and caesarean delivery[20,21,22].

The prevalence of excessive gestational weight gain has increased[23–26] in parallel with increases in obesity prevalence[27,28]. Deputy *et al.*[23] found 20.9%, 32.0% and 47.2% of women gained low, adequate, and excessive gestational weight, respectively, in a cross-sectional, population-based study on women delivering singleton infants in the United States. According to the Institute of Medicine guidelines[18], the prevalence of excessive gestational weight gain has increased by 31% from 1990 to 2005 in singleton pregnancies among adolescents. Mean gestational weight gain among underweight and normal-weight women was within the recommended range, whereas it was higher in overweight and obese women[18].

Excess gestational weight gain in overweight/obese women is primarily due to increased fat mass and not to fat-free mass[3,18,29]. Gains in fat mass during pregnancy are highly variable[9,18]. Lof *et al.*[13] found significant correlations between REE and fat-free mass, but not between REE and total body fat. REE is lower among women with higher fat mass accrual than among women with fat-free mass accrual[3].

In a South African context, Dugas *et al.*[30] found ethnic differences in total energy expenditure within a non-pregnant cohort. Black women had a lower total energy expenditure compared to white women, as well as a smaller fat-free mass[30]. No differences in REE were found between black and white women after adjusting for differences in body composition[30]. There are minimal data about weight gain patterns of pregnant South African women due to difficulties in data collection throughout pregnancy[31]. Kruger[31] stated that the paucity of data resulted in unclear recommendations for monitoring pregnancy weight gain in South African outpatient clinics.

Given the substantial contribution of maternal REE to total energy expenditure, REE may be an important consideration in understanding variations in body composition[3]. The present research, therefore, aims to determine the relationship between longitudinal changes in REE during pregnancy and body composition in pregnant women of the Tlokwe Municipality area.

Given the high prevalence of excessive gestational weight gain during pregnancy and the risks thereof, research into the relationship between longitudinal changes in REE and body composition may prove useful in adjusting recommendations of nutritional intake and physical activity during pregnancy to promote healthy pregnancy outcomes.

Materials and methods

Research design

A longitudinal observational cohort study-design was followed within the longitudinal Habitual Activity Patterns during PregnancY (HAPPY)-study. Women were measured in their first- (9-14 weeks), second- (20 – 22 weeks) and third trimester (28-32 weeks) of pregnancy.

Participants

We recruited 41 pregnant women using advertisements in the local press and the consulting rooms of local gynaecology and maternal health clinics in the Tlokwe Municipality of Potchefstroom, North West Province, South Africa. Participants were included when they met the following criteria: literate, healthy pregnant women from any ethnic background, over 18 years of age, and in their first trimester of pregnancy (9 – 14 weeks of gestation). Participants were excluded from the study if they presented with a mental handicap or had physical limitations. Participants that indicated an interest in the research were asked to give their informed consent to participate in the research by signing an informed consent form. Ethical approval – complying with the Declaration of Helsinki – has been obtained from the Ethics Committee of the North-West University (NWU-00044-10-A1).

Demographic and pregnancy-related information

All participants completed a demographic questionnaire, compiled primarily for the current study, in order to gather information regarding age and ethnicity. In cases where some participants' home language was neither Afrikaans nor English, a translator (appointed by the clinic) translated the questions of the survey for the participants.

Additional questions regarding pregnancy-related data were collected including the following: pre-pregnancy weight (kg), weeks of pregnancy, type of pregnancy (single, twin, or triplets), expected date of birth, and the number of previous pregnancies. A health screen was performed concerning risk factors for physical activity during pregnancy and for cardiovascular disease based on the American College of Sports Medicine[32] criteria of major signs or symptoms suggestive of cardiovascular, pulmonary, or metabolic disease, as well as the contraindications for exercising when pregnant.

Body composition measurements

At all measurement points, body composition measurement of height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg) were measured using the standard procedures according to the international standards for anthropometric assessment described by the International Society for the Advancement of Kinanthropometry[33]. Weight was measured using an electronic scale (Beurer, Germany); height was measured with a stadiometer. Weight and height were used to calculate BMI, by dividing weight (kg) by the square of height (m). Participants' BMI was classified into underweight (<18.5 kg/m^2), normal (18.5 – 24.9 kg/m^2) and overweight and obese (>25.0 kg/m^2) according to the American College of Sports Medicine[32] guidelines.

Body composition was estimated from three skinfold measurements using a skinfold calliper (Harpenden, England). The sum of the triceps, supra-iliac, and thigh skinfolds to the nearest 0.5 mm was measured in order to calculate the sum of skinfolds. Fat mass was calculated by determining body density from the sum of the three skinfolds[32] and incorporating it into trimester-specific equations of Van Raaij *et al*.[34]. Fat-free mass was calculated by subtracting fat mass from body weight in each of the trimesters.

Gestational weight gain, measured using an electronic scale (Beurer, Germany), was computed for each trimester by subtracting the measured weight of the previous trimester from the weight measured in the specific trimester. Gestational weight gain (kg) in the first trimester was calculated by subtracting self-reported pre-pregnancy weight from measured weight in the first trimester. Gestational weight gain was classified into inadequate (<11.5 kg), adequate (11.5 – 16.0 kg) and excessive (>16.0 kg) according to the Institute of Medicine[18] guidelines.

Resting energy expenditure

Resting energy expenditure was determined through indirect calorimetry with the FitMate^{TM} (Cosmed, Italy). The FitMate^{TM} is a metabolic analyzer designed for the measurement of oxygen consumption and energy expenditure during rest and exercise[35]. Nieman *et al*.[35] concluded that the Fitmate^{TM} gave accurate and reproducible oxygen consumption and REE measurements for female adults. Ventilation is measured by a turbine flow meter, while analyses of the fraction of oxygen in expired gases are measured through a galvanic fuel cell oxygen sensor[35]. Standard metabolic formulas are used by the FitMate^{TM} to calculate oxygen consumption (measured in ml/min) and energy expenditure (measured in kJ/day) is calculated using a fixed respiratory quotient of 0.85[35].

Participants were requested not to perform any exercises during the 24 hours preceding the resting metabolic rate measurement. They were also requested to fast from food omitting water for at least 10 hours before this measurement. Calibration of the FitMate^{TM} was done before each participant’s test. Participants were requested to remain awake for the whole testing period. Participants were invited to rest for 10 minutes (preparation), and then to breathe through an anti-bacterial filter for 15 minutes (REE measurement), during which time the fraction of oxygen in expired gases was quantified in order to determine REE. The first minute of measurement was discarded because it is considered to be a stabilisation period for breathing adaptation to the equipment. REE was then divided by weight and presented in kJ/kg body weight for each participant.

Procedure

All participants in the study were requested to complete an informed consent form once the study protocol had been explained to them. After that, the participants' demographic information was collected. The anthropometric and body composition measurements were taken. The participants were requested to lie on their left side in order to measure their REE and resting blood pressure and heart rate. We used the left lateral position from the first measurement point because the growth of the foetus will usually require the mother to change her horizontal position from the supine to the left side in order to remain comfortable when lying down. The procedure was repeated in each trimester.

Statistical analysis of data

The SPSS ver. 25.0 (IBM, SPSS Inc., Chicago, I11) statistical program was used to determine the demographic characteristics of the participants through descriptive statistics by reporting means and standard deviation. Anthropometric, body composition variables and REE were reported for each trimester. Departure from normality was evaluated by using the Shapiro-Wilk test and Quantile-Quantile plots.

A repeated-measures ANOVA was performed in order to compare the means of the body composition variables and REE measured in each trimester. Bonferroni posthoc tests were performed to determine between which trimester the differences in the variables were observed. Pearson's correlations were computed to determine whether the maternal change (Δ) in body composition variables (height, weight, fat mass, fat-free mass, the sum of skinfolds and gestational weight in each trimester) was associated with changes in REE. Correlations are reported as r. A multiple regression analysis was then performed to determine the relationship between the independent variables (Δ weight, Δ BMI, Δ fat mass, Δ fat-free mass, Δ sum of the skinfolds and gestational weight gain) in each trimester and the dependent variable Δ REE in each trimester. A *p*-value of less than 0.05 was considered statistically significant for all analyses. All analyses were adjusted in terms of age and ethnicity.

Results

Demographic information concerning the participants in their first trimester is presented in Table 1. The age of the women varied from 19 to 38 years, and their self-reported pre-pregnancy weight ranged from 35 kg to 94 kg. Ethnicity breakdown of participants was 40% Caucasian, 32% black, and 28% mixed race.

Table 1: Demographic information of pregnant women in their first trimester (Mean / SD)

	N	Mean	SD
Age (years)	72	28	5
Pre-pregnancy weight (kg)	72	63	13
Ethnicity (%)			
White	29	40	
Black	23	32	
Mixed race	20	28	
Underweight / Normal / Overweight and Obese (%)*			
Underweight (BMI < 18.5 kg/m^2)	2	5	
Normal (BMI = 18.5 – 24.9 kg/m^2)	20	49	
Overweight and Obese (BMI ≥ 25.0 kg/m^2)	19	46	
Gestational weight gain (%)**			
Inadequate (<11.5 kg)	2	18	
Adequate (11.5 – 16 kg)	6	55	
Excessive gain (>16 kg)	3	27	
Number of previous pregnancies (%)			
0	29	40	
1	29	40	
2	12	17	
3	2	3	
Type of pregnancy (%)			
Single	46	98	
Twin	1	2	

N = sample size, SD = Standard deviation, kg = kilogram, BMI = Body Mass Index, kg/m^2 = kilogram per meter squared, % = percentage,

* Categorized according to the American College of Sports Science[32]

* Categorized according to the Institute of Medicine[18]

Anthropometric and REE data are presented in Table 2. Mean estimated pre-pregnancy weight was 62.9 ± 13.0 kg. Participants' mean weight increased from 67.3 ± 15.0 kg in the first trimester to 74.0 ± 16.3 kg in the second trimester, and then to 77.4 ± 12.1 kg in the third trimester of pregnancy.

Gestational weight gain from pre-pregnancy to the first trimester was estimated at 3.2 ± 3.6 kg. From the first trimester to the second trimester gestational weight gain was calculated as 5.2 ± 5.4 kg, and from the second trimester to the third trimester, the participants gained 4.9 ± 3.1 kg of weight.

The sum of three skinfolds averaged 69.9 ± 23.1 mm in the first trimester, 74.5 ± 24.4 in the second trimester, and 82.3 ± 6.2 mm in the third trimester. The estimated fat mass showed a similar increase as the pregnancy progressed: 18.6 ± 8.8 kg in the first trimester, 20.7 ± 9.3 kg in the second trimester, and 22.4 ±8.4 kg in the third trimester. Fat-free mass also increased from the first trimester (48.7 ± 5.6 kg), to the second trimester (52.7 ± 5.6 kg) and to the third trimester (55.6 ± 6.2 kg).

Table 2: Body composition data and REE of pregnant women in each trimester

Variable	**First trimester**		**Second trimester**		**Third trimester**		***P***	**Effect size (Partial η^2)**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**		
Weight (kg)	67.3	15.0	74.0	16.3	77.1	12.1	0.000	0.839
BMI (kg/m^2)	25.5	5.1	28.4	5.8	29.0	5.1	0.000	0.809
Fat mass (kg)*	18.6	8.8	20.7	9.3	22.4	8.4	0.024	0.359
Fat free mass (kg)**	48.7	5.6	52.7	5.6	55.6	6.2	0.000	0.840
Sum of three skinfolds (mm)	69.9	23.1	74.5	24.4	82.3	24.5	0.111	0.329
Triceps skinfold (mm)	22.0	7.4	22.3	7.0	23.2	7.2	0.518	0.113
Supra-iliac skinfold (mm)	17.0	9.2	19.3	8.9	20.8	8.9	0.012	0.552
Mid-thigh skinfold (mm)	30.9	9.7	32.9	11.1	38.4	10.6	0.001	0.707
Gestational weight gain***	3.2	3.6	5.2	5.4	4.9	3.1	0.093	0.448
REE (kJ/day)****	5608	1251	5445	1621	6011	1845	0.409	0.208
REE (kJ/kg/day)****	82.2	18.0	74.2	22.8	77.7	17.0	0.108	0.427

SD = Standard deviation, *p* = statistical significance, kg = kilogram, m = meter, BMI = Body Mass Index, % = percentage, mm = millimetre, REE = Resting Energy Expenditure, kJ/day = kilojoule per day, kJ/kg/day = kilojoule per kilogram body weight per day

* = As calculated using the 3-skinfold method to determine body density[43] and thereafter incorporating body density into trimester-specific equations to determine body fat mass[34].

** = Calculated by subtracting fat free mass from body weight

*** = Gestational weight gain of first trimester calculated by subtracting self-reported prepregnancy weight from measured weight in the first trimester

**** = As measured by the FitMate™ in kilojoule per kilogram body weight per day.

Resting energy expenditure during the first trimester was 5608 ± 1251 kJ/day. A decline of 50 kJ/day in REE was observed in the second trimester (5445 ± 1621 kJ/day) when compared to the first trimester. Resting energy expenditure was determined as 6011 ± 1845 kJ/day in the third trimester. Figure 1 shows the change in REE, expressed in kJ per kg per day throughout pregnancy. When adjusted for by weight, REE during the first trimester equated 82.2 ± 18.0 kJ/kg/day, 74.2 ± 22.8 kJ/kg/day in the second trimester and 77.7 ± 17.0 kJ/kg/day in the third trimester.

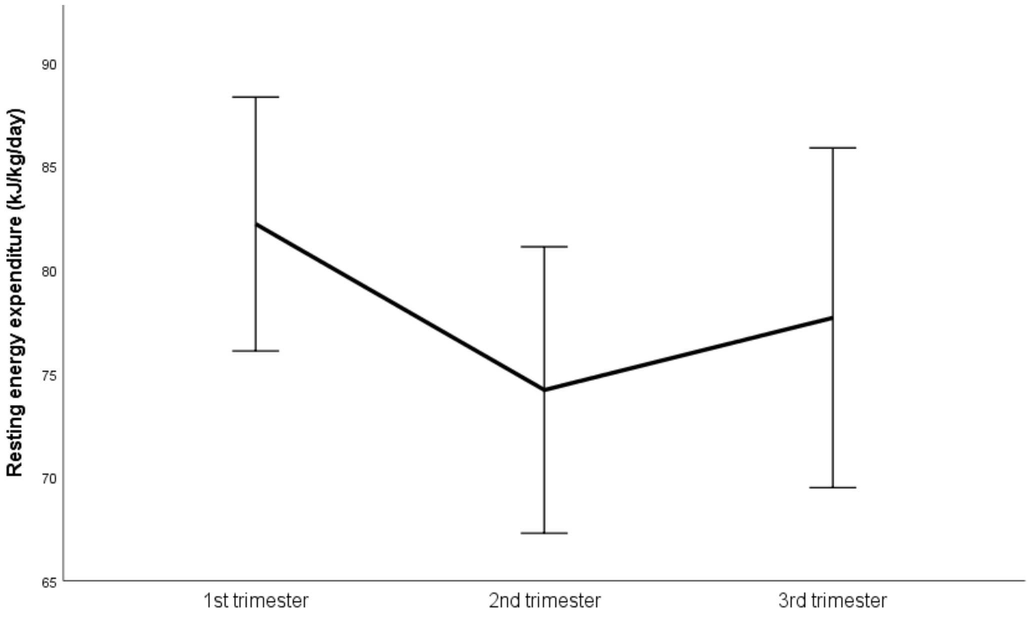

Figure 1: Change in REE (measured in kJ/kg/day) throughout pregnancy

Results from the repeated measures ANOVA indicated a significant difference between the trimesters in terms of weight [*F*(2, 11) = 31.175, $p < 0.05$], BMI [*F*(2, 11) = 23.334, $p < 0.05$], supra-iliac skinfold [*F*(2, 11) = 6.779, $p = 0.012$], mid-thigh skinfold [*F*(2, 11) = 13.243, $p = 0.001$], fat mass [*F*(2, 12) = 6.707, $p = 0.024$], and fat free mass [*F*(2, 11) = 28.913, $p = 0.000$]. Follow up Bonferroni post-hoc comparisons between all trimesters indicated that each pairwise difference was statistically significant in terms of weight and BMI, however the supra-iliac skinfold measurement was only statistically significantly different between the second and third trimester ($p = 0.007$), and the mid-thigh skinfold was only statistically significantly different between the first and second trimester ($p = 0.001$), and between the first and third trimesters ($p = 0.007$), but not between the second and third trimester ($p = 0.492$). Differences in fat mass between trimesters was only statistically significant between the second and third trimester ($p = 0.045$), but not between the first and second ($p = 0.183$) and also not between the first and third trimester ($p = 0.071$). Differences in fat free mass were statistically significant from the first to the second trimester ($p = 0.000$), the second to the third trimester ($p = 0.002$) and from the first to the third trimester ($p < 0.001$).

No statistically significant difference was observed between the trimesters for sum of skinfolds [*F*(2, 11) = 2.702, $p = 0.111$], triceps skinfold [*F*(2, 11) = 0.699, $p = 0.518$], gestational weight gain [*F*(2, 8) = 3.240, $p = 0.093$], REE measured in kJ/day [*F*(2, 7) = 1.017, $p =0.409$], and REE measured in kJ/kg/day [*F*(2, 8) = 2.976, $p =0.108$].

Correlations between the variable of interest, namely the change (Δ) REE – vs the change in body composition variables, are presented in Table 3. Change in BMI, gestational weight gain and fat mass were positively correlated with Δ REE (kJ/day) in both the first to the second trimester as well as in the second to the third trimester. The Δ in the sum of three skinfolds was not correlated with Δ REE.

