Accelerometer use to assess Physical Activity in Pregnancy - A Validation Study

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DECLARATION

I, Gudani Goodman Mukoma, hereby declare that this dissertation is my own work. It is being submitted for the degree of Master of Science in Medicine in the field of Biokinetics at the University of the Witwatersrand, Johannesburg, South Africa. It has not been submitted before for any degree or examination at this, or any other, University.

Signed

This 31st day of January 2019, in Johannesburg.

DEDICATION

This dissertation work is dedicated to my wife, Abigail and two sons Dziphathutshedzo and Andisa Mufunwa, who have always been a constant source of support and encouragement during the challenges of graduate school and life. I am truly thankful for having you in my life. This work is also dedicated to my parents, Caroline and Joseph Mukoma, who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve. I also dedicate this work to my four siblings, Gundo, Anza, Ritonde and Muimeleli.

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ABSTRACT

Background

Little is known about physical activity (PA) patterns in pregnancy. Previous epidemiological research suggests that most women do not participate in regular PA during pregnancy. However, these estimates are often based on the use of crude measures that are not validated and may be prone to error. Furthermore, given the limited research using objective, comprehensive and validated methods, there is currently no commonly accepted measurement tool used to assess PA during pregnancy.

Aim

The aim of this study was to assess the validity of accelerometer devices in measuring physical activity energy expenditure (PAEE) during pregnancy.

Methods

Pregnant women (n = 22) in their first trimester (<14 weeks, longitudinal) between the ages of 18- 40, were invited to participate. In addition, women in their 2nd and 3rd trimesters were invited for a once off testing (cross-sectional). All participants completed a 60-minutes submaximal walking protocol with different intensities, each having a 5-min duration. Participants wore one ActiGraph, Axivity and GENEActiv on the left wrist, and one ActiGraph on the waist. Energy expenditure was measured using the Oxycon. Physical activity for pregnant and non-pregnant women, at each stage of the walking protocol, was compared using the Wilcoxon rank-sum test. The relationships between accelerometers, placement positions, and criterion validity were assessed using Pairwise correlation.

Results

Significant differences in energy expenditure estimates were observed when using the hip-worn ActiGraph (p=0.03) and GENEActiv (p=0.05) accelerometers between the pregnant and non-pregnant participants. In the pregnant participants, moderate significant correlations were found between the Axivity and GENEActiv accelerometers (r =0.43) at 15 minutes rest, and the ActiGraph-wrist and GENEActiv accelerometers (r =0.39) at 5km/h. When comparing placement position for the pregnant sample, significant relationships were observed between the ActiGraph worn on the hip versus the waist, but only during rest (r =0.56), 3km/hr (r =0.41) and 5km/hr (r =0.76). None of the accelerometers showed consistent correlation with the Oxycon for measuring energy expenditure during this protocol.

Conclusion

Although there were some relationships found between the pregnant and non-pregnant participants when measuring PA using ActiGraph-hip and GENEActiv accelerometers during the walking test protocol, and when comparing placement position of the hip versus the waist using ActiGraph accelerometers, in general, these accelerometers did not provide consistent correlations between each other or the Oxycon for both the pregnant and non-pregnant participants. As a result a clear pattern for measuring EE during PA was not observed, and further research is needed to confirm this data and provide an accurate tool for measuring PA during pregnancy.

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LIST OF ABBREVIATIONS/NOMENCLATURE

PA	Physical Activity
GDM	Gestational Diabetes Mellitus
EE	Energy Expenditure
PAEE	Physical Activity Energy Expenditure
WHO	World Health Organisation
US	United States
BMI	Body Mass Index
SA	South Africa
HIV	Human Immunodeficiency Virus
AIDS	Acquired Immune Deficiency Syndrome
NCDs	Non Communicable Diseases
SANHANES	South African National Health and Nutrition Survey
SADHS	South African Demographic and Health Survey
THUSA	Transition and Health during Urbanisation in South Africa
ACTH	Adrenocorticotrophic hormone
CRH	Corticotrophin realising hormone
ACOG	American College of Obstetricians and Gynaecologists
HR	Heart rate
HRV	Heart rate variability
LMICs	Low to middle-income countries
GWG	Gestational weight gain
IOM	Institute of Medicine
NHANES	National Health and Nutrition Estimation Survey
ALSPAC	Avon Longitudinal Study of Parents and Children
MVPA	Moderate to vigorous physical activity
SES	Socio-economic status
CVD	Cardiovascular disease
PPAQ	Pregnancy Physical Activity Questionnaire
IPAQ-SF	International Physical Activity Questionnaire-short form
GPAQ	Global Physical Activity Questionnaire
SB	Sedentary behaviour
AQUAA	Activity Questionnaire for Adults and Adolescents

AEE	Activity Energy Expenditure
LPA	Light-intensity Physical Activity
DLW	Doubly Labelled Water
TEE	Total Energy Expenditure
VO_2	Oxygen uptake
PAR-Q	Physical Activity Readiness Questionnaire
MET	Metabolic equivalent
VCO_2	Carbon Dioxide production
OM	Oxycon Mobile
VE	Ventilation
HREC	Human Research Ethics Committee
IQR	Inter Quartile Range

Chapter 1

1.1 Introduction

Physical activity (PA) is a significant contributor in enhancing one's health. Moreover, PA is known to be positively related to a lowered risk of diabetes, obesity, hypertension, and cardiovascular diseases (Harrison et al., 2011, Melzer et al., 2010). In addition, regular PA can positively impact pregnant women, as benefits may include improved emotional well-being, lowered risk of gestational diabetes mellitus (GDM), preeclampsia, excessive maternal weight gain and may prevent difficulties during labour (Harrison et al., 2011, da Silva et al., 2016). The occurrence of gestational hypertensive disorders, GDM, foetal growth restriction and premature birth, are closely related to the increased risk of cardiovascular disease and mortality in adulthood, therefore, the prevention of these pregnancy related complications becomes necessary (Rich-Edwards et al., 2014). In addition, maternal physical activity has been found to be closely linked with a decreased incidence of preterm birth and obesity in adult life (da Silva et al., 2016).

Levels of physical activity are regularly monitored to assess population health behaviours and are associated with health status including morbidity and mortality rates. In order to identify changes and current physical activity levels within a population, accurate assessment is also required. Further, PA is also used to examine the usefulness of interventions designed to increase activity levels and to determine its relationship with health outcomes, as well as dose-response relationships and behaviour surveillance (Prince et al., 2008, Wareham et al., 1998).

Understanding each of the above aspects is important for effective public health interventions and relies heavily on accurate measurement instruments. Epidemiological research that has been carried out in previous years shows that around 50-60% of pregnant women do not engage in regular PA (Zhang & Savitz, 1996, Evenson et al, 2004). However, these estimates are often based on the use of invalidated measures or measures that may be prone to error (Evenson et al., 2004, Poudevigne et al., 2006). Therefore, validating an instrument is a process that in large focuses on reducing error in the measurement process (Kimberlin et al., 2008).