There were no significant correlations between the Δ REE expressed per kg body weight (kJ/kg/day) and body composition variables from the first to the second trimester. Despite the non-significant associations from the first to the second trimester, the Δ REE (kJ/kg/day) was positively correlated with changes in BMI, gestational weight gain as well as fat mass from the second to the third trimester of pregnancy. Again, the Δ Sum of three skinfolds failed to be correlated with the adjusted Δ REE (kJ/kg/day) from the second to the third trimester of pregnancy

Table 3: Pearson correlations between changes in Resting Energy Expenditure (kJ per day and kJ per kilogram weight per day) and change in maternal body composition

	First trimester to secondtrimester		**Second trimester to third trimester**	
Correlations	**R**	***p***	**r**	***p***
Δ REE (kJ per day) and:				
Δ BMI	0.384*	0.043	0.655*	0.010
Gestational weight gain	0.430*	0.026	0.631*	0.014
Δ Sum of skinfolds	0.199	0.193	0.196	0.271
Δ Fat mass	0.348	0.061	0.542*	0.034
Δ Fat free mass	0.527*	0.020	0.381	0.278
Δ REE (kJ per kg body weight per day) and:				
Δ BMI	0.148	0.262	0.590*	0.022
Gestational weight gain	0.197	0.195	0.552*	0.031
Δ Sum of skinfolds	0.133	0.283	0.251	0.216
Δ Fat mass	0.180	0.218	0.542*	0.034
Δ Fat free mass	0.292	0.224	0.253	0.481

r = Pearson correlation, *p* = statistical significance, REE = Resting Energy Expenditure, kJ = kilojoule, Δ = change variable, BMI = Body Mass Index
* Statistical significance

Results from the regression analysis are presented in Table 4. The regression analysis indicated no statistically significant findings between the Δ REE (expressed per kg body weight) and changes in body composition from to the first to the second trimester. The latter did statistically significantly predict the change in Δ in REE from the second to the third trimester.

Table 4: Regression analysis between the change of REE (kJ per kg body weight per day) and change in body composition variables

	Odds ratio		
Trimester	**R^2**	***p*-value**	**F**
From first to second trimester	0.222	0.373	1.141
From second to third trimester	0.930*	0.000	23.296

ANOVA = Analysis of Variance, R = Correlation coefficient, F = F statistic, * = Statistically significant

Discussion

The aim of the study was to determine the relationship between longitudinal changes in REE and changes in body composition during pregnancy in South African women. The main results indicate that there is a significant correlation between change in REE and changes in body composition (change in BMI, gestational weight gain and fat mass) from the first to the second trimester and from the second to the third trimester of pregnancy. These significant associations were more relevant from the second to the third trimester of pregnancy as compared to changes observed from the first to the second trimester. In agreement with this observation, changes in body composition variables explained 93% of the change in REE from the second to the third trimester, whereas the change in body composition variables did not explain the variability in the change in REE from the first to the second trimester.

Our findings relate to a study by Berggren *et al.*[3], where the potential impact of REE relative to variations body composition are addressed. In their cohort of primarily normal and overweight women, REE increased significantly from before conception through late pregnancy. A study by Berggren *et al.*[3] found REE to increase 27% throughout pregnancy which translates into a mean increase of around 1674 kJ/day, a clinically relevant variation. No minimal clinically significant difference of REE between trimesters of pregnancy has been researched. Despite methodological and cohort difference amongst studies related to REE during pregnancy, most studies found an increased REE across pregnancy[13,29,36,37]. However, we did not find any statistically significant increases in REE throughout pregnancy. Contradictorily, our results indicated a decrease in REE from the first to the second trimester. One hypothesis is that the first calorimetric measurement in these women (although totally non-invasive) may have been slightly inflated by the novelty of the experimental situation, which is well known to systematically induce some stress (by anticipation) and which result in an increase in both heart rate and REE.

Furthermore, when REE was adjusted for weight, REE (kJ/kg/day) decreased even more dramatically in the second trimester. Possible explanations for these contradictory results could be due to energy-sparing adaptations, predominantly expressed as a depression in REE, as a consequence of an energy intake insufficiency as proposed by Poppitt *et al.*[19] in a cohort of Gambian women. Poppitt *et al.*[19] highlight the problem with which we are faced when making recommendations for energy intake and –expenditure as discrepancies between the energy costs of pregnancy in low-to-middle-income countries may be due to the highly individual nature of a mother’s metabolic response to pregnancy. Nevertheless, REE (both adjusted and unadjusted for weight) increased in the third trimester of pregnancy in our results, although modestly.

Results in terms of body composition during pregnancy were consistent with other previous studies[13,37–39]. More specifically, statistically significant changes were found between trimesters of pregnancy in terms of weight, supra-iliac and mid-thigh skinfolds. These results are similar to those reported by Sidebottom *et al.*[39], who noted that subcutaneous fat begins to accumulate around six weeks after conception and continues to increase through 35 weeks of pregnancy. Although the sum of skinfolds globally increased throughout each trimester of pregnancy, our results indicated insignificant statistical changes between trimesters. Nonetheless, the supra-iliac and mid-thigh skinfolds increased significantly throughout pregnancy which confirms the findings of Sidebottom *et al.*[39], who also found a large increase in the thigh skinfold of 37%. Contradictorily to the sum of the three skinfolds, the calculated fat mass did increase significantly, which confirms several previous studies[3,40,41]. From a South African point of view, Kruger[31] has pointed out that a paucity of data on weight gain during pregnancy exists in South African women and further emphasized the importance of assessing body composition as a double burden was present with both undernutrition and obesity co-existing as public health concerns in South African pregnant women. This situation can lead to adverse maternal and infant outcomes.

The relationship between changes in REE and changes in body composition variables were statistically significant from the first to the second and from the second to the third trimester. Changes in REE are expected to be associated with changes in fat-free mass as it represents the metabolically active tissue, whereas fat mass is much less metabolically active per proportional tissue unit[3]. Berggren *et al.*[3] stated that REE was relatively lower among women with greater fat mass deposition (as compared to FFM storage) during pregnancy, especially during late pregnancy. Excess gestational weight gain in overweight/obese pregnant women is primarily associated with greater fat mass deposition and less lean mass accumulation[40]. Thus, ideally, gestational weight gain should be classified into fat- and fat-free mass components as REE (and thus total energy expenditure) is known to be more related to fat-free mass than to fat mass. This new information could useful in promoting physical activity in overweight/obese pregnant women and will be beneficial to perinatal outcomes[42].

The strengths of the study include the longitudinal design, reliable and reproducible measurements of REE and the use of body compositional data not only related to weight and BMI. Previously reported research mostly made use of only two measurement periods, namely before and during pregnancy. Our study measured participants in all three trimesters. Indirect calorimetry (FitMate^{TM}) provides a reliable estimate of REE[3]. To date most studies have focused on weight and BMI as body composition variables and the relationship thereof to various pregnancy-specific outcomes. Body Mass Index does not differentiate between fat- and muscular tissue, and as these variables have implications to REE direct assumptions is difficult.

Limitations to the study included no objective pre-gravid measures of REE and body anthropometrics, a convenient sampling method and possible co-founders to REE. Besides, skinfold thickness measurements used to assess body composition were limited to three anatomical sites, and they represent an estimate of peripheral fat (excluding the central/visceral fat component). Note furthermore that the algorithm used to predict total body fat from skinfolds assumes a fixed proportion between peripheral and central body fat. Besides, for technical, medical, social, ethical and psychological reasons, pre-pregnancy baseline weight could not be tracked before the onset of pregnancy and was based on participant recall during pregnancy. Measuring women before they conceived it would have provided a more objective understanding of gestational weight gain and how this affects REE. Subsequent studies should include a case-control design recruiting non-pregnant women as a control group. Due to a convenient sampling method, likely, that our sample was not an accurate representation of a general population sample. We also acknowledge that REE measurements may have been influenced by other essential co-founders, including dietary factors (including food intake disturbances), and physical activity habits.

In summary, clinical research could benefit from resting energy expenditure measurements (REE) and tracking changes in body composition during pregnancy considering that the recommendations for dietary intake and physical activity could be individually tailored to women’s needs based on REE measurements[3,9]. Unfortunately, standard calorimetric equipment may not routinely be used in clinical obstetrical practice since it is rather costly and requires trained personnel. Finally, the above application might be especially relevant in a South-African context as the wide variability of REE observed in this population mandates different personal recommendations for both energy intake (dietary habits) and energy expenditure (habitual physical activity).

Acknowledgement

We thank all the women who participated in the study. The research was funded by the National Research Foundation South African-Swiss Joint Programme, award number UID 78606 and the South African Sugar Association, project no 224. Any opinion, findings and conclusions or recommendations expressed in this material are those of the authors, and therefore the NRF does not accept liability regarding it.

Declaration of Interest

All authors contributed to the preparation of the manuscript and reported no conflict of interest.

Conference presentation

The manuscript was presented at the *24th annual Congress of the European College of Sport Science*[44].

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CHAPTER 5: RELATIONSHIPS BETWEEN ENERGY INTAKE AND EXPENDITURE AND BIRTH OUTCOMES DURING PREGNANCY IN A SOUTH AFRICAN COHORT OF THE TLOKWE MUNICIPAL AREA

Title page

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Keywords:
Birth outcomes, energy balance, energy expenditure, energy intake, pregnancy,

Manuscript prepared for submission to: *Journal of Pregnancy and Child Health* [Impact Factor: 0.53]

Abstract

Introduction: Energy imbalances due to lifestyle behaviors during pregnancy may influence birth outcomes. However, the wide divergence of methods applied hampers the precise determination of the relationship between birth outcomes and energy balance. The study, therefore, aims to determine the relationship between energy intake and expenditure and birth outcomes during pregnancy in women of a South African cohort.

Materials and Methods: Data from the longitudinal observational study, Habitual Activity Patterns during PregnancY (HAPPY) study, were analyzed. Measurements collected in the first (9 – 12 weeks), second (20 – 22 weeks), and third trimester (28 – 32 weeks) of pregnancy for energy intake were determined with a validated semi-quantitative food frequency questionnaire. Energy expenditure was calculated from resting energy expenditure as measured by indirect calorimetry (FitMate®), activity energy expenditure was measured with a combined heart-rate and accelerometer device (ActiHeart®). Diet-induced thermogenesis was calculated as ten percent of the total energy expenditure measured with the ActiHeart®. Birth outcomes (birth weight, birth length, gestational age at birth, and head circumference) were obtained from medical records. Pearson correlation was performed in order to determine the relationship between energy intake and -expenditure and birth outcomes.

Results: Energy intake increased from the first trimester to the second trimester (328 ± 2523 kJ/day) and decreased from second to third trimester (322 ± 3314 kJ/day). Energy expenditure decreased from first to second trimester (629 ± 2715 kJ/day) and increased from second to third trimester (720 ± 2573 kJ/day). Most infants reported appropriate for gestational age birth weight (82.4%), while a small percentage of infants were either small for gestational age (5.9%) or large for gestational age (11.8%). Energy expenditure in the third trimester was negatively associated with head circumference ($r = -0.844$, $p = 0.017$) and birth weight ($r = -0.677$, $p = 0.045$). No statistically significant relationship was found between energy intake, energy balance, and birth outcomes.

Conclusion: A negative energy balance during pregnancy seems to be beneficial in terms of delivering an appropriate for gestational age infant. Energy expenditure in the third trimester was negatively associated with both head circumference and birth weight of the infant.

Keywords: birth outcomes, energy balance, energy expenditure, energy intake, pregnancy

Introduction

Energy intake during pregnancy provides the energy to ensure full-term delivery of a healthy new-born infant of adequate size and body composition by a woman whose weight, body composition, and energy expenditure are accordant to long-term good health and well-being (FAO, 2001). The accumulation of energy in the extra weight of the mother and fetus occurs during pregnancy, which represents a combination of altered energy intake together with alterations in the components of energy expenditure (Yu *et al.*, 2006). However, energy intake and expenditure during pregnancy vary considerably in the course of the pregnancy, which is interpreted as a means of promoting a healthy birth outcome (Catalano *et al.*, 1998; King *et al.*, 1994; Kopp-Hoolihan *et al.*, 1999; Prentice & Goldberg, 2000).

In a systematic review, Blumfield *et al.* (2012) found no relationship between the increment in energy intake from early to late pregnancy and the amount of gestational weight gain. Even though bodyweight increased significantly, only small, non-significant increases in reported energy intake were observed (Abeysekera *et al.*, 2016; Bell & Robson, 2016; Blumfield *et al.*, 2012; Highman *et al.*, 1998). The lack of a significant relationship between observed energy intake and gestational weight gain suggests that other factors might be responsible for maintaining an energy balance and a viable birth outcome, which might be mitigated by a decrease in energy expenditure (Blumfield *et al.*, 2012). With a higher proportion of women being overweight/obese at the inception of pregnancy, reporting decreased physical activity and increased sedentary behavior, decreased energy expenditure might explain the positive energy deposition of pregnancy (Blumfield *et al.*, 2012).

Previous research has shown that total energy expenditure increases between the first and third trimester of pregnancy (Abeysekera *et al.*, 2016; Butte & King, 2005). Total energy expenditure consists of resting energy expenditure (60 – 75%), diet-induced thermogenesis (10%), and active energy expenditure (15 – 30%) (Byrne *et al.*, 2011; McArdle *et al.*, 2015). Resting energy expenditure relates to the energy required to sustain vital functions (Abeysekera *et al.*, 2014; McArdle *et al.*, 2015) and correlates well with total energy expenditure, especially in persons who are not physically active (Catalano *et al.*, 2003). Resting energy expenditure tends to increase during pregnancy (Abeysekera *et al.*, 2016; Berggren *et al.*, 2017; Butte & King, 2005; FAO, 2001; Rasmussen, 2017; Yu *et al.*, 2006) and is a significant variable related to changes in gestational weight gain (Berggren *et al.*, 2017). Berggren *et al.* (2016) state that resting energy expenditure is inversely associated with gestational weight gain and has a significant influence on total energy expenditure.

Active energy expenditure, a component of total energy expenditure, relates to energy expended above resting levels due to bodily movements or, otherwise stated, physical activity (Abeysekera *et al.*, 2014;

McArdle *et al.*, 2015). Active energy expenditure is the most variable component of all the components of total energy expenditure, even in pregnancy (Abeysekera *et al.*, 2014; Butte *et al.*, 2004). Although numerous studies have proven the benefits of physical activity during pregnancy (American College of Obstetricians and Gynecologists, 2015; Cid & González, 2016; Downs *et al.*, 2012; IOM, 2009; Leite *et al.*, 2016; Takito & Benício, 2010; Tinius *et al.*, 2017), active energy expenditure tends to decline during pregnancy (Butte & King, 2005; Byrne *et al.*, 2011; Löf, 2011; Melzer *et al.*, 2009). The decrease in active energy expenditure might be a metabolic adaptation to offset the energy expenditure of pregnancy to ensure adequate energy for the fetus or may be a behavioral adaptation due to the discomfort or increased fatigue of moving when pregnant (Byrne *et al.*, 2011). Energy-sparing through reducing active energy expenditure might be especially relevant in extremely active women and women with heavy physical workloads (Kopp-Hoolihan *et al.*, 1999). To understand the dose-response effects of physical activity during pregnancy on birth outcomes, carefully controlled and sufficiently powered experimental/intervention studies are needed (Downs *et al.*, 2012), together with a valid measurement of physical activity (Chasan-Taber *et al.*, 2007; Downs *et al.*, 2012).

Comparatively, diet-induced thermogenesis comprises only a small, i.e., approximately 10%, the proportion of total energy expenditure, and denotes the energy required for the digestion, absorption, and assimilation of food intake (Abeysekera *et al.*, 2014; McArdle *et al.*, 2015). During pregnancy, however, diet-induced thermogenesis is likely to remain unaltered (Prentice *et al.*, 1989; Prentice *et al.*, 1996). Increased energy intake consistently exceeds energy expenditure, which leads to a positive energy balance whereby excess energy is stored as gestational weight gain (Byrne *et al.*, 2011; Guidotti *et al.*, 2016).

Desirable gestational weight gain associated with an optimal birth outcome relates to the prevention of maternal mortality and complications of pregnancy, labor, and delivery while providing an optimal outcome for the infant, in terms of allowing adequate fetal growth and maturation (FAO, 2001). A gestational weight gain of between 10 and 14 kg, with a mean of 12 kg, is associated with an ideal ratio for optimal birth outcomes (FAO, 2001). The nutritional status of the women before conception should also be taken into account when assessing optimal weight gain during pregnancy. Women with a pre-pregnancy body mass index (BMI) < 19.8 kg/m^2 should gain 12.5 – 18 kg during the entire pregnancy, whereas a woman with a BMI between 19.8 and 26 kg/m^2 before pregnancy needs to gain only 11.5 – 16 kg. The recommended weight gain for overweight and obese women should even be less (Forsum, 2004; IOM, 2009). Obesity and its co-morbidities in South African women pose a significant health problem, with 38% of women classified as obese (Averett *et al.*, 2014). The high prevalence of obesity in South Africa is particularly elevated in women, as indicated by Sartorius *et al.* (2015), who confirmed the female gender (mainly Black/African and White ethnicity) as a critical determinant of higher obesity risk in South Africa. Possible adverse outcomes that may occur with an increased BMI during pregnancy include pre-eclampsia, gestational diabetes, complicated delivery, congenital abnormalities, and macrosomia (Daniels & Grobbelaar, 2015). An intervention study by Liu *et al.* (2015) found promising birth outcome results by reducing gestational weight gain in a cohort of overweight or obese African-American pregnant women when maintaining physical activity and reducing energy intake. Gestational weight gain that lies within the guidelines set by the Institute of Medicine (IOM, 2009) is associated with optimal birth outcomes.

The IOM (2009) concluded that active energy expenditure, based on energetic fundamentals, generated moderate gestational weight gain. Healthy eating and physical activity plans will help to prevent excessive gestational weight gain and promote a healthy fetal environment and birth outcome (Clapp, 2006; Mottola, 2013). Birth outcomes can be measured by different variables, though birth weight is most generally reported as it is the most easily measured indicator of the intrauterine environmental impact of fetal development (Leite *et al.*, 2016). Other birth outcome variables include birth length, head- and abdominal circumference, gestational age, Apgar score at one and five minutes post-birth as well as the type of delivery (Jayakody & Senanayake, 2015; Tinius *et al.*, 2017). In an intervention study aimed at reducing excessive gestational weight gain in a small group of overweight and obese pregnant African-American women, Liu *et al.* (2015) found no significant differences in birth outcomes between the intervention and control group. However, outcomes, such as birth length, prematurity, and gestational diabetes, appeared to be improved as compared to the control group (Liu *et al.*, 2015). Conversely, Reid *et al.* (2014) found that pregnant women who spent less time in moderate-to-vigorous physical activity and more time in sedentary behavior tend to deliver macrosomic infants.

The energy needs of well-nourished women in economically high-income societies differ from women from low-to-middle-income societies (FAO, 2001). Davies *et al.* (2012) substantiated the associations between socioeconomic variables and birth outcomes where they found that women who had a lower household income were at an increased risk of being underweight which could have increased their risk of prematurity and low birth weight, height, and head circumference, in a cohort of South African pregnant women. Furthermore, Most *et al.* (2018) showed that low energy expenditure might contribute to adverse birth outcomes in African-American women and, in particular, to their impaired weight loss postpartum. Pearson *et al.* (2015) indicated that most literature regarding physical activity trends during pregnancy is derived from international studies, with limited data on South African women with high obesity and overweight rates. Chasan-Taber *et al.* (2007) also reported that most studies of physical activity during pregnancy relied upon self-report measures, and none of the studies validated their measures within a population of pregnant women. Studies of physical activity during pregnancy in South Africa have mostly made use of self-reported questionnaires (Maputle *et al.*, 2014; Muzigaba *et al.*, 2014; Watson *et al.*, 2016). Objectively measured physical activity has generally been limited to pregnant women residing in high-income countries, thus studies are needed to objectively examine physical activity in women residing in low-to-middle-income countries (Downs *et al.*, 2012). The inherent subjectivity of questionnaires limits the establishment of a precise dose-response relationship between physical activity and birth outcomes (Chasan-Taber *et al.*, 2007; Downs *et al.*, 2012).

According to Bell and Robson (2016), rigorous investigations in energy metabolism during pregnancy mandate sophisticated measures of energy intake and energy expenditure (resting energy expenditure and physical activity) in order to offer practical guidance to women and healthcare providers. Birth outcomes are influenced by dietary intake, physical activity, and weight gain (Whitaker *et al.*, 2016). Therefore, the research question posed by the study is: What is the relationship between energy intake and expenditure during pregnancy and birth outcomes in pregnant women from the Tlokwe Municipality area of South Africa?

Understanding the relationship between energy balance and birth outcomes will be beneficial and can assist in providing dietary and physical activity recommendations. Conclusions from this study could be used to improve patient guidance and counseling, which endorses healthy birth outcomes by promoting healthy lifestyles during pregnancy, employing a healthy diet and regular physical activity, as well as by controlling gestational weight gain. Another benefit of the study is the exploration of the association between maternal lifestyle, physical activity (including free-living physical activity and sedentary behavior), and birth outcomes.

Methods

Study design

We followed a longitudinal observational cohort study-design within the longitudinal Habitual Activity Patterns during PregnancY (HAPPY)-study. We measured women in their first- (9-14 weeks), second- (20 – 22 weeks), and third trimester (28-32 weeks) of pregnancy.

Participants

We recruited 41 pregnant women through advertisements placed in the local press, and the consulting rooms of local gynecologists and maternal health clinics in the Tlokwe Municipality of Potchefstroom, North West Province, South Africa. Included participants met the following inclusion criteria: literate, healthy pregnant women from any ethnic background, over 18 years of age, and in their first trimester of pregnancy (9 – 14 weeks of gestation). Participants were excluded from the study if they were mentally disabled or had physical limitations. Participants indicating interest in the study were asked to give their informed consent to participate in the study by signing an informed consent form. Ethical approval – complying with the Declaration of Helsinki – has been obtained from the Ethics Committee of the North-West University (NWU-00044-10-A1).

Pregnancy-related, demographic information and body composition measurements

All participants completed a demographic questionnaire, compiled specifically for the current study, in order to gather information regarding ethnicity, employment status, education level, and income per annum. In cases where some participants' home language was neither Afrikaans nor English, the languages the researcher spoke, a translator (appointed by the clinic), translated the questions of the researcher to the participants.

Pregnancy-related questions included: 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 (yes/no), smoking habits (current smoker/ex-smoker/non-smoker), alcohol consumption (none/number of drinks per day), and drug use (yes/no) in the previous three months. A health screen was performed concerning risk factors for physical activity during pregnancy and for cardiovascular disease based on the American College of Sports Medicine (ACSM, 2014) criteria of significant signs or symptoms suggestive of cardiovascular, pulmonary, or metabolic disease as well as the contraindications for exercising when pregnant.

Medical records, obtained from routine visits to the gynecologists and clinics, yielded information on potential risk factors such as diagnosed gestational diabetes mellitus (yes/no), gestational hypertension (yes/no), and pre-eclampsia (yes/no).

Body composition measurement of height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg) were measured using the standard procedures according to the international standards for anthropometric assessment described by the International Society for the Advancement of Kinanthropometry (Stewart *et al.*, 2011). Weight was measured using an electronic scale (Beurer, Germany), and height using a stadiometer. Weight and height were used to calculate BMI by dividing weight (kg) by the square of height (m). Participants BMI was classified into underweight (<18.5 kg/m^2), normal (18.5 – 24.9 kg/m^2) and overweight and obese (>25.0 kg/m^2) according to the ACSM (2018).

Energy intake

At every measurement point, each participant's dietary intake was measured employing a semi-quantitative food frequency questionnaire, which determined the nutrient intake of the participant in every trimester (MacIntyre *et al.*, 2001). The data were analyzed using the Food-Finder 4 program (Medical Research Council, Tygerberg, South Africa). Energy intake (measured in kJ/day) was calculated as well as carbohydrate, fat, and protein intake (grams/day).

Energy expenditure

Total energy expenditure is calculated by the sum of resting energy expenditure, diet-induced thermogenesis, and active energy expenditure.

Resting energy expenditure

Resting energy expenditure was determined using indirect calorimetry with the FitMate® (Cosmed, Italy). The FitMate® is a metabolic analyzer designed for the measurement of oxygen consumption and energy expenditure during rest and exercise (Nieman *et al.*, 2006). Nieman *et al.* (2006) concluded the Fitmate® gives accurate and reproducible oxygen consumption and REE measurements for female adults ($r = 0.97$, $p = 0.579$). Ventilation is measured by a turbine flow meter, while analyses of the fraction of oxygen in expired gases are measured through a galvanic fuel cell oxygen sensor (Nieman *et al.*, 2006). Standard metabolic formulas are used by the FitMate® to calculate oxygen consumption (measured in ml/min), and energy expenditure (measured in kJ/day) is calculated using a fixed respiratory quotient of 0.85 (Nieman *et al.*, 2006).

Participants were requested not to perform any exercises during the 24 hours preceding the resting energy expenditure measurement. They were also asked to fast from all food for at least 10 hours before this measurement. Calibration of the FitMate® was done before each participant was subjected to the measurement. During the test, participants were requested to remain awake for the whole testing period. Participants were asked to rest for 10 minutes (preparation), and then to breathe through an anti-bacterial filter for 15 minutes (REE measurement), during which time the fraction of oxygen in expired gases was quantified to determine REE. The first minute of measurement was discarded because it is considered a stabilization period for breathing adaptation to the equipment. REE was then divided by weight and presented in kJ/kg body weight for each participant.

Active energy expenditure

Active energy expenditure was determined through an objective assessment based on combined accelerometry (movement counts) and heart rate response (ActiHeart®, CamNtech Ltd., Cambridge, UK).

The device is a waterproof, self-contained logging device that allows physical activity to be measured synchronously with the heart rate (Brage *et al.*, 2005). The ActiHeart® reports simulated heart rate within one beat per minute, above 30 beats per minute, which is comparable to heart rate monitors (Boudet & Chamoux, 2000; Brage *et al.*, 2005). 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 device to measure physical activity were scientifically validated (p = 0.9) in healthy pregnant women in Switzerland (Melzer *et al.*, 2012).

At every measurement interval in the study, activity energy expenditure was measured for seven days. The following parameters were extracted from the data: AEE, DIT, and TEE. The AEE, DIT, and TEE measurements were expressed in kJ/kg/min.

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

Before the measurements, the ECG pads were placed on the chest to form an arc across the heart. Fifteen-minutes was given to determine a good signal ensuring accurate measurement of the heart rate for the following seven consecutive days. When 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. Two-minutes of quiet sitting was required after the step test to determine the participants' recovery heart rates.

As soon as the step test information was downloaded using the accompanying software, the Actiheart® was set to the "Advanced Energy Expenditure" mode. Participants wore the device for seven consecutive days. The ActiHeart® was programmed to measure energy expenditure using 30-second epochs (counts per minute). The women were advised to take the monitor off when they were bathing or showering and to put it on again immediately afterward. The device was removed after seven days, and the data captured was downloaded using the accompanying software (Version 2.132, Cambridge Neurotechnology Ltd, Cambridge, UK). Participants were encouraged to wear the ActiHeart® for seven days. If the participants did not adhere to this recommendation, the data were trimmed and only the days on which measurements were taken. For accurate results, participants should have worn the ActiHeart® for at least four days, in which one of the days should have been a weekend day (CamNtech, 2010).

Diet-induced thermogenesis

Diet-induced thermogenesis was estimated by the ActiHeart® device, which is factored in as a constant of 10% of the total energy expenditure (CamNtech, 2010).

Energy balance

Energy balance was determined by subtracting total energy expenditure (the sum of resting energy expenditure, diet-induced thermogenesis, and active energy expenditure) from total energy intake.

Birth outcomes

The following birth outcomes were obtained from medical records: gender (male/female, date of birth, birth weight (kg), birth length (cm), gestational age at birth (weeks), head circumference (cm) and mode of delivery (vaginal birth/cesarean section). The babies were categorized into three groups according to birth weight: small for gestational age (< 2500 g), appropriate for gestational age (2500 - 3700 g), and large for gestational age (> 3700 g) (Battaglia & Lubchenco, 1967).

Statistical Analysis

Statistical analyses were performed with the SPSS ver. 25.0 software package (IBM, SPSS Inc., Chicago, IL). Descriptive statistics for the energy intake and expenditure variables of each trimester were performed, reporting means, and standard deviations. Additionally, descriptive statistics were also performed on the birth outcome variables (birth weight, birth length, gestational age at birth, head circumference, mode of delivery, and gender of the infant).

Partial correlation was used to determine the relationship between the birth outcomes (variables of interest such as birth weight, birth length, gestational age, and head circumference) and energy intake and -expenditure during pregnancy. A *p*-value of less than 0.05 was considered statistically significant for all analyses. In all analyses, an adjustment was made for age, ethnicity, smoking status, alcohol consumption, BMI (first trimester), and categories of birth weight (small-, appropriate- and large for gestational age).

Results

The demographic information of the participants is illustrated in Table 1. Participants' mean age was 28 ± 5 years, and their ethnicity was approximately equal according to the major groupings in South Africa.

Most participants' home language was Afrikaans (61.1%). Mean household income per annum varied with most of the participants' households earning between R 50 000 (27.1%) and R 50 000 – R 100 000 (22.9%). Participants reported having no children (40.3%), one child (40.3%), two children (16.7%), and three children (2.8%) at home. One participant was an active smoker (2.4%), and another was an ex-smoker (2.4%), while most participants were non-smokers (95.1%). Two participants (4.9%) indicated they had used alcohol in the previous three months before testing.

Table 1: Demographic information of pregnant women in their first trimester

	N	Mean	SD
Age (years)	72	28	5
Prepregnancy weight (kg)	72	63	13
BMI (kg/m^2)	41	25.48	5.10
	N	**%**	
Underweight / Normal / Overweight and Obese *			
Underweight (BMI < 18.5 kg/m^2)	2	5	
Normal (BMI = 18.5 – 24.9 kg.m^2)	20	49	
Overweight and Obese (BMI ≥ 25.0 kg/m^2)	19	46	
Ethnicity			
White	29	40	
Black	23	32	
Coloured	20	28	
Number of previous pregnancies			
0	29	40.3	
1	29	40.3	
2	12	16.7	
3	2	2.8	
Smoking status			
Ex-smoker	1	2.4	
Smoker	1	2.4	
Non-smoker	39	95.1	
Alcohol use in the last three months (%)			
No alcohol use	39	95.1	
Alcohol use	2	4.9	

N = sample size, kg = kilogram, kg/m^2 = kilogram per meter squared, BMI = Body Mass Index, SD = standard deviation, % = percentage

* Categorized according to ACSM (2018)

Table 2 shows the change in energy intake, energy expenditure, and gestational weight throughout pregnancy. Energy intake increased from the first trimester to the second trimester by 328 ± 2523 kJ/day and decreased from the second to the third trimester by 322 ± 3314 kJ/day. Energy expenditure decreased from the first to the second trimester by 629 ± 2715 kJ/day, while a 720 ± 2573 kJ/day increase was observed from the second to the third trimester. The decrease in energy expenditure from first to second trimester is primarily attributed to a decrease in resting energy expenditure of 265 ± 1664 kJ/day, as well as a decrease in active energy expenditure of 215 ± 2297 kJ/day. From the second to the third trimester, energy expenditure increased as a result of an increase in resting energy expenditure (720 ± 2573 kJ/day). Gestational weight gain was 3.23 ± 3.61 kg in the first trimester, 5.18 ± 5.37 kg in the second trimester, and 4.90 ± 3.10 kg in the third trimester. A more detailed description of energy intake and –expenditure is given by Van Oort *et al*. (2019).

Table 2: Changes in energy intake, energy expenditure and gestational weight gain of pregnant women from first to second trimester, and from second to third trimester

Variable	**First to second trimester**		**Second to third trimester**	
	Mean	**SD**	**Mean**	**SD**
Δ Energy intake (kJ/day)	328	2523	-322	3314
Δ Energy expenditure (kJ/day)	-629	2715	720	2573
Δ Resting energy expenditure (kJ/day)	-265	1664	675	1662
Δ Active energy expenditure (kJ/day)	-215	2297	98	1880
Δ Diet-induced thermogenesis (kJ/day)	- 62	270	34	211
Δ Energy balance (kJ/day)	1275	2965	-551	9593
Δ Gestational weight gain (kg)	5.18	5.37	4.90	3.10

SD – Standard Deviation, Δ = change, kJ/day – kilojoule per day, g/day – gram per day, kg – kilogram

The birth outcomes are presented in Table 3. On average, our participants gained 13.50 ± 5.59 kg during the pregnancy, as indicated in Table 3 as gestational weight gain. The mean birth weight of the participants' infant was 3113 ± 538 g. At birth, the average gestational age of the infants was 39.18 ± 1.47 weeks. Birth length was measured as 48.18 ± 4.64 cm, while head circumference was 34.76 ± 1.36 cm. Most infants had an appropriate for gestational age birth weight (82.4%). Two infants (5.9%) presented with a small for gestational age birth weight and four infants (11.8%) with a large for gestational age birth weight. There was an equal distribution between normal vaginal delivery (50%) and cesarean delivery (50%). Approximately 48% of the infants were male, whereas 52% were female. There were only singleton births in our cohort.

Correlations between energy intake, energy expenditure, and energy balance with birth outcomes are illustrated in Table 4. No statistically significant relationships were found between energy intake, energy balance, and birth outcomes. Energy expenditure in the third trimester was negatively correlated with head circumference (r = -0.844, p = 0.017) and weight of the infant (r = -0.677, p = 0.045). Otherwise, no statistically significant correlations were found between energy expenditure and birth outcomes.

Table 3: Birth outcomes (gestational weight gain, birth weight, gestational age at birth, birth length, head circumference, birth weight category, mode of delivery and gender of the infant)

	N	**Mean**
Gestational weight gain (kg)	12	13.50 ± 5.59
Birth weight (g)	34	3113 ± 538
Gestational age at birth (weeks)	26	39.18 ± 1.47
Birth length (cm)	33	48.18 ± 4.64
Head circumference (cm)	29	34.76 ± 1.36
Birth weight category (%) (Battaglia & Lubchenco, 1967)		
Small for gestational age (< 2500 g)	2	5.9
Appropriate for gestational age (2500 – 3700 g)	28	82.4
Large for gestational age (> 3700 g)	4	11.8
Mode of delivery (%)		
Normal vaginal delivery	16	50
Cesarean delivery	16	50
Gender of the infant (%)		
Male	12	48
Female	13	52

N = Sample size, ± = Standard deviation, g = gram, cm = centimetre, % = percentage

Figure 1 illustrates the relationship between energy balance and birth outcome (appropriate for gestational age and large for gestational age) during all trimesters of pregnancy. Women who had appropriate for gestational age infants had a negative energy balance during their whole pregnancy (first trimester = -10134 kJ/day, second trimester = -8049 kJ/day, third trimester = -5428 kJ/day). Women who had large for gestational age infants had a positive energy balance (4058 kJ/day) in their first trimester, a slightly negative energy balance in their second trimester (- 267 kJ/day) and a negative energy balance in their third trimester (-3591 kJ/day).