However, because of the limited research that has been done using objective and validated methods, there is presently no commonly accepted measurement tool used to assess PA during

pregnancy (Harrison et al., 2011). Activity monitors such as accelerometers have made objective measurement of PA easier and they are mostly used because of their validity for quantifying duration and intensity of PA, their high degree of reproducibility and the fact that they correlate with energy expenditure (EE) in different populations and settings (McParlin et al., 2010, Bell et al., 2013).

Furthermore, the majority of instrument validation studies have been conducted in a healthy adult populations and few have addressed specific populations such as pregnancy; where choosing the right instrument remains a challenge (Van Remoortel et al., 2012). Pregnancy is associated with various physical, cardiovascular, hormonal, respiratory and metabolic changes, which in turn affect the expectant mother's response to exercise (Lumbers, 2002, Ezmerli, 2000). Increases in cardiac output, heart rate and maternal resting oxygen consumption (VO_2) make physical activity measurement unique during the gestational period (Lumbars, 2002; Ezmerli, 2000).

The relative placement and position of the accelerometer on the body is another important issue to consider when measuring PA. Godhe et al. (2013) presented a moderate correlation ($r = 0.47$) for estimating EE from aerobic PA when the accelerometer is worn on the hip and a weak correlation ($r = 0.34$) when worn on the wrist. However, when combined with body mass, a strong correlation was found between accelerometer data for the hip and EE ($r= 0.73$). Trost et al. (2005) and Warren et al., (2010) recommend that the choice of instrument and placement position be suited to the aim of the research.

Many studies have assessed the validity of self-report measures of physical activity during pregnancy (Bell et al., 2013, Haakstad et al., 2010, Chasan-Taber et al., 2004), whilst other studies have assessed pedometers versus accelerometers (Harrison et al., 2011). Further research is needed on alternative accelerometer devices, as well as positional placement in pregnant woman. The assessment of physical activity is essential to design interventions to increase physical activity and track adherence to recommendations, and assess outcome measures (Berlin et al., 2006). If epidemiological studies are to confirm the role of physical activity in the treatment and prevention of disease during pregnancy, improved methods of quantifying physical activity are necessary.

1.2 Problem Statement

Although accelerometers have been validated in the general population, currently there is very little known information about physical activity patterns in pregnancy with previous estimates mostly based on subjective assessment measures that are prone to error (Harrison et al., 2011). Only a few pregnancy specific studies (Lindseth & Vari, 2005, Stein et al., 2003, Harrison et al., 2011) have been done to validate accelerometers and placement position during pregnancy. Given the importance of physical activity in pregnancy, validated PA measurement tools are necessary to estimate energy expenditure (EE) in pregnant women. This is in order to determine physical activity levels and assess the role of physical activity and health outcomes in an accurate, yet feasible, manner.

1.3 Study Aim

The primary aim of this study was to assess the validity of accelerometer devices in measuring physical activity energy expenditure (PAEE) during pregnancy using the Oxycon mobile as a metabolic assessment tool.

1.3.1 Study Objectives

a) To describe energy expenditure during a walking protocol in pregnant woman and control participants.
b) To compare energy expenditure at each stage of the walking protocol between pregnant and control participants.
c) To compare energy expenditure between different accelerometers and placement position.
d) To compare the accelerometers energy expenditure against the Oxycon.

Chapter 2: Literature Review

Pregnant women who engage in regular PA benefit the same way as non-pregnant women, however, measuring PA levels during pregnancy still poses a challenge due to the many biomechanical and physiological factors that effect PA testing. Therefore, in order to promote PA effectively and quantify the effects of interventions for pregnant women, PA measurement during pregnancy needs to be more accurate.

2.1 Physical activity patterns and prevalance of overweight and obesity

Previous research has shown that the fourth leading risk factor for mortality is physical inactivity, which accounts for 6% of deaths, whilst overweight and obesity are known causes of 5% of global mortality (WHO, 2009). Globally, in 2010 about 23% of adults aged 18 and above were not engaging in enough PA (men 20% and women 27%) (WHO, 2017). Furthermore, it was also observed that 81% of adolescents between the ages of 11-17 years were also not active enough (WHO, 2017). Adolescent girls appear to be more inactive (84%) than adolescent boys (78%) (WHO, 2017). In addition, adult women appear to be particularly more prone to low PA levels. For example, the South Africa Demographic and Health Survey (SADHS) reported in 2003 that 63% of adult women are inactive. Similary, the Transition and Health during Urbanisation in South Africa (THUSA) study, measuring PA in black South Africans in the Northwest Province, found that 35.5% of black women were inactive and only 31.7% were moderately active (Voster et al, 2005).

The impact of physical activity and diet during pregnancy on health is complex and multi-faceted (Health Committee, 2015). In the general public, activity patterns and diets are evidently changing in the United States (US) and by the 1980s it was observed that physical activity was on a decline and dietary quality in the US was getting worse, coupled with increasing obesity rates across the United States and Europe (Popkin, Adair & Ng, 2011). In 2008, overweight and obesity were estimated to affect nearly 1.5 billion adults worldwide (Popkin, Adair & Ng, 2011). Furthermore, between the 1990–2010 period repeated surveys conducted in over 40 countries using the same methods reported data that shows trends which suggests that more than 2 billion people are possibly already overweight or obese today (Nguyen et al., 2009). There appears to be a greater burden for much of Asia, Latin America, the Middle East, and Africa. This is due to differences in fat patterning and the negative cardio metabolic health effects of a body mass index (BMI) at levels far below the standard BMI cut off of 25kg/m^2 for

overweight (Nguyen et al., 2009, WHO, 2004). The prevalence of overweight and obesity grew for all countries in Asia, the Middle East, Africa, and Latin America at about 0.7 percentage points per year. Furthemore, an estimated 19% of rural women and 37.2% of urban women are overweight or obese (Popkin, Adair & Ng, 2011).

In South Africa (SA), as more economic development occurs and HIV/AIDS mortality rates come under control, non-communicable diseases (NCDs) are increasingly becoming a major healthcare burden (Mayosi et al., 2009). In particular, recent health statistics report that the obesity epidemic has been increasing and about 61% of SAs population is reportedly overweight or obese, with the prevalence being higher in adult women over the age of 55 years (Baleta & Mitchell, 2014). Similarly, statistics from the National Department of Health, (2016) also reported a rapid increase of obesity rates with almost 70% of women and 40% of men in South Africa that are 15 years or older either overweight or obese. Furthermore, the South African National Health and Nutrition Survey (SANHANES-1), found that the percentage of general obesity based on body mass index (BMI) was significantly higher in women as compared to men. It was shown that about 24.8% of women were overweight and 39.2% being obese (Shisana et al., 2014).

In accordance with these results, about 68.2% of the women had a waist circumference that puts them at an increased risk for metabolic disorders, such as type 2 diabetes and hypertension (Shisana et al., 2014). Reports also show that one in five boys and one in four girls between the ages of 2 and 14 years are overweight or obese. Additionally, 43% of deaths in South Africa are caused by obesity-related diseases which includes heart diseases, type 2 diabetes, stroke and some cancers (National Department of Health, 2016). Although globalisation and urbanisation are considered to be major drivers of the emerging epidemic, the etiology of obesity is complex (Yumuk et al., 2014). In addition to the biology of individuals, there are behavioural determinants, along with economic, environmental and socio-cultural factors that play a role in the development of this condition (Yako, 2012, Griera et al., 2007, Steynn & Mchiza, 2014, Puoane & Tsolekile, 2008). Obesity is among the top five risk factors for an early death, however, despite the demonstrated contribution of PA to the overall health and obesity management and prevention, few individuals are sufficiently active (Health Committee, 2015).

Although research has demostrated that physical activity plays a pivotal role in weight management, optimising body composition and improving overall health, globally the

prevalance of obesity is still very high especially in women. Further, obesity has been closely associated health complications during pregnancy and childbirth, therefore, interventions that are focused on promoting a more active lifestyle during pregnancy and preventing excessive weight gain are warrented.

2.2 Physiological adaptations during pregnancy

Pregnancy is a time in a woman's life that is related to considerable anatomical, physiological and psychological changes which may encourage low levels of PA, or sedentary behaviour (Downs et al., 2012). It causes various hormonal, immunologic, and metabolic alterations that may act as a "stress test" on a woman's body (Motosko et al., 2017). The changed levels of circulating hormones, increased blood volume, and metabolic adaptions underlie the important physiological changes that are fundamental for the development of the foetus (Motosko et al., 2017) and are essential for both the mother and foetus to cope with the demands of child birth(Tan & Tan, 2013).

2.2.1 Cardiovascular changes

Pregnant women undergo profound cardiovascular system adaptations like an increase in heart rate during submaximal exertion and while at rest, increased blood volume, respiratory volume, and resting cardiac output, a drop in uteroplacental blood flow and venous return to the heart (Skow et al., 2017). The cardiovascular system changes that occur during pregnancy are quite extreme and begin in early pregnancy. It is known that by eight weeks of gestation, the cardiac output has increased by 20% (Soma-Pillay et al., 2016), and will continue to rise by 30-50% througout pregnancy (Soma-Pillay et al., 2016; San-Frutos et al., 2011). The blood flow to the uterus and placenta, which is fundamental for the growth of the foetus, contributes to 25% of the cardiac output (Soma-Pillay et al., 2016). Cardiac output is the product of stroke volume and heart rate. In pregnancy, the blood volume increases, and as a result there is a rise in the quantity of blood returning to the heart (preload). The afterload is then decreased because of maternal vasodilation, resulting in the stroke volume increasing by 20-30% throughout pregnancy (Soma-Pillay et al., 2016; San-Frutos et al., 2011).

Systemic vascular resistance also decreases throughout pregnancy and get to its lowest around 20 weeks of gestation followed by a slow increase until term (Carbillon, Uzan & Uzan, 2005). The diastolic blood pressure decreases to its lowest at 28 weeks before increasing again towards

term, whilst systolic blood pressure remains stable (Melchiorre, Sharma & Thilaganathan, 2012). The decrease of plasma colloid osmotic pressure by 10-15% accompanies an increase in plasma volume (Tan & Tan, 2013). Pregnant women may also be more susceptible to pulmonary oedema, as a result of the 30% decrease in pulmonary capillary wedge pressure (Tan & Tan, 2013).

On the contrary, maternal resting heart rate increases in early pregnancy, peaking at 12-20 beats per minute higher than pre-pregnancy (Soma-Pillay et al., 2016; San-Frutos et al., 2011). The heart rate peaks and plateaus in the third trimester, which helps to preserve the increased cardiac output even when the stroke volume declines towards term (Soma-Pillay et al., 2016).

2.2.2 Respiratory changes

During pregnancy, the upper respiratory airway anatomy is subjected to various changes and there is also a significant rise in oxygen demand (Izci et al., 2006, Soma-Pillay et al., 2016). This is caused by a 15% rise in metabolic rate and a 20% increase in oxygen intake (Soma-Pillay, et al., 2016). There is also a rise in minute ventilation, mostly due to a rise in tidal volume rather than the respiratory rate (Soma-Pillay, et al., 2016).

The growing uterus and the rise in abdominal pressure elevates the diaphragm by 4 cm during pregnancy (Soma-Pillay, et al., 2016; Hegewald & Crapo, 2011). Despite pregnant women having a larger chest circumference, the chest wall compliance is reduced, and with an elevated diaphragm, total lung capacity, and functional residual capacity decreases (Soma-Pillay, et al., 2016). In early pregnancy, the inspiratory reserve volume is lowered, as a result of the rise in tidal volume (Soma-Pillay, et al., 2016). The lower functional residual capacity and the increase in maternal oxygen consumption shows that oxygen reserves for pregnant women is much lower and therefore, they are at a higher risk of becoming hypoxic (Tan & Tan, 2013).

2.2.3 Endocrine changes

During pregnancy, in order to meet the rise in metabolic requirements of the mother and foetus, the endocrine system undergoes some adaptations. The hypothalamic pituitary axis which is crucial for controling various key metabolic activities, increases the level of hypothalamic releasing hormones (Tan & Tan, 2013). As a result, there is a rise in the making of thyroxine-

binding globulin by the liver, which also increases the levels of thyroxine and tri-iodothyronine (Soma-Pillay et al., 2016).

Similarly, oestrogen concentrations in the maternal circulation increase with increasing gestational age (Weiss, 2000). Oestrogens play a key role in uterine contractility and is also important for development and function of the uterus. Progesterone is also one of the main pregnancy hormones that rise exponentially in early pregnancy (Andersson et al., 2008). This hormone is known to sustain the pregnancy state and therefore too much or too little may lead to miscarriage (Soma-Pillay et al., 2016; Byrns, 2014). Meaning that during pregnancy, there has to be a fine balance between progesterone and oestrogen in order to control uterine activity (Mesiano & Welsh, 2007).

2.2.4 Musculoskeletal changes

The musculoskeletal system is also affected by the anatomical and biomechanical changes that occur during pregnancy (Artal & O'Toole, 2003). During pregnancy, the uterus enlarges because of the growing foetus resulting in weight gain. Furthermore, there is a shift forward and downward of the centre of mass, which results in gait changes such as a decrease in single-support time and stride length (Gilleard, 2013).