Table 4: Pearson correlations between energy intake and expenditure with birth outcomes

Variables	First Trimester r	First Trimester *p*	Second Trimester r	Second Trimester *p*	Third Trimester r	Third Trimester *p*
Relationship between energy intake and birth outcomes						
Gestational age (weeks)	-0.244	0.469	0.209	0.537	-0.205	0.625
Head circumference (cm)	0.109	0.764	0.348	0.294	-0.439	0.277
Length of the infant (cm)	-0.351	0.263	0.341	0.233	-0.121	0.776
Weight of the infant (kg)	0.316	0.316	0.149	0.611	-0.273	0.513
Relationship between energy expenditure and birth outcomes						
Gestational age (weeks)	-0.378	0.203	-0.036	0.901	0.173	0.657
Head circumference (cm)	-0.065	0.834	-0.146	0.619	-0.844	0.017*
Length of the infant (cm)	0.230	0.411	0.159	0.556	0.663	0.051
Weight of the infant (kg)	-0.235	0.400	-0.006	0.983	-0.677	0.045*
Relationship between energy balance and birth outcomes						
Gestational age (weeks)	0.018	0.961	0.336	0.312	-0.210	0.617
Head circumference (cm)	0.232	0.549	0.410	0.211	-0.120	0.798
Length of the infant (cm)	-0.511	0.108	0.123	0.676	-0.367	0.371
Weight of the infant (kg)	0.295	0.378	0.068	0.817	0.044	0.918

r = Partial correlation, *p* = significance level, cm = centimetre, kg = kilogram, * = statistically significant

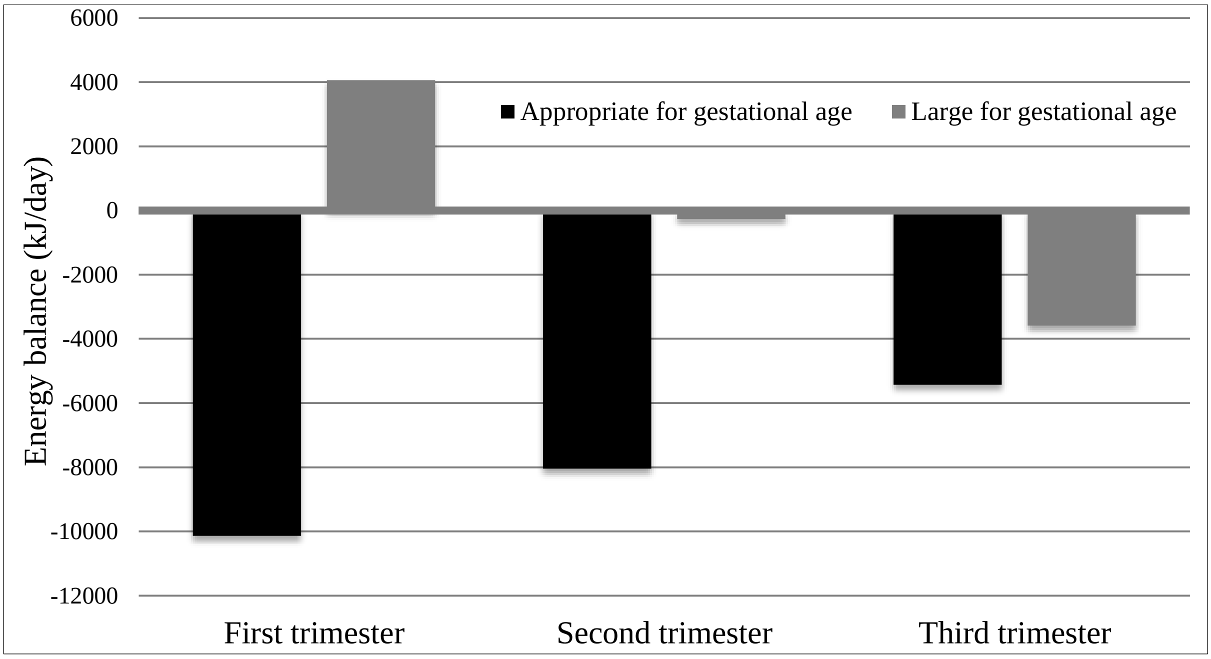

Figure 1: **Birth outcome in relation to energy balance during all trimesters of pregnancy**

Discussion

Main finding

A negative energy balance during pregnancy seems to be beneficial in terms of the delivery of an appropriate for gestational age infant. Additionally, we found energy expenditure in the third trimester to be negatively associated with both the head circumference and weight of the infant. In this study, we included energy balance in relation to birth outcomes, where most previous studies on birth outcomes only focused on one aspect of energy balance, either energy intake (Awasthi *et al.*, 2015; Bell & Robson, 2016; Imdad & Bhutta, 2011; Imdad & Bhutta, 2012; Lagiou *et al.*, 2011; Pereira-Da-Silva *et al.*, 2013) or energy expenditure. The energy balance was not related to birth outcomes during any of the trimesters. Kopp-Hoolihan *et al.* (1999) stated that pregnant women could compensate for a variety of metabolic responses by minimizing fat deposition and by a reduction of the energy needed for activity energy expenditure. This metabolic plasticity provides the potential for healthy birth outcomes independent of energy intake or –expenditure.

Energy expended was mostly considered as physical activity (da Silva *et al.*, 2017; Jayakody & Senanayake, 2015; Leite *et al.*, 2016; Lindqvist *et al.*, 2016; Rêgo *et al.*, 2016; Ruifrok *et al.*, 2014; Tinius *et al.*, 2017) or resting energy expenditure (Berggren *et al.*, 2017). Only a few studies related to birth outcomes and energy balance included both energy intake and expenditure (De Groot *et al.*, 1994; Most *et al.*, 2018). De Groot *et al.* (1994) measured both energy expenditure and intake but concentrated on changes in the digestibility and metabolizability of energy to conserve energy during pregnancy. Similar to our results, they also found a negative energy balance during pregnancy and concluded that possible energy savings through higher diet digestibility and metabolizability were minimal (De Groot *et al.*, 1994). A more recent study, Most *et al.* (2018), researched the energy expenditure and intake of African American women compared to Caucasian women during pregnancy. They found body mass-adjusted energy expenditure to be significantly lower in African-American women as compared to white pregnant women (Most *et al.*, 2018). Therefore the overestimation of energy requirements in African American women during pregnancy might lead to unintentional overeating and contribute to excessive weight gain and postpartum weight retention, which is more prevalent in African American women.

Energy intake and birth outcomes

Malnutrition, both under- and overnutrition, is common in South Africa and varies in underweight and obesity across race and gender (Averett *et al.*, 2014). Energy intake in this study increased from the first to the second trimester, then again declined in the third trimester. Abeysekera *et al.* (2016) found no significant changes in energy intake throughout pregnancy, similar to our results. In a meta-analysis, Jebeile *et al.* (2016) explored the relationship between changes in energy intake in pregnancy and maternal weight gain. In both high- and low-to-middle-income countries, no relationship was found between energy intake from early to late pregnancy and the amount of gestational weight gain (Jebeile *et al.*, 2016).

Energy expenditure and birth outcomes

Nevertheless, accumulation of energy in the extra weight of the mother and fetus occurs, which represents a combination of altered energy intake together with changes in the components of energy expenditure (Yu *et al.*, 2006). High variability has been seen in gestational weight gain, energy deposition, and energy expenditure and, as such, in the energy costs during pregnancy, which should be covered by energy intake (Butte *et al.*, 2004). Löf *et al.* (2005) did not find any significant relationships between the resting energy expenditure in the first ($r = 0.040$) or second half ($r = 0.198$) of pregnancy and birth weight. However, resting energy expenditure was significantly related to gestational weight gain (r = 0.736 in the first half and r = 0.653 in the second half of pregnancy). Resting energy expenditure is a principal component of the energy needs during pregnancy and is reflected by gestational weight gain (Löf *et al.*, 2005). In our cohort, resting energy expenditure was high in the third trimester, possibly accounting for the high energy expenditure and, subsequently, the negative energy balance in this period. It can, therefore, be assumed that the negative relationship between energy expenditure and head circumference and weight of the infant is primarily attributed to resting energy expenditure and not to activity energy expenditure or diet-induced thermogenesis.

We did not find any significant associations between energy expenditure in the first and second trimesters of pregnancy to birth outcomes. Similarly to our findings, Lindqvist *et al.* (2016) also failed to demonstrate associations between energy expenditure due to physical activity and birth weight, which they attributed to insufficient sample size. Another study by Ruifrok *et al.* (2014) also attributed their inability to find associations between physical activity and birth weight for the same reason. Energy expenditure in the third trimester, however, was significantly associated with a decreased head circumference, which is similar to findings by Rao *et al.* (2003) and Bonzini *et al.* (2014). Rao *et al.* (2003) found that the association between physical activity and head circumference only held in undernourished women (< 45 kg) and stated that moderate physical activity only had a small effect on birth weight in well-nourished women. Bonzini *et al.* (2014) focused on occupational, physical activity (long working hours) and cautioned against interpreting their results, motivating the need for more research in order to establish a causal effect.

Clapp (2006) concluded that women's physical activity and diet during various time-points in pregnancy influence birth outcomes by altering the availability of oxygen and substrate of the fetus. Energy expenditure during the third trimester was significantly associated with a decreased birth weight.

Furthermore, women who delivered appropriate birth weight for gestational age infants had a negative energy balance throughout pregnancy. In numerous studies, the positive contribution of physical activity during pregnancy in preventing excessive gestational weight gain has been established (da Silva *et al.*, 2017; Downs *et al.*, 2012; Gaston & Vamos, 2013; Liu *et al.*, 2015) and could provide a means to limit the risks of the detrimental effects of excessive gestational weight gain on birth outcomes, especially in overweight and obese women (Gaston & Vamos, 2013; IOM, 2009 Pearson *et al.*, 2015; Tinius *et al.*, 2017). Through the promotion of physical activity in pregnant South African women, the prevalence of non-communicable diseases and obesity might be reduced for South African women and their offspring (Pearson *et al.*, 2015).

Relationship between obesity/overweight and birth outcomes

The higher prevalence of women who begin pregnancy overweight or obese, with decreased physical activity and increased sedentary behavior, may explain the positive energy deposition of pregnancy (Jebeile *et al.*, 2016). Despite the variability in energy expenditure, Jebeile *et al.* (2016) also reported little or no change in energy intake during pregnancy despite rapid weight gain. They attributed it to the high prevalence of obesity and excessive gestational weight gain currently found in women of reproductive age. Pre-pregnancy body mass index is a strong predictor of birth weight (Galtier-Dereure *et al.*, 2000). A study by Rode *et al.* (2007) found maternal weight gain to strongly affect infant birth weight in underweight and normal-weight women, but less so in overweight and obese women. In our cohort, 46% of the cohort was classified as overweight or obese before pregnancy, which is similar to other South African studies (Averett *et al.*, 2014; Baleta & Mitchell, 2014; Sartorius *et al.*, 2015). Sartorius *et al.* (2015) confirmed the female gender (mainly black/African and white ethnicity) as a vital determinant of the higher obesity risk in South Africa. As stated by Eriksson *et al.* (2010), the high-fat content of the mother stimulates fetal growth. The additional energy deposited due to the excess fat associated with being overweight or obese could have moderated birth weight despite the negative energy balance observed in the first and third trimester and the small positive energy balance in the second trimester.

Birth outcomes

The average gestational weight gain of the women was 13.50 ± 5.59 kg. The Institute of Medicine (IOM, 2009) recommends a gestational weight gain of 11.5 – 16 kg for normal weight (18.5 – 24.9 kg/m^2) women, 7 – 11.5 kg for overweight women (25.0 – 29.9 kg/m^2) and 5 – 9 kg for obese women (≥ 30 kg/m^2). Our cohort only delivered mostly appropriate for gestational age infants with a small percentage of infants falling in the small- and large for gestational age birth weight categories. Another South African study found a 38.54% prevalence of low birth weight infants (gestational age of 37.16 weeks) in their study of 1073 mothers, aged 20 to 35 years in the Tshwane district of South Africa (Tshotetsi *et al.*, 2019). They attributed the high prevalence of low birth weight to older maternal age, prematurity, inadequate prenatal care, and Human Immunodeficiency Virus (Tshotetsi *et al.*, 2019). Although prematurity (born before 37 weeks of gestation) is the main predictor of delivering a low birth weight infant, the participants in our study did not deliver prematurely. The average head circumference of the infants from Tshotetsi *et al.* (2019) was 33.21 ± 2.21 cm, while our study indicated a head circumference of 34.76 ± 1.36 cm, which is very similar.

Strengths and limitations

The strengths of the study include the measurement of both energy intake and energy expenditure, an objective measurement of habitual physical activity, and the longitudinal study design. Ruifrok *et al.* (2014) recommended that both sides of the energy balance should be taken into account in relation to birth weight. We also incorporated an objective measurement of habitual physical activity, the ActiHeart®, which has been validated to accurately measure activity-related energy expenditure during pregnancy (Melzer *et al.*, 2012). The longitudinal study design provided us with the capability to examine the energy intake and energy expenditure patterns of changes taking place throughout pregnancy. As stated by Kopp-Hoolihan *et al.* (1999), many cross-sectional studies have shown an immense amount of variability in the metabolic changes that occur during pregnancy.

Limitations in our study include self-reported prepregnancy weight, small sample size, convenience sampling, as well as the subjective measurement of energy intake measurement. Self-reported prepregnancy weight might have influenced the measurement of gestational weight gain and might thus have influenced our results. Our sample size was smaller than other cross-sectional, population-based studies examining the relationship between energy intake and energy expenditure to birth outcomes. Additionally, convenience sampling might not have been representative of the general pregnant population. The subjective nature of the semi-quantitative food frequency questionnaire could have led to high or low energy reporting, a common observation in pregnant and nonpregnant women (Nowicki *et al.*, 2011) and could thus have influenced equating energy balance and the relationship thereof to birth outcomes.

Conclusion

A negative energy balance during pregnancy seems to be beneficial in terms of delivering an appropriate for gestational age infant. Future research should establish more concrete causal links between energy intake- and expenditure and birth outcomes, implementing preventative measures in order to mitigate the increased prevalence of obesity in pregnant women and its associated detrimental effects on birth outcomes.

Acknowledgments

We thank all the women who participated in the study. The research was funded by the National Research Foundation South African-Swiss Joint Program, award number UID 78606, and the South African Sugar Association, project no 224. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors, and therefore the NRF does not accept liability regarding it.

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CHAPTER 6: SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

6.1. Summary

The high prevalence of obesity in South-African women poses a significant public health problem due to the associated co-morbidities. Obesity and excessive gestational weight gain during pregnancy are associated with an increased risk for adverse birth outcomes such as delivering a large for gestational age infant and delivery complications. Prevention of adverse birth outcomes could potentially be abated by advocating a decreased energy intake by following a healthy diet, decreasing energy intake and increasing energy expenditure by increasing regular physical activity.

The problem statement (Chapter 1) indicated that pregnancy represents a critical period in the reproductive lives of women, influencing the immediate and long-term health of the infant and mother. Energy balance dictates gestational weight gain and correlates with birth weight. Energy imbalances can negatively affect pregnancy outcome. Both excessive and inadequate energy intake can detrimentally influence South African women, who function in different socio-economic circumstances. Both over- and undernutrition are prevalent in South Africa due to rapid urbanisation and severe poverty. There is insufficient longitudinal research in a South African context regarding birth outcomes and energy balance during pregnancy. Therefore, the formulation of the research question for this study was: What is the objectively determined longitudinal energy expenditure and energy intake during pregnancy, and how does it relate to birth outcomes?

The literature review (Chapter 2) provided an overview of the influence of energy balance on birth outcomes during pregnancy. The physiological changes during pregnancy are aimed at conserving energy in order to ensure a viable infant. Energy balance, where energy intake and expenditure is balanced, is essential for optimal birth outcomes. Energy balance also dictates body composition and gestational weight gain. Gestational weight is a significant determinant of the incremental energy needs during pregnancy because it not only determines energy deposition but also determines the increase in total energy expenditure resulting from the energy cost of moving a larger body mass. Energy intake is influenced by pregnancy, as macronutrient metabolism and dietary behaviour changes increase energy intake. However, the accuracy of dietary information during pregnancy is hampered by self-reporting, and consequently, dietary guidelines during pregnancy vary widely. Energy expenditure consists of resting energy expenditure, diet-induced thermogenesis and active energy expenditure. Resting energy expenditure increases during pregnancy due to the metabolism of newly synthesised tissue related to foetal growth. The component of diet-induced thermogenesis is considered to be small and relates to the energy required to digest, absorb, and assimilate food nutrients. Changes in diet-induced thermogenesis tend to be insignificant during pregnancy. Active energy expenditure – the most variable component of total energy expenditure – represents the amount of energy expended in activities of daily living and physical activity.

Physical activity provides numerous benefits for the pregnant mother, as well as for the foetus and can even provide long-term health benefits for both. Benefits to the expectant mother include improved cardiovascular health, prevention of excessive weight gain, protection against gestational diabetes and preeclampsia, enhanced psychological wellbeing, fewer cases of caesarean delivery and a shorter duration of labour. The foetus is not at an increased risk of distress during maternal physical activity. Similarly to the mother, the foetus experiences benefits from maternal physical activity such as enhanced birth weight, decreased fat mass, improved stress tolerance and advanced neurobehavioral maturation. The minimal risks associated with physical activity during pregnancy are due to no studies linking physical activity to adverse birth outcomes such as spontaneous abortions or disabilities at birth. In South Africa, limited research exists with regards to physical activity in the pregnant population. Due to the social and environmental differences of South African women, factors which influence physical activity participation are also likely to be different in South African women as compared to an international cohort. South African women do not meet the prescribed physical activity recommendations during pregnancy. Black urban South African women are a particularly vulnerable group for low levels of habitual physical activity.

Given the physiological effects of diet and habitual physical activity during pregnancy and the influence thereof on foetal growth, promoting a healthy lifestyle during pregnancy is essential to optimal birth outcomes. The theory of foetal origins proposes that a stimulus acting during pregnancy – such as diet and physical activity – may lead to permanent alterations in physiology influencing the adulthood of the infant. Interventions aimed at reducing unhealthy behaviour during pregnancy, such as excessive energy intake and a sedentary lifestyle presented by excessive gestational weight gain, may have the potential to impact the health of future generations positively. Excessive gestational weight gain is associated with many adverse health outcomes for both mother and child, including an increased risk of caesarean delivery, post-partum weight retention and future overweight and obesity in the infant. As foetal growth is locally regulated, many maternal lifestyle factors, such as physical activity and nutrition, influence foetal-placental growth and size at birth. Birth weight is the most easily measured outcome as an indicator of the impact of the intrauterine environment on foetal development. Maternal anthropometrics are an essential factor related to birth weight. Other birth outcomes include head circumference, waist circumference and ponderal index. Modification of energy intake and energy expenditure during pregnancy could provide a preventative or therapeutic value in improving pregnancy outcomes. The interplay between nutrition and physical activity during pregnancy predicts body composition changes and all these factors influence birth outcomes. Against the current knowledge as reported in the literature review, longitudinal data would be needed to investigate and understand the interrelationships between the energy balance, body composition and birth outcomes.

During the longitudinal observational cohort study, Habitual Activity Patterns during PregnancY (HAPPY), energy expenditure and energy intake data was collected. Measurements were taken in the first (9 – 12 weeks), second (20 – 22 weeks) and third (28 – 32 weeks) trimester of pregnancy. Energy intake and macronutrient intake was determined by a semi-quantitative food frequency questionnaire while resting energy expenditure was measured by gas exchange analyses using the Fitmate®. Active energy expenditure and diet-induced thermogenesis were objectively determined by a combined heart rate and accelerometry device – the ActiHeart®. Body composition measurements of height, weight, and fat mass using skinfolds were measured. Birth outcomes (birth weight, birth length, gestational age at birth, and head circumference) were obtained from medical records. From the data collected, the objectives of this study were addressed, and the hypotheses tested. The results of the study were presented in the format of three research manuscripts, Chapter 3 – 5.

Chapter three addressed the first objective of the study to determine the changes in energy intake and expenditure from the first to the third trimester of pregnancy in South African women of the Tlokwe Municipal area. No statistically significant changes were observed in energy intake- and expenditure during pregnancy. The additional energy expenditure in the third trimester, mostly attributed to resting energy expenditure, was partly compensated for by the decrease in active energy expenditure.

Chapter four examined the relationship between longitudinal changes in resting energy expenditure and changes in body composition during pregnancy. Changes in body composition were significantly related to REE from the second to the third trimester, but not from the first to the second trimester.

Chapter five aimed to determine the relationship between energy intake and expenditure and birth outcomes during pregnancy in women of a South African cohort. A negative energy balance during pregnancy shows a trend toward a benefit in terms of delivering an appropriate for gestational age infant.

6.2. Conclusion

The conclusions drawn from this research are presented according to the set hypotheses that were tested, as stated in Chapter One:

<u>Hypothesis 1:</u>

Energy intake will increase significantly, while energy expenditure will decrease significantly from the first to the third trimester of pregnancy in South African women of the Tlokwe Municipal area.

Energy intake increased slightly from the first trimester (8841 ± 3456 kJ/day) to the second trimester (9134 ± 3046 kJ/day); however, energy intake declined in the third trimester (8171 ± 3017 kJ/day). Energy expenditure decreased from the first trimester (10234 ± 2314 kJ/day) to the second trimester (9423 ± 2732 kJ/day), whereas a slight increase was observed in the third trimester (9535 ± 2326 kJ/day). However, the change in both energy intake ($p = 0.66$) and energy expenditure ($p = 0.31$) from the first to the third trimester was not statistically significant.

The changes observed in energy intake and – expenditure during pregnancy in South African women of the Tlokwe Municipality area was not statistically significant and was not in the direction indicated in the hypotheses. Therefore, the hypothesis is ***rejected***.

<u>Hypothesis 2:</u>

The resting energy expenditure of pregnant women will increase significantly from the first to the third trimester of pregnancy and present a significant positive relationship with body composition in women of the Tlokwe Municipal area.

Resting energy expenditure, adjusted for body weight, decreased from the first trimester (82.2 ± 18.0 kJ/kg/day) to the second trimester (74.2 ± 22.8 kJ/kg/day), however, increased in the third trimester (77.7 ± 17.0 kJ/kg/day). The change in resting energy expenditure was, nevertheless, not statistically significant ($p = 0.108$). The change in resting energy expenditure, adjusted for body weight, was statistically significantly related to the change in body mass index ($r = 0.59$, $p = 0.02$), gestational weight gain ($r = 0.55$, $p = 0.03$) and change in fat mass ($r = 0.54$, $p = 0.03$) from the second to the third trimester. Changes in body composition variables significantly predicted the change in resting energy expenditure, adjusted for weight, from the second to the third trimester ($R^2 = 0.93$, $p \leq 0.01$), but not from the first to the second trimester ($R^2 = 0.22$, $p = 0.37$).

The changes observed in resting energy expenditure were not statistically significant. Changes in resting energy expenditure were statistically significantly related to changes in body composition variables from the second to the third trimester and not throughout pregnancy in South African women of the Tlokwe Municipality area. Therefore, the hypothesis is ***partially accepted***.

<u>Hypothesis 3:</u>

A moderate increase in energy intake and energy expenditure during pregnancy will have a significant positive relationship with the birth outcomes of women of the Tlokwe Municipal area.

Energy intake increased slightly from the first trimester (8841 ± 3456 kJ/day) to the second trimester (9134 ± 3046 kJ/day), then decreased in the third trimester (8171 ± 3916 kJ/day). Energy expenditure showed a similar increase from the first (10234 ± 2314 kJ/day) to the second trimester (9423 ± 2732 kJ/day), and then again experienced a slight decrease in the third trimester (9535 ± 2326 kJ/day). Energy intake and energy expenditure through all trimesters of pregnancy were not statistically significantly related to birth outcomes, except for energy expenditure in the third trimester which was negatively associated with head circumference ($r = -0.94$, $p = 0.02$) and birth weight ($r = -0.68$, $p = 0.05$). However, when energy intake and expenditure were described collectively, a negative energy balance during all trimesters seemed to be beneficial in terms of birth outcomes, more specifically in delivering an appropriate for gestational age infant. Therefore, the hypothesis is ***partially accepted*** as a negative energy balance was positively associated with an appropriate for gestational age infant. However, energy intake was not associated with birth outcomes, and energy expenditure only showed a modest relationship to birth outcomes, and only in the third trimester.

During pregnancy, energy is required for foetal development. The manipulation of physiological processes ensures an internal balance of energy availability to the foetus. Both an increase in energy intake and a decrease in energy expenditure have been proposed as mechanisms to achieve an internal energy balance. However, insignificant changes in energy intake- and energy expenditure throughout pregnancy were observed in this study and consequently oversimplifying energy expenditure as a single entity is injudicious. Resting energy expenditure, the most significant contributor to energy expenditure, showed a similar trend compared to energy balance throughout pregnancy. By physiologically regulating resting energy expenditure, and subsequently preserving energy balance, the body ensures that sufficient energy for foetal growth is provided. Interindividual differences in resting energy expenditure, therefore, provide a homeostatic control system to increase energy expenditure in overweight or obese women and abate the increase in resting energy expenditure in lean women during pregnancy. Consequently, the homeostatic control system adjusts energy availability to the foetus, ensuring that it is not excessive or inadequate. Although this homeostatic control promotes a healthy birth outcome, it is not infallible, where excessive energy conserves and -intake and decreased energy expenditure contribute to adverse birth outcomes such as the delivery of a large-for-gestational-age infant.

Resting energy expenditure and as a result - energy balance - therefore also influence body compositional changes throughout pregnancy. Even with insignificant changes in energy intake and –expenditure throughout pregnancy, weight gain still occurred. Dramatic changes in body composition in the second trimester, where gestational weight gain was the highest, coincided with a decrease in resting energy expenditure. Changes in resting energy expenditure also predicted body composition changes in late pregnancy. Realising resting energy expenditure is essential as it can provide information that may be implemented as preventative and rehabilitative concepts to improve birth outcomes. Increasing resting energy expenditure can be achieved by increasing muscle mass through physical activity and exercise. Conversely, physical activity levels decreased during pregnancy, lowering active energy expenditure, which promoted a positive energy balance, and which can lead to risks related to excessive gestational weight.

A negative energy balance, on the other hand, could provide a means to deliver an appropriate for gestational age infant, in particular in the presence of an obese woman. A negative energy balance could be especially relevant in South African women due to the high prevalence of obesity that increases the risk of delivering a large for gestational age infant. Pre-pregnancy weight should also be taken into consideration when determining the energy balance equation and the relationship thereof to birth outcomes as overweight and obese women have surplus energy available before conception and throughout pregnancy. To further substantiate the effect of energy expenditure in the third trimester, energy expenditure had a statistically significant relationship with birth weight. This relationship provides motivation for pregnant women to continue with physical activity in the third trimester of pregnancy in order to increase energy expenditure. The increase in energy expenditure promotes a negative energy balance which is positively related to healthy birth outcomes. As illustrated in Figure 6.1, energy balance – influenced by various components of energy intake and energy expenditure – is related to body composition during pregnancy and body composition changes, are associated with birth outcomes such as birth weight and head circumference.

The answer to the research question posed is that energy expenditure and energy intake did not change throughout pregnancy. However, the various components of energy expenditure did in order to moderate energy balance. Specifically, a decrease in physical activity throughout pregnancy led to a decrease in active energy expenditure, whereas resting energy expenditure showed a similar trend to energy balance. A negative energy balance had a positive association with birth outcomes – delivering an appropriate for gestational age infant, whereas a positive energy balance was negatively associated with birth outcomes – delivering a large for gestational age infant.

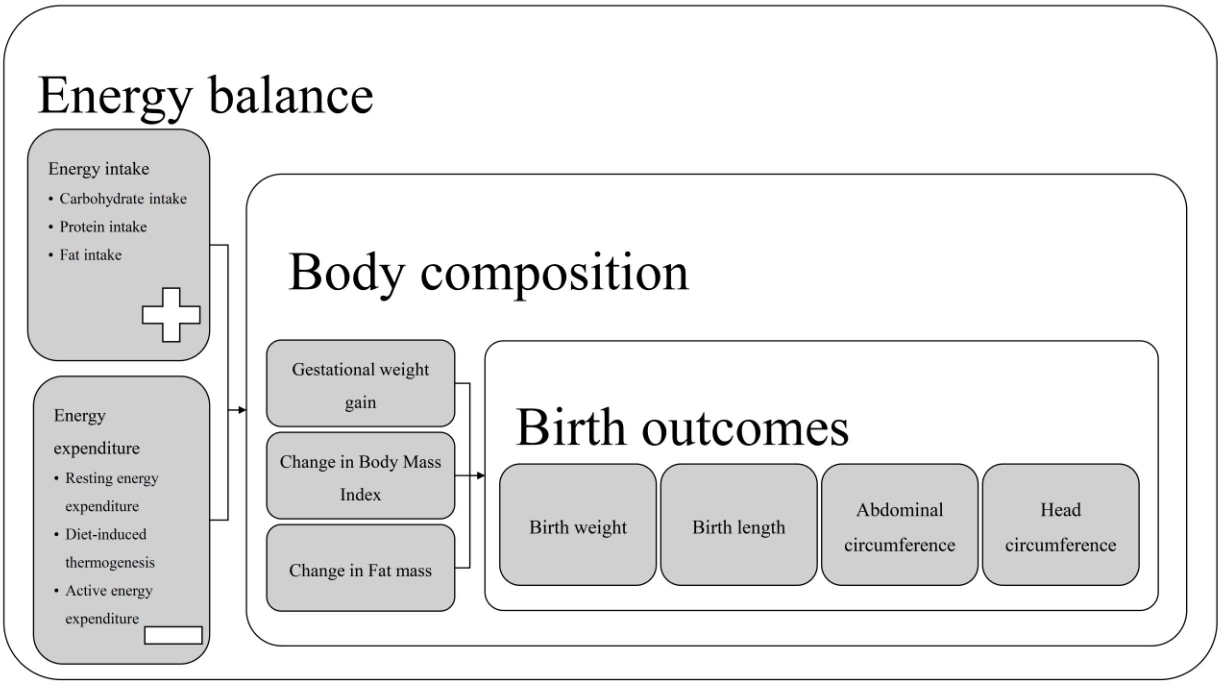

Figure 5-1: The relationship between energy balance, body composition and birth outcomes

Pregnancy represents an integral part of women's health. Pregnancy can be a motivating factor to improve the health of both mother and infant through healthy lifestyle choices. These healthy lifestyle choices include increasing physical activity levels and consuming a diet which will prevent excessive gestational weight gain, but also provide the energy and nutrients essential for healthy birth outcomes. With this study, insight into how changes in energy intake and expenditure influence birth outcomes during pregnancy in South African women of the Tlokwe municipal area was obtained. South African women's diverse culture and different socio-economic status generate varied energy intake and energy expenditure during pregnancy. Additionally, the intense rate of urbanisation in the South African population over the last two decades has caused an increase in the consumption of energy-rich foods in conjunction with a decrease in physical activity levels. The energy imbalance – increased energy intake and decreased energy expenditure – has caused an increase in the prevalence of overweight and obesity, especially in South African women in general. The rise in overweight and obesity pose risks during pregnancy such as gestational diabetes, increased risk of caesarean section as well as the delivery of a large for gestational age infant. Large for gestational age infants are related to subsequent detrimental health outcomes for the offspring in later life. South-African policies should introduce obesity prevention and management interventions which integrate nutrition and physical activity in the preconception period in women of reproductive age. These interventions should be tailored during pregnancy to a level that will not increase gestational weight gain above recommended levels.

A limiting factor in providing accurate advice on optimal weight gain and dietary changes for pregnant women is the lack of research into energy intake and expenditure. Research in terms of energy balance during pregnancy lacks objective measurements of energy expenditure, be it resting energy expenditure and active energy expenditure or energy intake. The use of questionnaires, although easily administered, lacks objectivity and may preclude the establishment of a dose-response relationship between energy expenditure and birth outcomes. Additionally, only a few studies measured energy intake and expenditure longitudinally. Further information on energy balance during pregnancy is essential before guidelines are produced in order to offer advice regarding gestational weight gain. Objective measurements of changes in energy expenditure are crucial when implementing effective weight management programmes in maternal health.

6.3. Contribution to current knowledge

The novelty of the findings of this study is the provision of objective longitudinal data on energy intake and expenditure during pregnancy, how it relates to body composition and its relationship to birth outcomes. Furthermore, the study divided each integral component of the energy balance equation, whereas other studies only focused on a single component and related the specific component to birth outcomes. When equating predictors of birth outcomes, it is necessary to incorporate an objective, free-living, longitudinal study design throughout the whole pregnancy. Our study introduced the concept of recommending increased levels of physical activity and a healthy dietary intake in order to promote a negative energy balance during pregnancy, especially in overweight or obese women, which will be beneficial in terms of delivering an appropriate for gestational age infant. Implementing the aforementioned also provides a means to improve compliance with gestational weight gain guidelines.

6.4. Limitations

Limitations noted when interpreting the results of this study and which should be taken into consideration in future research, are:

- Drop-out of participants due to the longitudinal nature of the study was a challenge, especially of women from low-socio-economic areas. Drop-out was mainly due to non-compliance with scheduled clinic visits.
- Pre-pregnancy was self-reported and based on participant recall in the first trimester.
- Energy intake data was collected using a semi-quantitative food frequency questionnaire, and thus recall bias and underreporting of energy intake, a common occurrence during pregnancy, might have occurred.

- Resting energy expenditure was measured with indirect calorimetry instead of expensive and sophisticated direct calorimetry. Even though indirect calorimetry is useful in large observational studies, as it does not require strict precautions, determining the absolute resting metabolic rate with direct calorimetry would have provided more accurate and reliable results. Furthermore, the resting metabolic rate of the foetus was not taken into consideration.
- The lack of standardised body composition measurements in pregnant women was limited to basic anthropometric measurements, including height, weight, skinfold measurements restricted to three anatomical sites. Although incorporated in the study, limited research exists relating to algorithms used to measure fat mass through skinfolds during pregnancy. Algorithms used to predict total body fat from skinfolds assume a fixed proportion between peripheral and central body fat, which might not have been the case, especially during pregnancy.
- As gestational diabetes mellitus and antiretroviral medication are positively associated with new-born adiposity, controlling for this co-variate would have provided a more accurate determination of the relationship between energy intake, energy expenditure and birth outcomes.

6.5. Recommendations

The following recommendations might strengthen the determination of a relationship between energy intake and expenditure to birth outcomes.

- Recruitment of participants can be oversampled by 50% to allow for possible drop-out.
- Pregravid recruitment of participants will minimize the bias of self-reported pre-pregnancy weight.
- Including and educating participants on food diaries and cell phone applications to measure and the notation of energy-, macro- and micronutrient intake in a free-living environment throughout pregnancy will improve our understanding of dietary intake during pregnancy and limit recall bias and underreporting of energy intake.
- Measuring absolute resting metabolic rate through direct calorimetry in a clinical environment and factoring in the resting metabolic rate of the foetus will strengthen the findings.
- More sophisticated measurements of body composition during pregnancy can be incorporated – underwater weighing, air displacement plethysmography, deuterium dilution, ultrasound and magnetic resonance imaging. Establishing accurate algorithms to determine body composition in pregnant women is warranted.

6.6. Future research

Based on the findings of this study, and to obtain a better understanding of the energy balance during pregnancy, future research should consider the following potential investigations:

- Determining the minimal clinical important difference (MCID) in active energy expenditure, resting energy expenditure, energy intake and gestational weight gain associated with a positive birth outcome. The establishment of MCID should be ethnic-specific and will assist in drafting dietary intake guidelines in conjunction with physical activity guidelines during pregnancy to balance energy provision for both mother and offspring.
- Developing a dietary and physical activity intervention study in overweight- or obese pregnant women to understand the interaction and intervention effect on the energy balance of pregnant women, body composition changes and birth outcomes.
- Researching body compositional changes during pregnancy with objective measurements in order to obtain accurate data for understanding the associated risk for birth outcomes.
- Determination of the fat- and fat-free mass of the infant could help to determine the subtle effect of maternal physical activity and diet during pregnancy on infant body composition and the implication thereof for long-term health.

APPENDICES

Appendix A: Ethical approval

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Ethics Committee
Tel +27 18 299 4850
Fax +27 18 293 5329
Email Ethics@nwu.ac.za

Prof SJ Moss

ETHICS APPROVAL OF PROJECT

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

Project title : Longitudinal Patterns of Habitual Physical Activity in Healthy Pregnant South-African Women and Associations with Foetal Growth Parameters and Birth Outcomes	
Ethics number:	N W U - 0 0 4 4 - 1 0 - A 1
Approval date: 2010-07-13	**Expiry date**: 2015-07-12

Special conditions of the approval (if any): None

General conditions:

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

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

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

Yours sincerely

Prof MMJ Lowes
(chair NWU Ethics Committee)

Appendix B: Language editing

Brendon John Wocke
Brendon.wocke@gmail.com

P.O .Box 1150
Knysna
6570

I, the undersigned, Brendon Wocke, hereby confirm that I have proofread and edited the doctoral thesis entitled

Physical activity and energy balance in relation to birth outcomes during pregnancy in the Tlokwe municipal area: A longitudinal study

AF van Oort

Please do not hesitate to contact me should you have any questions.

Sincerely,

Brendon Wocke

Wocke

Appendix C: Informed consent

Habitual Activity Patterns
during
Pregnancy
(HAPPY-study)

NORTH-WEST UNIVERSITY
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Physical activity, Sport and Recreation
Tel: (018) 018 299 1821

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

25 January 2010

Informed consent

PART 1

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

Measurements will be conducted during four stages/measurement points of your pregnancy. These stages are: 1st trimester (9 - 12 weeks), 2nd trimester (20 - 22 weeks), 3rd trimester (28 - 32 weeks) and 3 months after the birth of the baby. The duration of the test will be approximately one hour and 30 minutes. The test protocol will be explained during the evaluation. You will be requested to remove your upper clothes for accurate anthropometric- and body composition measurements. Your habitual physical activity will be measured by Actiheart® heart rate monitor with integrated accelerometer (CamNtech Ltd., UK), which will require you to wear this instrument for 7 consecutive days and return it in its original state. After this, an eight minute step test with a ramp protocol on a step box (21.5 cm in height) will be performed. As with any exercise test, certain risks and discomforts may apply. The risks involved in this exercise test may include abnormal blood pressure, fainting, disorder of heartbeat, and in the most extreme instances, heart attack, stroke or death. Every effort will be made to minimize these risks by continuously monitoring participants throughout exercise testing. It is the participant's responsibility to inform the study investigator if you feel dizzy, ill-feeling or any other symptoms. If any discomfort is experienced, you may stop at any time during the step test. A resting metabolic rate measurement will also be performed. You will be requested to breathe through an anti-bacterial filter for 15 minutes after a 10 minute resting period.