Moreover, in the third trimestster, pregnant women experience an increase in abdominal volume, which may result in lowering the trunk's range of motion (Foti et al., 2000). The weight gain may also cause an increase in joint forces around the hips and knees by as much as 100%, while engaging in weight bearing exercises such as running (Tan & Tan, 2013). As a result, these large forces may cause discomfort and increase damage to arthritic or previously unstable joints (Artal & O'Toole, 2003).

Additionally, there is a 50% prevalance of lower back pain during pregnancy which is mainly caused by an increase in lumbar lordosis (Artal & O'Toole, 2003). The changes in posture may affect balance, therefore putting the pregnant women at a higher risk of losing balance and an increased risk of falling (Artal & O'Toole, 2003). There is also an increase in laxity of ligaments which is influenced by the rise in levels of ooestrogen and relaxin, which increases pregnant women's susceptibility to strains and sprains (Tan & Tan, 2013).

2.3 Physical activity guidelines

Many individuals have sedentary lifestyles and do not meet the minimum recommendations for physical activity (Hsieh et al., 2015). The WHO recommends that adults aged from 18 and above years should engage in moderate physical activity to the total of at least 150 minutes throughout the week (in bouts of at least 10 minutes), or they can engage in vigorous physical activity that amounts to at least 75 minutes throughout the week. Alternatively, they can engage in an equivalent amount of both moderate and vigorous-intensity activity (WHO, 2012). Resistance exercise involving major muscle groups is recommended, and it is to be done on two or more days a week (WHO, 2012). These guidelines also apply during pregnancy; however, pregnant women may need to be extra cautious and should get medical advice before embarking on an exercise program (WHO, 2012). Additionally, women without any complications during their pregnancies should be advised to participate in cardiovascular and resistance exercises before, during, and after pregnancy (ACOG, 2015).

2.4 Benefits of regular physical activity (PA)

Although there is an enormous amount of evidence to encourage participation in physical activity in order to prevent and manage chronic diseases, only a limited number of research seems to exists for the pregnant population, more especially in low and middle-income countries (LMICs) (Evenson, Savitz & Huston, 2004). Regular engagement in moderate to high-intensity physical activity impacts positively on physical and mental health in the general population (ACOG, 2015), with research supporting the same rewards of engaging in physical activity throughout pregnancy for both mother and baby (Gaston et al., 2012). Furthermore, research has proven that the benefits of PA far outweigh the harm, and include, but are not limited to, improved cardiovascular and respiratory fitness, as well as a lowered risk of chronic diseases such as hypertension, coronary heart disease, stroke and diabetes. PA has also be associated with a lowered risk of falling and fractures mostly in the elderly population, and the ability to control weight gain (Darren et al., 2006, WHO, 2017). Additionally, PA also promotes the development and stengthening of bones (Spengler & Woll, 2013), provides psychological benefits such as improved self-confidence and self-image (Davies et al., 2011), and it also helps prevent breast and colon cancer (WHO, 2017).

2.4.1 Maternal benefits of PA

A large number of women discontinue exercising or decrease their PA levels after they discover they are pregnant (Melzer, 2010). Living a sedentary lifestyle while pregnant may contribute to some disorders such as hypertension, maternal obesity, gestational diabetes, pre-eclampsia, loss of muscular and cardiovascular fitness, development of varicose veins and an increased risk of physical complaints, for example dyspnea, pain of the lower back and insufficient psychological adjustment (Melzer, 2010, Royal College of Obstetricians and Gynaecologists, 2006). Whilst an upper level of safe activity is yet to be confirmed, the rewards of continuing to engage in physical activity throughout pregnancy are shown to outweigh any possible risks (Brown, 2002). Research has continued to prove that PA throughout pregnancy is safe with the results supporting that exercising while pregnant is rewarding for both the mother and foetus, with the benefits going further for the child until he or she reaches adulthood (Moyer et al., 2016).

Furthermore, regardless of socioeconomic status, mothers who are physically active during their pregnancy are more likely to have less complicated and shorter deliveries, full-term child birth, less signs of foetal distress, reduced chances of caesarian section, faster recovery period and less neonatal complications and normal child birthweight as compared to women who are not active (Van Oort, 2014, Moyer, 2016, Beckman & Beckman, 1990, Downs, 2012). Encouragingly, some evidence shows that the first stage of labour is shorter in exercising women and that exercise during the pregnancy may lower the rate of caesarean section (Davies, 2016).

Physical activity (PA) is also a possible intervention that might be effective for prevention and treatment of GDM, as it's already known to effectively prevent and help in the treatment of type 2 diabetes (van Poppel, 2014). Glucose metabolism is strongly associated with PA (Warehm et al., 2005), and maternal glucose homeostasis in pregnancy plays an important role in the programming of the endocrine pancreas (Hales & Barker, 2001). Physical activity initiated before and/or while pregnant lowers the risk and incidence of GDM, in part this is achieved by reducing excess gestational weight gained and stimulate a more advanced control of glucose metabolism (Moyer, 2016, van Poppel, 2014). Physical activity interventions have been found to be useful at improving glycaemic control in women who have developed GDM already (van Poppel, 2014). Previous studies that have been done found that training of the large muscle groups throughout pregnancy results in better insulin sensitivity and glucose utilization, and consequent normalization of blood glucose levels (van Poppel, 2014). In addition, women who

develop gestational diabetes while pregnant can use PA as an added therapy and are able to lower their insulin therapy and therefore have better metabolic control when compared to pregnant women who are sedentary (Hopkins et al., 2010).

Research also shows that reoccurring events of PA carried out over a longer period of time causes adaptations in the respiratory, cardiovascular, neuromuscular systems. Additionally, it also improves overall aerobic capacity, therefore women who are aerobically fit and continue with aerobic exercise throughout pregnancy possess a greater oxygen uptake, a low resting HR and an increased stroke volume than their non-active counterparts (Melzer et al., 2010). Moreover, continued participation in PA is likely to have important rewards in terms of mental health and emotional well-being (particularly self-esteem) while pregnant and after child birth (Diabetes care, 2002).

Nonetheless, there are still concerns about exercise while pregnant, with medical advice previously known to discourage women from continuing or starting regular exercise programmes (Clapp, 2001). On the other hand, recent research has also demonstrated that physical activity is not related to an increase in negative incidences (such as miscarriage, premature labour, premature rupture of the membranes, significant growth restriction or maternal injury) during pregnancy (Clapp, 2001). However, it may be important to reduce high impact exercise for women planning to become pregnant and to refrain from heavy lifting during the first trimester as some evidence suggests a high risk of miscarriage (Bo et al., 2016).