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

1. Department performing the research: **Physical activity, Sport and Recreation (PhASRec)**
2. Title of the project: **Longitudinal patterns of Habitual physical activity in Healthy pregnant South African women and associations with foetal growth parameters and birth outcomes**
3. Full names, surname and qualifications of the researcher/project leader: **Sarah Johanna Moss (PhD., MBA. Registered Biokineticist)**
4. Job title of the project leader/researcher: **Associate Professor, Niche area research leader: PhASRec**
5. Full names, surname and qualifications of the persons performing the tests: **Abie van Oort, BSc (Hon), Registered Biokineticist**
6. Name of supervising docter: **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. . ...

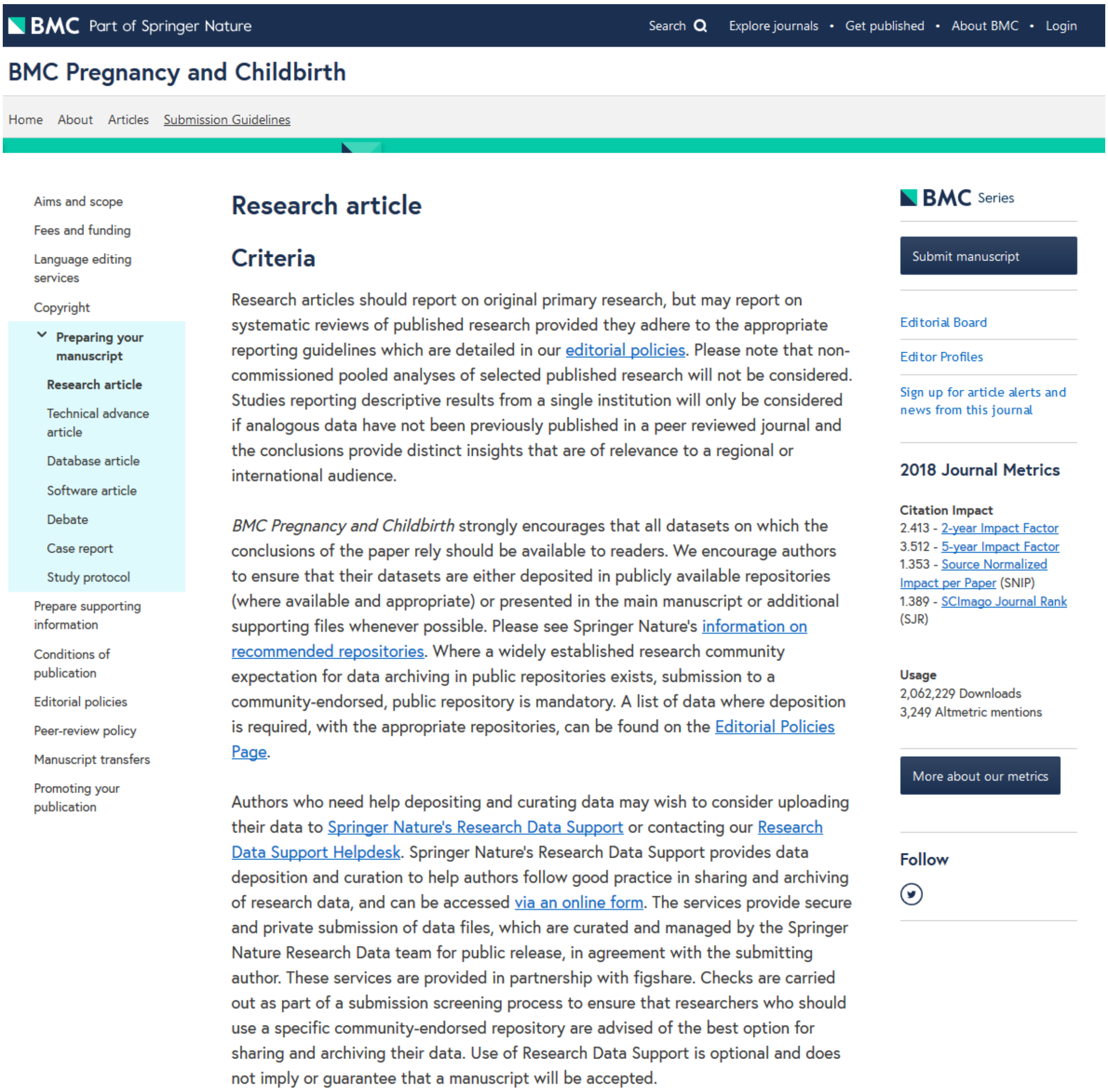
Signed at POTCHEFSTROOM on the …………………………

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 D: Journal Guidelines – BMC Pregnancy and Childbirth



Research article

Criteria

Research articles should report on original primary research, but may report on systematic reviews of published research provided they adhere to the appropriate reporting guidelines which are detailed in our editorial policies. Please note that non-commissioned pooled analyses of selected published research will not be considered. Studies reporting descriptive results from a single institution will only be considered if analogous data have not been previously published in a peer reviewed journal and the conclusions provide distinct insights that are of relevance to a regional or international audience.

BMC Pregnancy and Childbirth strongly encourages that all datasets on which the conclusions of the paper rely should be available to readers. We encourage authors to ensure that their datasets are either deposited in publicly available repositories (where available and appropriate) or presented in the main manuscript or additional supporting files whenever possible. Please see Springer Nature's information on recommended repositories. Where a widely established research community expectation for data archiving in public repositories exists, submission to a community-endorsed, public repository is mandatory. A list of data where deposition is required, with the appropriate repositories, can be found on the Editorial Policies Page.

Authors who need help depositing and curating data may wish to consider uploading their data to Springer Nature's Research Data Support or contacting our Research Data Support Helpdesk. Springer Nature's Research Data Support provides data deposition and curation to help authors follow good practice in sharing and archiving of research data, and can be accessed via an online form. The services provide secure and private submission of data files, which are curated and managed by the Springer Nature Research Data team for public release, in agreement with the submitting author. These services are provided in partnership with figshare. Checks are carried out as part of a submission screening process to ensure that researchers who should use a specific community-endorsed repository are advised of the best option for sharing and archiving their data. Use of Research Data Support is optional and does not imply or guarantee that a manuscript will be accepted.

2018 Journal Metrics

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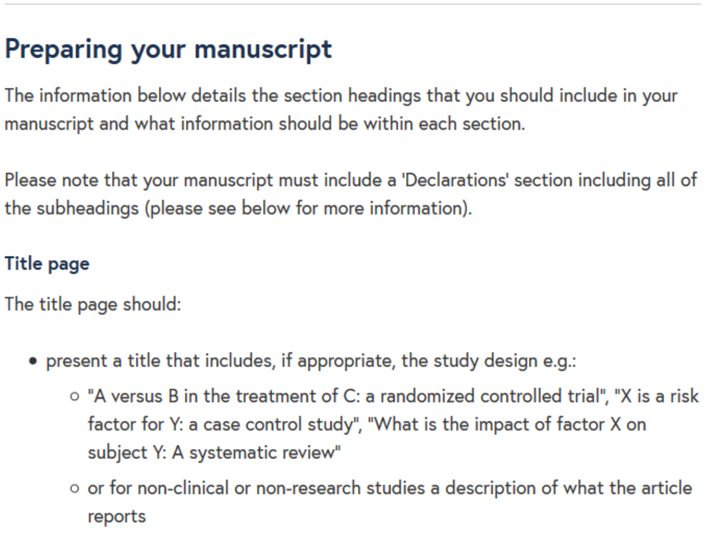

Preparing your manuscript

The information below details the section headings that you should include in your manuscript and what information should be within each section.

Please note that your manuscript must include a 'Declarations' section including all of the subheadings (please see below for more information).

Title page

The title page should:

- present a title that includes, if appropriate, the study design e.g.:
  - "A versus B in the treatment of C: a randomized controlled trial", "X is a risk factor for Y: a case control study", "What is the impact of factor X on subject Y: A systematic review"
  - or for non-clinical or non-research studies a description of what the article reports

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Abstract

The Abstract should not exceed 350 words. Please minimize the use of abbreviations and do not cite references in the abstract. Reports of randomized controlled trials should follow the CONSORT extension for abstracts. The abstract must include the following separate sections:

- **Background:** the context and purpose of the study
- **Methods:** how the study was performed and statistical tests used
- **Results:** the main findings
- **Conclusions:** brief summary and potential implications
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Keywords

Three to ten keywords representing the main content of the article.

Background

The Background section should explain the background to the study, its aims, a summary of the existing literature and why this study was necessary or its contribution to the field.

Methods

The methods section should include:

- the aim, design and setting of the study
- the characteristics of participants or description of materials
- a clear description of all processes, interventions and comparisons. Generic drug names should generally be used. When proprietary brands are used in research, include the brand names in parentheses
- the type of statistical analysis used, including a power calculation if appropriate

Results

This should include the findings of the study including, if appropriate, results of statistical analysis which must be included either in the text or as tables and figures.

Discussion

This section should discuss the implications of the findings in context of existing research and highlight limitations of the study.

Conclusions

This should state clearly the main conclusions and provide an explanation of the importance and relevance of the study reported.

List of abbreviations

If abbreviations are used in the text they should be defined in the text at first use, and a list of abbreviations should be provided.

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All manuscripts must contain the following sections under the heading 'Declarations':

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- Consent for publication
- Availability of data and materials
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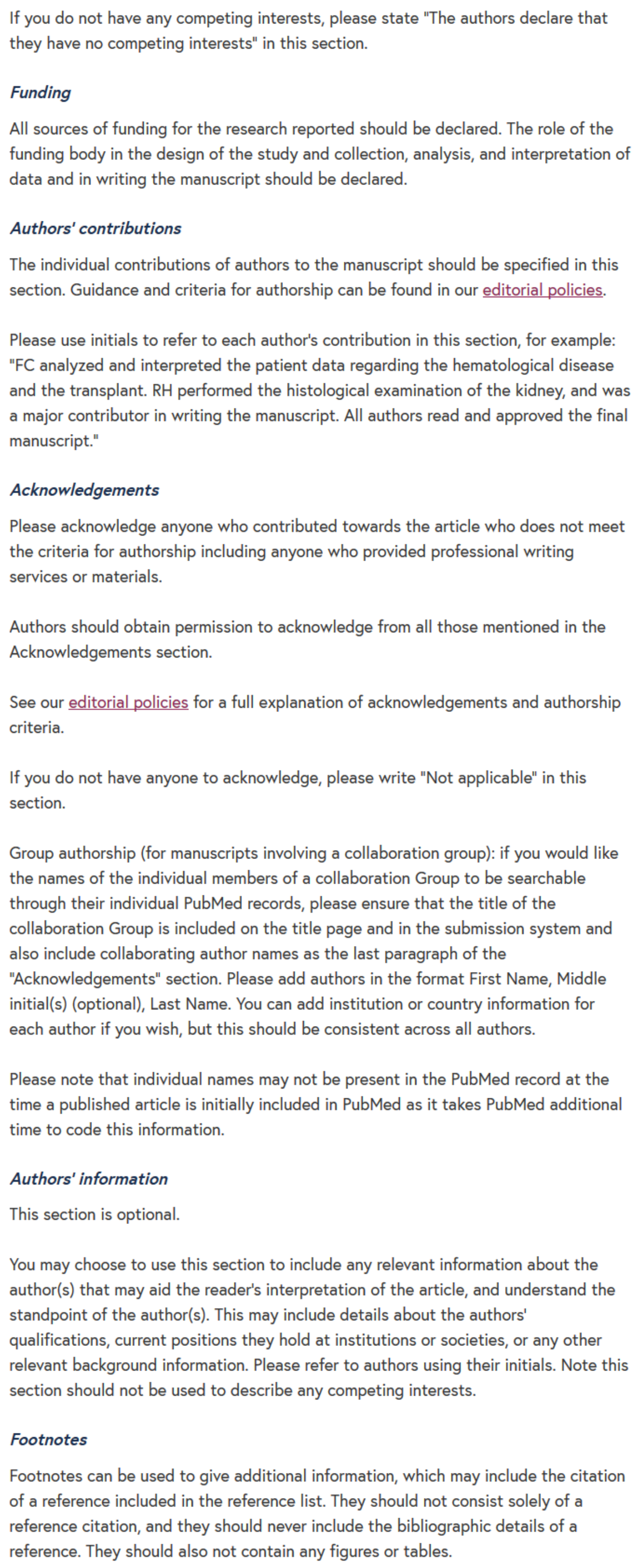

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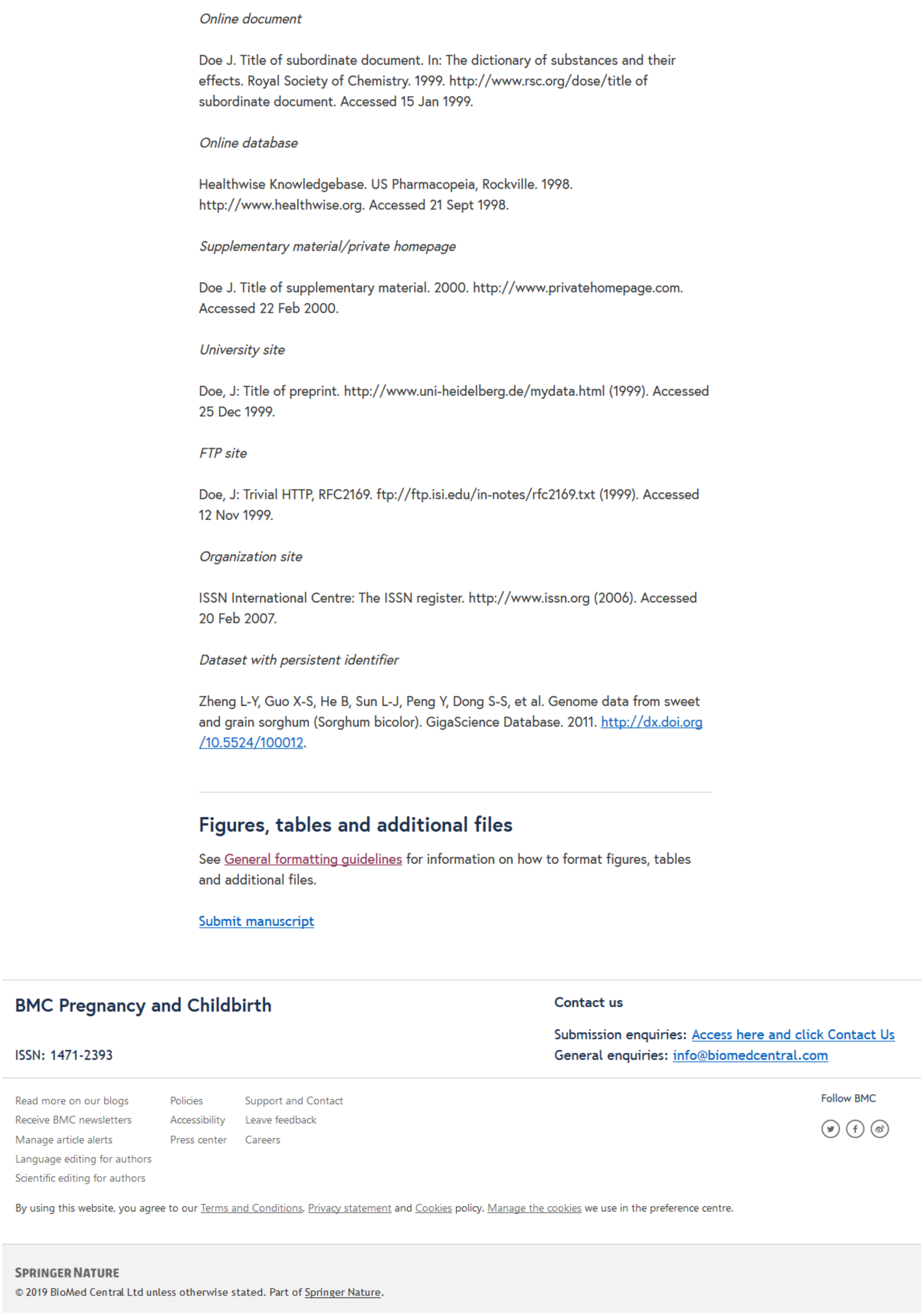

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Doe J. Title of subordinate document. In: The dictionary of substances and their effects. Royal Society of Chemistry. 1999. http://www.rsc.org/dose/title of subordinate document. Accessed 15 Jan 1999.

Online database

Healthwise Knowledgebase. US Pharmacopeia, Rockville. 1998. http://www.healthwise.org. Accessed 21 Sept 1998.

Supplementary material/private homepage

Doe J. Title of supplementary material. 2000. http://www.privatehomepage.com. Accessed 22 Feb 2000.

University site

Doe, J: Title of preprint. http://www.uni-heidelberg.de/mydata.html (1999). Accessed 25 Dec 1999.

FTP site

Doe, J: Trivial HTTP, RFC2169. ftp://ftp.isi.edu/in-notes/rfc2169.txt (1999). Accessed 12 Nov 1999.

Organization site

ISSN International Centre: The ISSN register. http://www.issn.org (2006). Accessed 20 Feb 2007.

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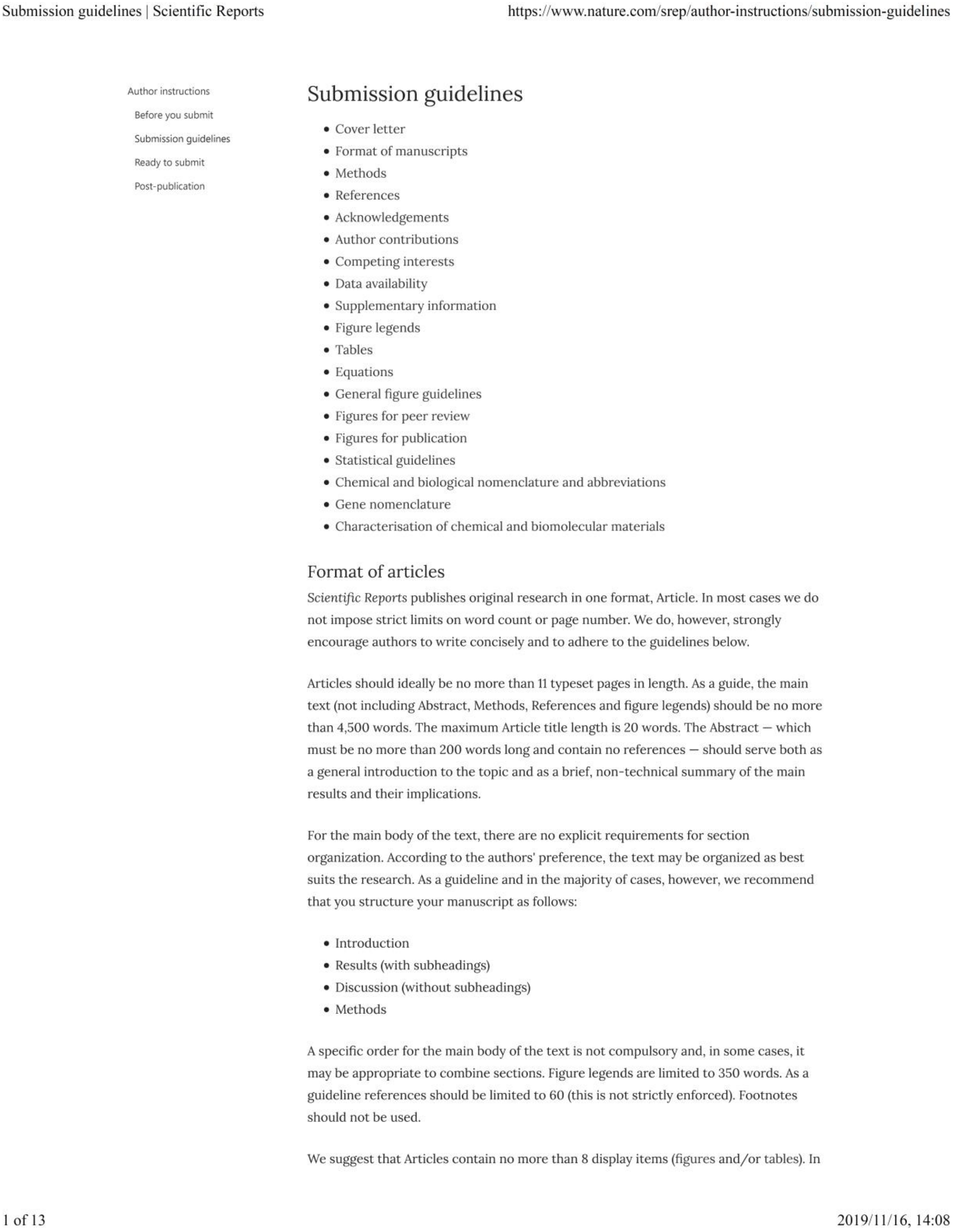

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- Format of manuscripts
- Methods
- References
- Acknowledgements
- Author contributions
- Competing interests
- Data availability
- Supplementary information
- Figure legends
- Tables
- Equations
- General figure guidelines
- Figures for peer review
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- Chemical and biological nomenclature and abbreviations
- Gene nomenclature
- Characterisation of chemical and biomolecular materials

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Articles should ideally be no more than 11 typeset pages in length. As a guide, the main text (not including Abstract, Methods, References and figure legends) should be no more than 4,500 words. The maximum Article title length is 20 words. The Abstract — which must be no more than 200 words long and contain no references — should serve both as a general introduction to the topic and as a brief, non-technical summary of the main results and their implications.

For the main body of the text, there are no explicit requirements for section organization. According to the authors' preference, the text may be organized as best suits the research. As a guideline and in the majority of cases, however, we recommend that you structure your manuscript as follows:

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- Results (with subheadings)
- Discussion (without subheadings)
- Methods

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Manaster, J. Sloth squeak. *Scientific American Blog Network* http://blogs.scientificamerican.com/psi-vid/2014/04/09/sloth-squeak (2014).

Hao, Z., AghaKouchak, A., Nakhjiri, N. & Farahmand, A. Global integrated drought monitoring and prediction system (GIDMaPS) data sets. *figshare* https://doi.org/10.6084/m9.figshare.853801 (2014).

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General figure guidelines

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Figures should be numbered separately with Arabic numerals in the order of occurrence in the text of the manuscript. When appropriate, figures should include error bars. A description of the statistical treatment of error analysis should be included in the figure legend. Please note that schemes are not used; sequences of chemical reactions or experimental procedures should be submitted as figures, with appropriate captions. A limited number of uncaptioned graphics depicting chemical structures - each labelled with their name, by a defined abbreviation, or by the bold Arabic numeral - may be included in a manuscript.

Figure lettering should be in a clear, sans-serif typeface (for example, Helvetica); the same typeface in the same font size should be used for all figures in a paper. Use 'symbols' font for Greek letters. All display items should be on a white background, and should avoid excessive boxing, unnecessary colour, spurious decorative effects (such as three-dimensional 'skyscraper' histograms) and highly pixelated computer drawings. The vertical axis of histograms should not be truncated to exaggerate small differences. Labelling must be of sufficient size and contrast to be readable, even after appropriate reduction. The thinnest lines in the final figure should be no smaller than one point wide. Authors will see a proof that will include figures.

Figures divided into parts should be labelled with a lower-case bold a, b, and so on, in the same type size as used elsewhere in the figure. Lettering in figures should be in lower-case type, with only the first letter of each label capitalized. Units should have a single space between the number and the unit, and follow SI nomenclature (for example, ms rather than msec) or the nomenclature common to a particular field. Thousands should be separated by commas (1,000). Unusual units or abbreviations should be spelled out in full or defined in the legend. Scale bars should be used rather than magnification factors, with the length of the bar defined on the bar itself rather than in the legend. In legends, please use visual cues rather than verbal explanations such as "open red triangles".

Unnecessary figures should be avoided: data presented in small tables or histograms, for instance, can generally be stated briefly in the text instead. Figures should not contain more than one panel unless the parts are logically connected; each panel of a multipart figure should be sized so that the whole figure can be reduced by the same amount and reproduced at the smallest size at which essential details are visible.

Figures for peer review

At the initial submission stage authors may choose to upload separate figure files or to incorporate figures into the main article file, ensuring that any inserted figures are of sufficient quality to be clearly legible.

When submitting a revised manuscript all figures must be uploaded as separate figure files ensuring that the image quality and formatting conforms to the specifications below.

Figures for publication

Each complete figure must be supplied as a separate file upload. Multi-part/panel figures must be prepared and arranged as a single image file (including all sub-parts; a, b, c, etc.). Please do not upload each panel individually.

Please read the digital images integrity and standards section of our Editorial and Publishing Policies. When possible, we prefer to use original digital figures to ensure the highest-quality reproduction in the journal. When creating and submitting digital files, please follow the guidelines below. Failure to do so, or to adhere to the following guidelines, can significantly delay publication of your work.

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1. Line art, graphs, charts and schematics

For optimal results, all line art, graphs, charts and schematics should be supplied in vector format, such as EPS or AI, and should be saved or exported as such directly from the application in which they were made. Please ensure that data points and axis labels are clearly legible.

2. Photographic and bitmap images

All photographic and bitmap images should be supplied in a bitmap image format such as tiff, jpg, or psd. If saving tiff files, please ensure that the compression option is selected to avoid very large file sizes.

Please do not supply Word or Powerpoint files with placed images. Images can be supplied as RGB or CMYK (note: we will not convert image colour modes).

Figures that do not meet these standards will not reproduce well and may delay publication until we receive high-resolution images.

3. Chemical structures

Chemical structures should be produced using ChemDraw or a similar program. All chemical compounds must be assigned a bold, Arabic numeral in the order in which the compounds are presented in the manuscript text. Structures should then be exported into a 300 dpi RGB tiff file before being submitted.

4. Stereo images

Stereo diagrams should be presented for divergent 'wall-eyed' viewing, with the two panels separated by 5.5 cm. In the final accepted version of the manuscript, the stereo images should be submitted at their final page size.

Statistical guidelines

Every article that contains statistical testing should state the name of the statistical test, the n value for each statistical analysis, the comparisons of interest, a justification for the use of that test (including, for example, a discussion of the normality of the data when the test is appropriate only for normal data), the alpha level for all tests, whether the tests were one-tailed or two-tailed, and the actual P value for each test (not merely "significant" or "P < 0.05"). It should be clear what statistical test was used to generate every P value. Use of the word "significant" should always be accompanied by a P value; otherwise, use "substantial," "considerable," etc.

Data sets should be summarized with descriptive statistics, which should include the n value for each data set, a clearly labelled measure of centre (such as the mean or the median), and a clearly labelled measure of variability (such as standard deviation or range). Ranges are more appropriate than standard deviations or standard errors for small data sets. Graphs should include clearly labelled error bars. Authors must state whether a number that follows the ± sign is a standard error (s.e.m.) or a standard deviation (s.d.).

Authors must justify the use of a particular test and explain whether their data conform to the assumptions of the tests. Three errors are particularly common:

- Multiple comparisons: When making multiple statistical comparisons on a single data set, authors should explain how they adjusted the alpha level to avoid an inflated Type I error rate, or they should select statistical tests appropriate for multiple groups (such as ANOVA rather than a series of t-tests).
- Normal distribution: Many statistical tests require that the data be approximately normally distributed; when using these tests, authors should explain how they tested their data for normality. If the data do not meet the assumptions of the test, then a non-parametric alternative should be used instead.
- Small sample size: When the sample size is small (less than about 10), authors should use tests appropriate to small samples or justify their use of large-sample tests.

Chemical and biological nomenclature and abbreviations

Molecular structures are identified by bold, Arabic numerals assigned in order of presentation in the text. Once identified in the main text or a figure, compounds may be referred to by their name, by a defined abbreviation, or by the bold Arabic numeral (as long as the compound is referred to consistently as one of these three).

When possible, authors should refer to chemical compounds and biomolecules using systematic nomenclature, preferably using IUPAC. Standard chemical and biological abbreviations should be used. Unconventional or specialist abbreviations should be defined at their first occurrence in the text.

Gene nomenclature

Authors should use approved nomenclature for gene symbols, and use symbols rather than italicized full names (for example Ttn, not titin). Please consult the appropriate nomenclature databases for correct gene names and symbols. A useful resource is LocusLink.

Approved human gene symbols are provided by HUGO Gene Nomenclature Committee (HGNC), e-mail: hgnc@genenames.org; see also www.genenames.org. Approved mouse symbols are provided by The Jackson Laboratory, e-mail: nomen@informatics.jax.org; see also www.informatics.jax.org/mgihome/nomen.

For proposed gene names that are not already approved, please submit the gene symbols to the appropriate nomenclature committees as soon as possible, as these must be deposited and approved before publication of an article.

Avoid listing multiple names of genes (or proteins) separated by a slash, as in 'Oct4/Pou5f1', as this is ambiguous (it could mean a ratio, a complex, alternative names or different subunits). Use one name throughout and include the other at first mention: 'Oct4 (also known as Pou5f1)'.

Characterization of chemical and biomolecular materials

Scientific Reports is committed to publishing technically sound research. Manuscripts submitted to the journal will be held to rigorous standards with respect to experimental methods and characterization of new compounds. Authors must provide adequate data to support their assignment of identity and purity for each new compound described in the manuscript. Authors should provide a statement confirming the source, identity and purity of known compounds that are central to the scientific study, even if they are purchased or resynthesized using published methods.

1. Chemical identity

Chemical identity for organic and organometallic compounds should be established through spectroscopic analysis. Standard peak listings (see formatting guidelines below) for 1H NMR and proton-decoupled 13C NMR should be provided for all new compounds. Other NMR data should be reported (31P NMR, 19F NMR, etc.) when appropriate. For new materials, authors should also provide mass spectral data to support molecular weight identity. High-resolution mass spectral (HRMS) data are preferred. UV or IR spectral data may be reported for the identification of characteristic functional groups, when appropriate. Melting-point ranges should be provided for crystalline materials. Specific rotations may be reported for chiral compounds. Authors should provide references, rather than detailed procedures, for known compounds, unless their protocols represent a departure from or improvement on published methods.

2. Combinational compound libraries

Authors describing the preparation of combinatorial libraries should include standard characterization data for a diverse panel of library components.

3. Biomolecular identity

For new biopolymeric materials (oligosaccharides, peptides, nucleic acids, etc.), direct structural analysis by NMR spectroscopic methods may not be possible. In these cases, authors must provide evidence of identity based on sequence (when appropriate) and mass spectral characterization.

4. Biological constructs

Authors should provide sequencing or functional data that validates the identity of their biological constructs (plasmids, fusion proteins, site-directed mutants, etc.) either in the manuscript text or the Methods section, as appropriate.

5. Sample purity

Evidence of sample purity is requested for each new compound. Methods for purity analysis depend on the compound class. For most organic and organometallic compounds, purity may be demonstrated by high-field 1H NMR or 13C NMR data, although elemental analysis (±0.4%) is encouraged for small molecules. Quantitative analytical methods including chromatographic (GC, HPLC, etc.) or electrophoretic analyses may be used to demonstrate purity for small molecules and polymeric materials.

6. Spectral data

Detailed spectral data for new compounds should be provided in list form (see below) in the Methods section. Figures containing spectra generally will not be published as a manuscript figure unless the data are directly relevant to the central conclusions of the paper. Authors are encouraged to include high-quality images of spectral data for key compounds in the Supplementary Information. Specific NMR assignments should be listed after integration values only if they were unambiguously determined by multidimensional NMR or decoupling experiments. Authors should provide information about how assignments were made in a general Methods section.

Example format for compound characterization data. mp: 100-102 °C (lit.^{ref} 99-101 °C); TLC ($CHCl_3$:MeOH, 98:2 v/v): $R_f = 0.23$; $[\alpha]_D = -21.5$ (0.1 M in n-hexane); ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.30 (s, 1H), 7.55-7.41 (m, 6H), 5.61 (d, J = 5.5 Hz, 1H), 5.40 (d, J = 5.5 Hz, 1H), 4.93 (m, 1H), 4.20 (q, J = 8.5 Hz, 2H), 2.11 (s, 3H), 1.25 (t, J = 8.5 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 165.4, 165.0, 140.5, 138.7, 131.5, 129.2, 118.6, 84.2, 75.8, 66.7, 37.9, 20.1; IR (Nujol): 1765 cm^{-1}; UV/Vis: λ_{max} 267 nm; HRMS (m/z): $[M]^+$ calcd. for $C_{20}H_{15}C_{l2}NO_5$, 420.0406; found, 420.0412; analysis (calcd., found for $C_{20}H_{15}C_{l2}NO_5$): C (57.16, 57.22), H (3.60, 3.61), Cl (16.87, 16.88), N (3.33, 3.33), O (19.04, 19.09).

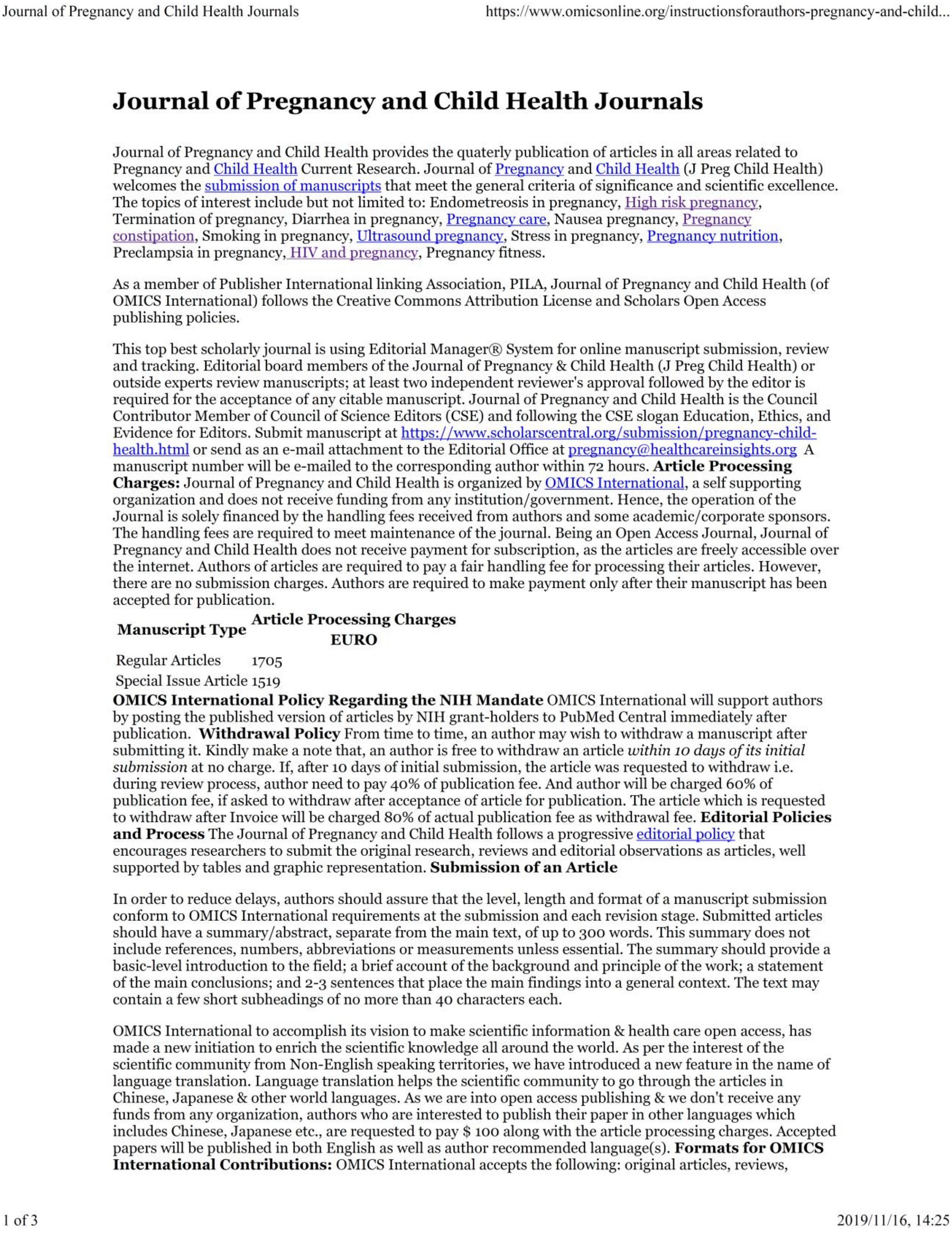
7. Crystallographic data for small molecules

Manuscripts reporting new three-dimensional structures of small molecules from crystallographic analysis should include a .cif file and a structural figure with probability ellipsoids for publication as Supplementary Information. These must have been checked using the IUCR's CheckCIF routine, and a PDF copy of the output must be included with the submission, together with a justification for any alerts reported. Crystallographic data for small molecules should be submitted to the Cambridge Structural Database and the deposition number referenced appropriately in the manuscript. Full access must be provided on publication.