2.4.2 Effects of PA on heart rate variability during pregnancy

Heart rate variability (HRV) is a non-harmful measure and a proxy to determine the overall health of the foetus and the foetal autonomic nervous system development (Dietz et al., 2016). Maternal physical activity has being shown to have an impact on foetal HRV depending on the mother's fitness level. May et al. (2012) found that PA throughout pregnancy is related to the lower foetal heart rate (HR) and the increase in foetal HR variability that persists post birth with a dose-response association with maternal exercise intensity and time (DiPietro et al., 2007). As found in other studies children with slow heart rate and a high variability are related to positive psychomotor and language developmental outcomes at 8 to 12 months, 2 years, and 3 years of age. Their reaction time is faster and they also have a high attention span during a task

than children of similar age, which supports findings that PA during pregnancy may be beneficial for cardiac and neuromotor development of offspring (Fox & Porges, 1985). Additionally, taking into consideration how the HRV is influenced by being overweight and obese, a high BMI has been linked with a lowered HRV and high sympathetic and low parasympathetic activity (Felber Dietrich et al., 2006). Sympathetic control changes as gestation progresses because of physiological changes of the maternal body in healthy pregnant women, which results in altered HRV when compared to healthy non-pregnant women (Stein et al., 1999).

The American College of Obstetricians and Gynaecologists (ACOG) guidelines supports any approach that is wide-ranging as they have no heart rate limitation (American College of Obstetricians and Gynaecologists, 2002). A meta-analysis study of pregnancy and exercise found that exercise intensities of 81% of the maximum heart rate, did not have any unfavorable or significant changes on the foetus or mother (Ostgaard, 1996). Similary, Bo et al., (2016) research also demonstrated that there is little risk of abnormal foetal heart rate response when active women exercise at <90% of their maximal heart rates in the second and third trimesters (Bo et al., 2016). However, current exercise guidelines recommend that pregnant women perform exercises that reduce hypoxic stress and the risk of abdominal injury, and should maintain a heart rate that is between 55% and 70% of the projected maximum or a perceived exertion of between 12 and 14 (‘somewhat hard’) (Barsky et al., 2012).

2.4.3 Impact of PA on obesity during pregnancy

Evidence from previous original research suggests that encouraging pregnant women to enhance their fitness and maintain it afterwards can result as a fundamental contribution to public health through reduction of the burden of disease caused by overweight and obesity (Brown, 2002). This is important since evidence has shown that pregnancy may be an initiator for gestational and long term obesity. In fact, women who have given birth have a 3.5 times increased chance of being obese over the next 5 years in comparison to women who have never given birth (Davis et al. 2009).

In a systematic review of African studies, by Onubi et al. (2015) they found that maternal obesity prevalence to be from 6.5% from the Democratic Republic of Congo antenatal bookings and 50.7% during the third trimester in Nigeria. In South Africa, this prevalence appears to be around 44% (Basu et al., 2010). This is of great concern, because maternal overweight and

obesity are strongly associated with unfavourable pregnancy outcomes, such as infant mortality and maternal morbidity (Black et al., 2013). In the same African review, mothers who were obese had a 1.8 times increased risk of having a macrosomic baby, and at a 1.6 times chance to having their new-born admitted into special or intensive care (Onubi et al., 2015). Additionally, obesity was also found to increase the risk of hypertension, pre-eclampsia, GDM, perinatal mortality, macrosomia and delivery complications (Galtier-Dereure, Boegner & Bringer, 2000). Furthermore, women who are overweight or obese before their pregnancy have an increased risk of miscarriage when compared to those with a normal BMI (Galtier-Dereure et al., 2000), and their risk for delivering via caesarean section may also be high (Guelinckx et al., 2008). As a consequence, women who fall pregnant when they are overweight or obese have longer stays in the hospital and sustain heavy financial costs when it's their time to deliver and with confinement and post-delivery (Galtier-Dereure, Boegner & Bringer, 2000).

Not only is absolute weight a concern during this period, but uncontrollable GWG is related with unfavourable outcomes. The US Institute of Medicine (IOM) has provided recommendations for gaining weight through pregnancy indexed to pre-pregnancy BMI: 12.5–18.0kg for underweight women; 11.5–16.0kg for normal weight women; 7.0–11.5 kg for overweight women and 5.0–9.0kg for obese women (IOM, 2009). Weight gain further than these guidelines, or excessive gestational weight gain (GWG), appears to be predictive of unfavorable maternal outcomes (Siega-Riz et al., 2009). Additionally, the consequences for insufficient gain include a higher risk for lower birth weight and preterm birth, whilst too much weight gain presents an increased risk for, caesarean delivery, large birthweight babies, as well as postpartum weight retention and long term childhood obesity (Nehring et al., 2013, Siega-Riz et al., 2009, Starling et al., 2015, Viswanathan et al., 2008, Heery et al., 2016). Furthermore, uncontrolled GWG is also related to maternal hypertension and pre-eclampsia development (Guelinckx et al., 2008).

In addition, uncontrolled weight gain through pregnancy or women who fall pregnant being overweight or obese, have a higher chance of developing gestational diabetes mellitus (Galtier-Dereure et al., 2000). A study done by Watson et al. (2015) outlined a prevalence of overweight/obesity at 69.3% in a cohort of black South African women, which was a 40% higher prevalence in comparison to results reported from US studies. The prevalence of overweight or obesity was related to socio-economic status (SES) (Watson et al., 2015). These findings are similar to those reported by Chasen-Taber et al. (2007), who discovered an overweight/obesity

rate of 49.1% in pregnant Latina women. However, the findings by Watson et al. (2017) outline the positive effects of physical activity at 29-33 weeks and excessive GWG, which provides evidence for PA as a tool in managing GWG during pregnancy.

According to SANHANES data, an increase in waist circumference, as well as overweight and obesity, happens in the middle of 15 and 35 years of age (Shisana, 2013). Since this period appears to be the childbearing age, it may be an opportune time to intervene to improve health behaviours (Lawlor & Chaturvedi, 2006), and contribute to achieving World Health Organizations Millennium goals of improving maternal health. In addition, it can also be declared that a good time to encourage women to be more active is during pregnancy as it is a period when fitness is naturally improved, and at that time women are more likely to be open-minded to health messages (Downs, 2012).

There is little data about physical activity patterns in pregnant South African women; however, black SA women may be at an increased risk of uncontrollable GWG (Pearson et al., 2015, Voster et al., 2005). Previous epidemiological research suggests that as little as 40 – 56% of women engage in recreational activity through pregnancy, while data from the NHANES reports that an estimated 54.3% of pregnant women in the United States (US) reported moderate to vigorous household activities (Evenson & Wen, 2010). In a longitudinal study done by Watson et al. (2016), 52% of the pregnant women residing in Soweto were grouped as being active in their second trimester, however, only a notable small amount of women continued to engage in physical activity in the third trimester, and their total physical activity notably dropped by 43.4% as the pregnancy proceeded in the third trimester.