8. Macromolecular structural data

Manuscripts reporting new structures should contain a table summarizing structural and refinement statistics. Templates are available for such tables describing NMR and X-ray crystallography data. To facilitate assessment of the quality of the structural data, a stereo image of a portion of the electron density map (for crystallography papers) or of the superimposed lowest energy structures (≥10; for NMR papers) should be provided with the submitted manuscript. If the reported structure represents a novel overall fold, a stereo image of the entire structure (as a backbone trace) should also be provided.

Appendix F: Journal Guidelines – Journal of Pregnancy and Child Health Journals



Journal of Pregnancy and Child Health Journals https://www.omicsonline.org/instructionsforauthors-pregnancy-and-child...

Journal of Pregnancy and Child Health Journals

Journal of Pregnancy and Child Health provides the quaterly publication of articles in all areas related to Pregnancy and Child Health Current Research. Journal of Pregnancy and Child Health (J Preg Child Health) welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. The topics of interest include but not limited to: Endometreosis in pregnancy, High risk pregnancy, Termination of pregnancy, Diarrhea in pregnancy, Pregnancy care, Nausea pregnancy, Pregnancy constipation, Smoking in pregnancy, Ultrasound pregnancy, Stress in pregnancy, Pregnancy nutrition, Preclampsia in pregnancy, HIV and pregnancy, Pregnancy fitness.

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Manuscript Type	Article Processing Charges EURO
Regular Articles	1705
Special Issue Article	1519

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In order to reduce delays, authors should assure that the level, length and format of a manuscript submission conform to OMICS International requirements at the submission and each revision stage. Submitted articles should have a summary/abstract, separate from the main text, of up to 300 words. This summary does not include references, numbers, abbreviations or measurements unless essential. The summary should provide a basic-level introduction to the field; a brief account of the background and principle of the work; a statement of the main conclusions; and 2-3 sentences that place the main findings into a general context. The text may contain a few short subheadings of no more than 40 characters each.

OMICS International to accomplish its vision to make scientific information & health care open access, has made a new initiation to enrich the scientific knowledge all around the world. As per the interest of the scientific community from Non-English speaking territories, we have introduced a new feature in the name of language translation. Language translation helps the scientific community to go through the articles in Chinese, Japanese & other world languages. As we are into open access publishing & we don't receive any funds from any organization, authors who are interested to publish their paper in other languages which includes Chinese, Japanese etc., are requested to pay $ 100 along with the article processing charges. Accepted papers will be published in both English as well as author recommended language(s). **Formats for OMICS International Contributions:** OMICS International accepts the following: original articles, reviews,

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abstracts, addendums, announcements, article-commentaries, book reviews, rapid communications, letters to the editor, annual meeting abstracts, conference proceedings, calendars, case-reports, corrections, discussions, meeting-reports, news, obituaries, orations, product reviews, hypotheses and analyses. **Cover Letter:** All submissions should be accompanied by a 500 words or less cover letter briefly stating the significance of the research, agreement of authors for publication, number of figures and tables, supporting manuscripts, and supplementary information. Also, include current telephone and fax numbers, as well as postal and E-mail address of corresponding author to maintain communication. **Article Preparation Guidelines Manuscript title:** The title should be limited to 25 words or less and should not contain abbreviations. The title should be a brief phrase describing the contents of the paper. **Author Information:** Complete names and affiliation of all authors, including contact details of corresponding author (Telephone, Fax and E-mail address). **Abstract:** The abstract should be informative and completely self-explanatory, briefly present the topic, state the scope of the experiments, indicate significant data, and point out major findings and conclusions. The abstract should summarize the manuscript content in 300 words or less. Standard nomenclature should be used and abbreviations should be avoided. The preferable format should accommodate a description of the study background, methods, results and conclusion. Following the abstract, a list of keywords (3-10) and abbreviations should be included. **Text: Introduction:** The introduction should set the tone of the paper by providing a clear statement of the study, the relevant literature on the study subject and the proposed approach or solution. The introduction should be general enough to attract a reader's attention from a broad range of scientific disciplines. **Materials and Methods:** This section should provide a complete overview of the design of the study. Detailed descriptions of materials or participants, comparisons, interventions and types of analysis should be mentioned. However, only new procedures should be described in detail; previously published procedures should be cited and important modifications of published procedures should be mentioned briefly. Capitalize trade names and include the manufacturer's name and address. **Results:** The results section should provide complete details of the experiment that are required to support the conclusion of the study. The results should be written in the past tense when describing findings in the authors'experiments. Previously published findings should be written in the present tense. Results and discussion may be combined or in a separate section. Speculation and detailed interpretation of data should not be included in the results but should be put into the discussion section. **Acknowledgement:** This section includes acknowledgment of people, grant details, funds, etc. **Note:** If an author fails to submit his/her work as per the above instructions, they are pleased to maintain clear titles namely headings, subheading. **References:** Only published or accepted manuscripts should be included in the reference list. Meetings abstracts, conference talks, or papers that have been submitted but not yet accepted should not be cited. All personal communications should be supported by a letter from the relevant authors. OMICS uses the numbered citation (citation-sequence) method. References are listed and numbered in the order that they appear in the text. In the text, citations should be indicated by the reference number in brackets. Multiple citations within a single set of brackets should be separated by commas. When there are three or more sequential citations, they should be given as a range. Example: "... now enable biologists to simultaneously monitor the expression of thousands of genes in a single experiment [1,5-7,28]". Make sure the parts of the manuscript are in the correct order for the relevant journal before ordering the citations. Figure captions and tables should be at the end of the manuscript. Authors are requested to provide at least one online link for each reference as following (preferably PubMed). Because all references will be linked electronically as much as possible to the papers they cite, proper formatting of the references is crucial. Please use the following style for the reference list: **Examples: Published Papers:**

1. Laemmli UK (1970) Cleavage of structural proteins during the assembly of the head of bacteriophage T4. Nature 227: 680-685.
2. Brusic V, Rudy G, Honeyman G, Hammer J, Harrison L (1998) Prediction of MHC class II- binding peptides using an evolutionary algorithm and artificial neural network. Bioinformatics 14: 121-130.
3. Doroshenko V, Airich L, Vitushkina M, Kolokolova A, Livshits V, et al. (2007) YddG from Escherichia coli promotes export of aromatic amino acids. FEMS Microbiol Lett 275: 312-318.

Note: Please list the first five authors and then add "et al." if there are additional authors.

Electronic Journal Articles Entrez Programming Utilities

1. https://www.ncbi.nlm.nih.gov/books/NBK25500/

Books:

1. Baggot JD (1999) Principles of drug disposition in domestic animals: The basis of Veterinary Clinical Pharmacology. (1stedn), W.B. Saunders Company, Philadelphia, London, Toranto.
2. Zhang Z (2006) Bioinformatics tools for differential analysis of proteomic expression profiling data from clinical samples. Taylor & Francis CRC Press.

Conferences:

1. Hofmann T (1999) The Cluster-Abstraction Model: unsupervised learning of topic hierarchies from text

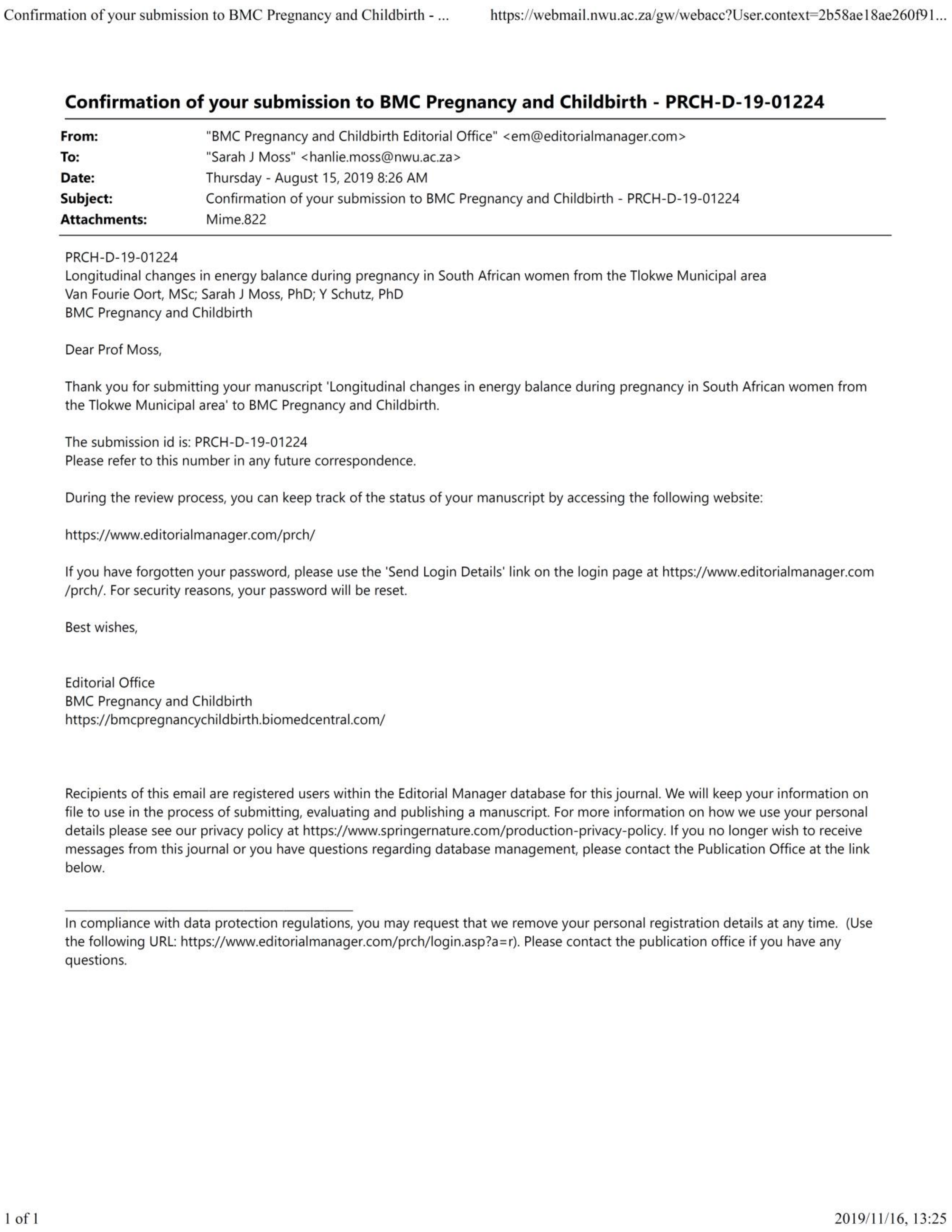
data. Proceedings of the International Joint Conference on Artificial Intelligence.

Tables: These should be used at a minimum and designed as simple as possible. We strongly encourage authors to submit tables as .doc format. Tables are to be typed double-spaced throughout, including headings and footnotes. Each table should be on a separate page, numbered consecutively in Arabic numerals and supplied with a heading and a legend. Tables should be self-explanatory without reference to the text. Preferably, the details of the methods used in the experiments should be described in the legend instead of in the text. The same data should not be presented in both table and graph form or repeated in the text. Cells can be copied from an Excel spreadsheet and pasted into a word document, but Excel files should not be embedded as objects. **Note:** If the submission is in PDF format, the author is requested to retain the same in .doc format in order to aid in completion of process successfully. **Figures:** The preferred file formats for photographic images are .doc, TIFF and JPEG. If you have created images with separate components on different layers, please send us the Photoshop files. All images must be at or above intended display size, with the following image resolutions: Line Art 800 dpi, Combination (Line Art + Halftone) 600 dpi, Halftone 300 dpi. See the Image quality specifications chart for details. Image files also must be cropped as close to the actual image as possible. Use Arabic numerals to designate figures and upper case letters for their parts (Figure 1). Begin each legend with a title and include sufficient description so that the figure is understandable without reading the text of the manuscript. Information given in legends should not be repeated in the text. **Figure legends:** These should be typed in numerical order on a separate sheet **Tables and Equations as Graphics:** If equations cannot be encoded in MathML, submit them in TIFF or EPS format as discrete files (i.e., a file containing only the data for one equation). Only when tables cannot be encoded as XML/SGML can they be submitted as graphics. If this method is used, it is critical that the font size in all equations and tables is consistent and legible throughout all submissions.

- Suggested Equation Extraction Method
- Table Specifications
- Equation Specifications

Supplementary Information: Discrete items of the Supplementary Information (for example, figures, tables) referred to at an appropriate point in the main text of the paper. Summary diagram/figure included as part of the Supplementary Information (optional). All Supplementary Information is supplied as a single PDF file, where possible. File size within the permitted limits for Supplementary Information. Images should be a maximum size of 640 x 480 pixels (9 x 6.8 inches at 72 pixels per inch). **Proofs and Reprints:** Electronic proofs will be sent as an e-mail attachment to the corresponding author as a PDF file. Page proofs are considered to be the final version of the manuscript. With the exception of typographical or minor clerical errors, no changes will be made in the manuscript at the proof stage. Authors will have free electronic access to the full text (HTML, PDF and XML) of the article. Authors can freely download the PDF file from which they can print unlimited copies of their articles. **Copyright:** Submission of a manuscript implies that the work described has not been published before (except in the form of an abstract or as part of a published lecture, or thesis) and that it is not under consideration for publication elsewhere. All works published by OMICS International are under the terms of the Creative Commons Attribution License. This permits anyone to copy, distribute, transmit and adapt the work provided the original work and source is appropriately cited.

Appendix G: Proof of manuscript submission - Article 1



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From:	"BMC Pregnancy and Childbirth Editorial Office" <em@editorialmanager.com>
To:	"Sarah J Moss" <hanlie.moss@nwu.ac.za>
Date:	Thursday - August 15, 2019 8:26 AM
Subject:	Confirmation of your submission to BMC Pregnancy and Childbirth - PRCH-D-19-01224
Attachments:	Mime.822

PRCH-D-19-01224
Longitudinal changes in energy balance during pregnancy in South African women from the Tlokwe Municipal area
Van Fourie Oort, MSc; Sarah J Moss, PhD; Y Schutz, PhD
BMC Pregnancy and Childbirth

Dear Prof Moss,

Thank you for submitting your manuscript 'Longitudinal changes in energy balance during pregnancy in South African women from the Tlokwe Municipal area' to BMC Pregnancy and Childbirth.

The submission id is: PRCH-D-19-01224
Please refer to this number in any future correspondence.

During the review process, you can keep track of the status of your manuscript by accessing the following website:

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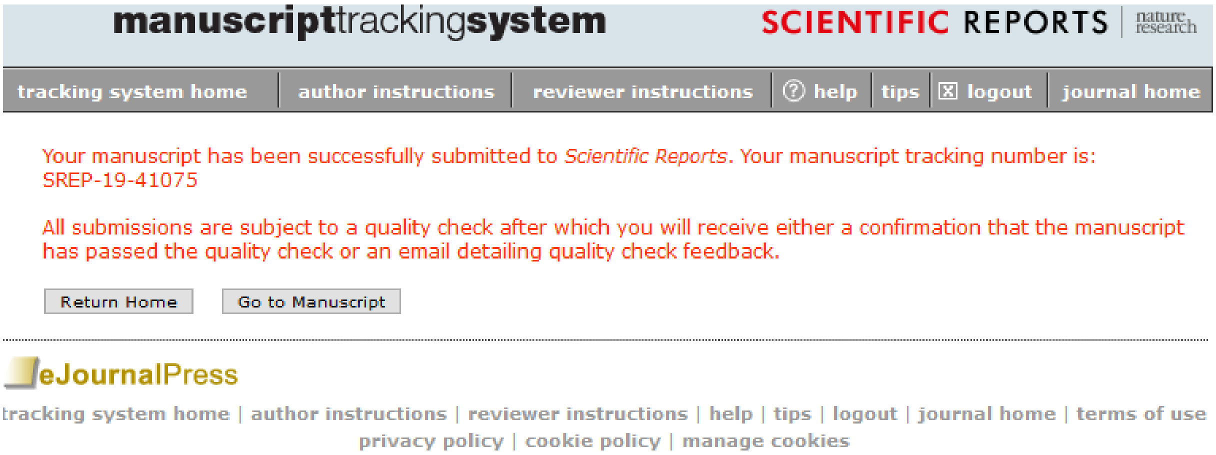
Appendix H: Proof of manuscript submission - Article 2



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All submissions are subject to a quality check after which you will receive either a confirmation that the manuscript has passed the quality check or an email detailing quality check feedback.

Appendix I: Data sheet – Demographic information

Habitual Activity Patterns during PregnancY

Initials and Surname: __________________________

Date:____

Trimester: ____________________________________

Measurement:

0 1 2 3 4

1 Demographic Information

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

2

Pregnancy Demographic Information

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

3

Contra-Indications & Risk factors

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

4 Anthropometric information

<table>
<tr><td colspan="11">Body mass index</td></tr>
<tr><td>Length</td><td colspan="3"></td><td>Weight</td><td colspan="2"></td><td colspan="2">BMI</td><td colspan="2"></td></tr>
<tr><td colspan="11">Waist / Hip ratio</td></tr>
<tr><td>Waist circum-ference</td><td colspan="3"></td><td>Hip circum-ference</td><td colspan="2"></td><td colspan="2">Waist / Hip circum-ference</td><td colspan="2"></td></tr>
<tr><td colspan="11">Skinfolds</td></tr>
<tr><td>Triceps</td><td colspan="2"></td><td></td><td>Supra-iliac</td><td></td><td></td><td colspan="2">Mid thigh</td><td></td><td></td></tr>
<tr><td colspan="11">Fat percentage</td></tr>
<tr><td colspan="11">Bod-Pod Body composition</td></tr>
<tr><td colspan="2">Fat percentage</td><td colspan="3"></td><td colspan="3">Lean body mass</td><td colspan="3"></td></tr>
<tr><td colspan="2">Fat mass</td><td colspan="3"></td><td colspan="3">Lung volume</td><td colspan="3"></td></tr>
<tr><td colspan="11">Bio-electrical Impedance</td></tr>
<tr><td colspan="2">Total Body Water</td><td colspan="3"></td><td colspan="3">Fat percentage</td><td colspan="3"></td></tr>
</table>

5

Blood pressure, Resting Metabolic Rate and Nurtitional information

Heart rate (beats/min)	
Blood pressure (mm Hg)	/
Resting Metabolic Rate (ml O_2 / kg)	
ActiHeart	
AEE	
DEE	
TEE	
Nutritional calculations	
Total Dietary Intake	

6

Foetal growth parameters

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