The fundamental benefit for women who continue with exercise throughout their pregnancy is maintaining or improving fitness. Women of various socio-economic status (SES) and body mass index (BMI) can choose to embark on healthy lifestyle behaviours that can positively influence their health after child birth and lower their babies risk of developing chronic diseases such as obesity, diabetes and cardiovascular diseases (CVD) (Moyer, 2016).

2.5 Assessment and Validation of PA measurement tools during pregnancy

Viable and dependable measures of PA are needed to record physical activity in specific populations; assess the total amount of individuals meeting health recommendations; evaluate the

impact of different physical activity intensities on certain health parameters; and make comparisons between different cultures and examine the impact of interventions (Warehan, 1998). Physical activity measurement can be classified into self-report methods (questionnaires and diaries) and objective assessment (accelerometers, pedometers and heart rate monitors). Additionally, based on previous epidemiological research findings, 50-60% of pregnant women do not regularly engage in physical activity (Zhang & Savitz, 1996, Evenson et al., 2004). However, invalidated and simple measures, that may be prone to error, are often used to find these estimates (Poudevigne et al., 2006). A review emphasized the shortage of sufficient previous research in assessing PA through pregnancy, with most studies mainly making use of subjective methods, which is self-recall of activities and without any published proof of their reliability or validity (Poudevigne et al., 2006).

2.5.1 Subjective measures of physical activity (Activity recall and activity logs)

Subjective measures, such as PA recall questionnaires, are commonly utilized in epidemiological studies. They are cheap in cost and easy to administer when evaluating levels and patterns of physical activity in larger samples (Chasan-Taber et al., 2004, Strath et al., 2013, Shepherd, 2003). Recalling activities includes memory recall of the duration, frequency and intensity of different activities done over given times and are generally questionnaires whilst activity logs are in diary formats (Chasan-Taber et al., 2004).

However, the present number of questionnaires implies that their majority does not produce neither reliable or, valid nor comparable results (Shepherd, 2003). The absence of reliability is sometimes caused by seasonal and temporal variations in patterns of PA, however, failure of human memory to recall is also an essential complication. Further, even if one year activity patterns are re-evaluated in a period of a few days, the responses from questionnaires will always show a 50% or more difference (Shepherd, 2003). The reliability and validity of questionnaires to assess physical activity has been questioned (Shepherd, 2003), and only a few seem to relate properly with the more objective measures of physical activity, for instance accelerometry (Jacobs et al., 1993).

There are several questionnaires validated among pregnant women such as the Pregnancy Physical Activity Questionnaire (PPAQ), and the Kaiser Physical Activity Survey in pregnant women (Chasan-Taber et al., 2004, Schmidt et al., 2006). Chasen-Taber et al. (2004) developed

the Pregnancy Physical Activity Questionnaire (PPAQ), which has been found to have moderate reliability in measuring of physical activity throughout pregnancy. The association between the PPAQ and cut off points for accelerometers has varied between 0.08–0.58 for total PA, 0.20–0.49 for moderate intensity PA and 0.25–0.39 for vigorous intensity physical activity (Cirak et al., 2015, Channdonet, 2012). The International Physical Activity Questionnaire short-form (IPAQ-SF) is mostly used to evaluate PA levels in the general adult population also considering pregnant women. The IPAQ has also been previously validated using the ActiGraph accelerometer for predicting physical activity in non-pregnant and pregnant woman, however, the reliability and validity of the questionnaire was very poor in pregnancy (Craig et al., 2003, Sanda et al., 2017).

In a validation study done by Craig et al. (2003) (n = 2721), a reasonable association between the IPAQ and accelerometer was confirmed (r = 0.33), however no evaluation of absolute agreement was done between measures. Harrison et al. (2011) has found the IPAQ to have a low relationship and poor absolute agreement with accelerometry throughout pregnancy. Furthermore, outcomes from a study done by Watson et al. (2017), found a poor agreement between GPAQ and accelerometry for both physical activity and sedentary behaviour (SB), the GPAQ over estimated physical activity by 14.8 minutes a day in early pregnancy and by 15.8 minutes a day later in gestation. It also underestimated sedentary behaviour by 127.5 minutes a day at 14-18 weeks and 89.2 minutes a day at 29-33 weeks of gestation. Comparably, Oostdam et al. (2012) found a very low relationship between Activity Questionnaire for Adults and Adolescents (AQuAA) and accelerometry, which happen to have overestimated levels of physical activity through pregnancy. Previous research has also highlighted concerns over self-recalled questionnaires in pregnancy, as they may be insensitive in recording activities with lower intensities such as walking (Evenson et al., 2004).

2.5.2 Objective measures of physical activity

Objective measures are not dependent on any given information by the participant, instead they assess and record biomechanical or physiological responses of carrying out physical activity as it occurs. Furthermore, objective measures are not susceptible to the recalling problems or the reporting bias related with self-report methods (Trost & O'neil, 2013). With the assessment of PA becoming more regular in clinical practice, it is fundamental that healthcare professionals become more informed about the different methods and techniques to objectively assess peoples PA's behaviour (Trost & O'neil, 2013).

2.5.2.1 Accelerometers

Accelerometers are electronic movement sensors that respond to continuous acceleration, for example gravity, and are not reliant on an outside power source to function (Bouten et al., 1997). No supply of power is needed, despite needing storage for data, which results in the device been considerably reduced in size and weight. Uniaxial accelerometers regularly measure in the vertical plane and only in one direction, whereas triaxial accelerometers measure accelerations in the anteroposterior, mediolateral, and vertical direction.

Whether they are worn on the hip or wrist, accelerometers normally sample the acceleration of the body in all axes at a rate of 10–30 times/s (Trost, 2007). Additionally, with a frequency band between 0.3 to 3.5 Hz and an amplitude range of −6g to 6g, this should be enough to capture daily PA. Accelerations during activities of low intensity, such as walking or sedentary time, as well as high-intensity activities, such as jogging and jumping, can be assessed (Bouten et al, 1997). Given the different available activities an individual can carry out, triaxial accelerometers give more details and display a better correlation to activity energy expenditure (AEE) than uniaxial accelerometers (Bouten et al., 1994). The signal of acceleration is normally filtered, adjusted and integrated to give a common measure of activity intensity called ‘counts’ (Trost, 2007).

Regardless of how counts are calculated, it has been described that activity counts have a strong association with energy expenditure or work rate, and can give evidence of physical activity intensity (Trost, 2007). Many accelerometers have been evaluated through standardized activities in laboratory conditions. For example, accelerometers displayed a good to very good relationship ($r = 0.74$ to 0.95) while measuring energy expenditure during walking and running on a treadmill against portable calorimeters in the field settings, or in a controlled room environment (Nicolas et al., 2000, Levine et al., 2001). Body-worn accelerometers are able to measure step counts, time, how often and how hard the activity is, and as a result they give information that is accurate on physical activity under free-living conditions (Plasqui et al., 2007). Accelerometers summarises raw data into proprietary ‘counts’ and provide continuous acceleration data from which measures of physical activity can be obtained utilizing published algorithms which then improves methodological clarity and make it possible to compare data across studies (Arnardottir et al., 2013, Hildebrand et al., 2014, Sabia et al., 2014).

Most of the studies done recently have used accelerometers to predict the period spent in SBs and PA levels and their related energy cost; however, the accuracy of accelerometers in assessing behaviours on the lower end of the intensity spectrum is unclear (Florez-Pregonero et al., 2017). Although objective measurement with accelerometers has appeared to overcome the biasness of self-reporting, many problems coincide with their use (Healy et al., 2011, Lyden et al., 2011).

Accelerometers do not have the ability to report on the increased energy cost related with walking up the stairs or an incline and they cannot accurately assess activities such as cycling, lifting or carrying objects, which means they may underestimate the total physical activity energy expenditure (Trost, 2007). Additionally, in this current time, the presentation and interpretation of the data acquired from accelerometers still remains as a limitation (Ward et al., 2005). Furthermore, majority of the obtainable accelerometers have been evaluated to a large extent for their accuracy in predicting MVPA and not sedentary or light-intensity physical activity (LPA) (Freedson et al., 2012).

Currently, very few pregnancy-specific studies have measured PA objectively by using devices such as accelerometers (Lindseth & Vari 2005, Ogita et al., 1989, Stein et al., 2010). Accelerometers are non-invasive and are fitting to use in pregnancy. They provide insight in addition to self-report measures as they minimize responder and recall bias, providing a more tangible estimate of frequency, duration, and intensity of pregnant women's physical activity (da Silva, 2016). However, with the lack of research using objective, comprehensive and validated methods, there is currently no common measurement tool used to measure physical activity during pregnancy that is accepted (Harrison et al., 2011).

2.5.2.2 Doubly labelled water (DLW) method

In non-pregnant women, the doubly labelled water (DLW) method is used as the gold standard to measure energy expenditure of free-living conditions, at the same time it can also be used to predict activity related energy expenditure (Plasqui & Westerterp, 2007). However, the cost, amount of time it consumes, and requirement of an experienced operator make it prohibitive and as a result, other tools that are more practical are normally utilized to predict PAEE in population studies (Plasqui & Westerterp, 2007). Additionally, though this method gives an

accurate assessment of total energy expenditure (TEE), no details on physical activity patterns with regards to frequency, duration, and intensity is obtainable (Plasqui & Westerterp, 2007).

2.5.2.3 Direct and Indirect calorimetry

Direct calorimetry requires positioning the patient inside a compact chamber that is protected from the environment in order to predict EE by assessing the heat coming out of the body (Keeny, Notley & Daniel, 2017). It assesses the total heat of anaerobic and aerobic metabolisms. Additionally, although this method relies on easy principles of measuring PA it is not the most suitable for quantifying energy expenditure (Keeny, Notley & Daniel, 2017). Furthermore, direct calorimetry is known to have a more delayed response in assessing the heat released by the oxidative processes, which can be quickly measured by indirect calorimetry (Kenny & Jay, 2013).

Indirect calorimetry measures the distinction in carbon dioxide and oxygen contents between exhaled and inhaled air, which, along with minute ventilation, enables the measurement of oxygen consumption, and carbon dioxide production (Keeny, Notley & Daniel, 2017). Oxygen consumption and carbon dioxide production are regularly utilized to quantify the respiratory exchange ratio, and the prediction of substrate utilization. This enables the quantification of energy expenditure using the caloric equivalents for macronutrients (Keeny, Notley & Daniel, 2017). However, indirect calorimetry only predicts energy expenditure and it is unable to estimate metabolic heat production which makes it a limitation. Metabolic heat production represents the volume of energy that is freed as heat during the metabolic processes, which is not directed to conduct external work. Furthermore, while at rest, energy expenditure is equivalent to metabolic heat manufacturing as no outside work is done (Whipp & Wasserman 1969), which means indirect calorimetry is unable to accurately measure this energy expenditure.

2.5.2.4 Heart rate monitoring

Heart rate (HR) monitors are relatively inexpensive and have a storage capacity that can cover a few days (for minute-by-minute heart rate). They have made ongoing heart rate monitoring a more practical technique for measuring PA (Trost & O'Neil, 2013). Furthermore, because of the direct proportion between heart rate and energy expenditure while performing constant ex-

ercise, heart rate monitoring remains a useful technique to evaluating physical activity. However, this method has several problems associated with it, components such as body size, age, emotional stress, amount of muscle mass used and cardiorespiratory fitness impacts the heart rate-oxygen consumption (VO_2) relationship (Trost & O'Neil, 2013).

The HRs reaction is likely to be delayed temporarily behind alterations in movement and frequently remains raised after the termination of the movement. Additionally, HR monitoring may also be of restricted use in evaluating total daily physical activity, for instance, in a case were a patients large percentage of the day is spent in relatively inactive pursuits such as sitting behind a desk (Livingstone et al., 1992). However, it is essential to take into account that various methods have been established to address some of these restrictions, for example, utilizing heart rate indices that control for individual distinctions in resting HR, the calibration of HR and work rate on an individual basis (Livingstone et al., 1992, Trost, 2001).

2.6 Accelerometers vs DLW method, and indirect calorimetry

Gold-standard measures of energy expenditure such as indirect calorimetry from respiratory gas analysis and the doubly-labelled water (DLW) method have been used in a number of previous studies to validate wrist acceleration data (van Hees et al., 2011, Esliger et al., 2011). These techniques have their own limitations, which include the cost of conducting studies on large population samples, as well as its use in collecting PA intensity or PA in free living conditions. Although there have been many laboratory studies to clarify the relationship between these techniques and accelerometers, they cannot begin to assess all the diverse range of human activities that makes up the complex issue of physical activity (White et al., 2016). On the other hand, accelerometers are user-friendly and display few hassles to the participants (no chest straps or electrodes) and they have the capability to identify incidental physical activity and activity patterns under free living conditions (Trost, 2007).

Although there are many known tools to assess PA, the question of their accuracy to assess PA during pregnancy still remains. The physiological changes that occurs during pregnancy do come as a challenge for assessing PA during this time, however, due to the burden of obesity and the benefits that comes with being physically active during pregnancy, a valid and reliable measurement tool is needed.

Chapter 3: Methodology

3.1 Study design

The associations between the energy expenditure (EE) estimates from the Oxycon and accelerometers (ActiGraph-wrist, ActiGraph-hip, Axivity and GENEActiv), placement position (wrist and hip) of the ActiGraph accelerometer and EE estimates of the three different wrist-worn accelerometers (ActiGraph, Axivity and GENEActiv) were assessed using a combination of a cross-sectional and longitudinal, observational design on pregnant and non-pregnant woman living in the Johannesburg area.

3.2 Site of study

The study was conducted at the Centre for Exercise Science and Sports Medicine, located at the University of Witwatersrand, Parktown, Johannesburg, Gauteng Province of South Africa.

3.3 Study population

A purposive convenience sample of thirty five female participants (22 pregnant and 13 non-pregnant women) volunteered to participate in this study. The testing procedure was explained and an information sheet (appendix D) was provided to the participant by the researcher. Data analysis was performed on 32 participants (22 pregnant and 10 non-pregnant women), after three did not complete the test due to bad weather and/or missing data. Pregnant women in their first trimester (<14 weeks, longitudinal) between the ages of 18- 40 years, residing within a 50 km radius of Parktown, Johannesburg were recruited in their early stage of pregnancy (<14 weeks gestation) to participate in the study until the third trimester (longitudinal). In addition, women in their 2nd and 3rd trimesters were invited for a once off testing (cross-sectional).

3.4 Selection and recruitment of participants

Healthy pregnant women were recruited through word of mouth or with an advert (appendix F) at local clinics around the Johannesburg area, doctor's rooms and antenatal classes. In addition, healthy non-pregnant women were recruited through word of mouth.

3.4.1 Inclusion and Exclusion Criteria for the study

Table 1: Inclusion and Exclusion criteria for pregnant woman

Participant exclusion criteria	**Participant inclusion criteria**
At-risk pregnancy i.e. • Haemodynamically significant heart disease • Restrictive lung disease, heavy smoker • Incompetent cervix/cerclage • Multiple gestation at risk for premature labour • Persistent second or third trimester bleeding • Placenta praevia after 26 weeks gestation • Premature labour during the current pregnancy • Ruptured membranes, severe anaemia • Pregnancy induced hypertension • Unevaluated maternal cardiac arrhythmia • Chronic bronchitis, Orthopaedic limitations • Poorly controlled type I diabetes, Extreme morbid obesity • Extreme underweight (BMI <12) • History of extremely sedentary lifestyle, • Intrauterine growth restriction in current pregnancy • Poorly controlled seizure disorder, thyroid disease & hypertension/pre-eclampsia • Any kind of clinical diagnosis, e.g. depression, cardiovascular diseases, and diabetes mellitus	Willing to participate from the 1st, 2nd and 3rd trimester of pregnancy. Participants will be included if they received clearance for exercise testing from a medical doctor. Participants willing to do a walking protocol test.

Table 2: Inclusion and exclusion criteria for non-pregnant women

Participant exclusion criteria	Participant inclusion criteria
• Participants with any orthopaedic injuries • Participants with any known or diagnosed coronary artery diseases or cardiovascular disease • Participants who have had previous revascularization • Participants with unstable angina • Participants using pacemakers	• Willing to participate in the study • Willing to complete the walking protocol test • Clearance to exercise using a PAR-Q

3.5 Measuring tools or instruments

Testing procedure:

The total protocol including time, intensity and rest parameters of the walking test is detailed in Appendix A. Each of the participants were instructed not to consume a heavy meal, drink any caffeinated drinks, or use any nicotine substances within two hours prior to their test session. They were instructed not to participate in any exercise training 24 hours before the testing procedure. The entire test procedure was explained to the participants and they were informed that they can abort the test at any time without having to explain why. The objectives of the study were explained, an information sheet was provided (Appendix D) and a written informed consent (Appendix E) was signed by all, ensuring that there is no injury or other health issue preventing them from participating. The resting heart rate (one minute sitting down) was measured using the RS800 Polar Electro, USA. The participants performed an outdoor submaximal walking test on a running track wearing four accelerometers, on the wrist (1 ActiGraph, GENEactive and Axivity) and hip (1 ActiGraph) on the participant's dominant side using an adjustable belt. The same accelerometers were always placed at the same site on all participants. The facemask for VO_2 collection was fitted before warm-up and tested to make sure there was no air leakage. A medical doctor was onsite in case of emergencies and doctor's clearance to participate in physical activity was obtained for every participant beforehand.

Measurements:

- PAR-Q for clearance to participate in physical activity during pregnancy (http://www.csep.ca/cmfiles/publications/parq/parmed-xpreg.pdf) (Appendix B)
- Accelerometers: 3 different accelerometer devices were used: ActiGraph (1 worn on the hip and 1 worn on the wrist); GENEActive (worn on the wrist) and the Axivity (worn on the wrist). The outcome measure used in this study across all accelerometers was vector magnitude (vm).
- Spirometry (gold standard to measure PAEE) was used to validate the different accelerometer devices using an OxyconTM mobile device (Intra medic, Jaeger Oxycon Pro, 2013). The outcome measure used for the Oxycon was VO_2/kg/ml/min/kg
- Heart frequency and heart rate variability (RS800, Polar Electro) was measured using beats/min
- Borg Scale (Borg, 1982) – rating of Perceived Exertion (every single work load step) was measured on a scale from 14-20.
- Anthropometrics - weight (kg), height (m), BMI (kg/m^2) were measured before the walking test.
- Sociodemographic data (age, education, marital status, work status, parity) and the DALI study questionnaire (Jelsma et al., 2013) were used (Appendix C).

Accelerometers

Accelerometers function by determining acceleration across a given axis, using different technologies such as piezo–electric, micro–mechanical springs, and changes in capacitance (Welk, 2002). Several axis measurements can also be packed into a single monitor, which allows movement to be captured in multiple planes. The main purpose of accelerometers is that the sensor transform movements into electrical signals that are proportional to the muscular force producing motion (Melanson & Freedson, 1996). These signals are summed over a specified period of time (epoch) and stored. In this study participants wore three types of accelerometers on the non-dominant hand and hip i.e. ActiGraph (wrist & hip), GENEActiv (wrist) and the Axivity (wrist) until the end of the testing procedure. All accelerometers were initialised with a measurement frequency set at (100 Hz) and a measurement period of 3 hours. The recorded data was downloaded at (10 seconds epochs) and the raw accelerometry data (vector magnitude) for all accelerometers was used for the comparisons during the analysis.

Oxycon^{TM} mobile device

In this study the Oxycon Mobile (OM), (Jäger, Würzburg, Germany) was used as the criterion method to validate accelerometers. The OM is the portable version of the Jaeger Oxycon Pro (CareFusion GmbH, Hoechberg Germany) which is a PC-based system for measurement of oxygen uptake (VO_2), carbon dioxide production (VCO_2) and ventilation (VE). OM is a relatively light weight (950g) spirometric device that utilizes electrochemical sensors and sends the data to a host computer via telemetry (Intra medic, Jaeger Oxycon Pro, 2013). The portable system is held in place by straps, which are slipped over the participant's shoulders and securely clipped into place without limiting movement.

Calibration of the gas analysers, volume sensor and turbine were done as stated by manufacturers before each test. Gas exchange variables (oxygen uptake (VO_2); carbon dioxide production (VCO_2); and ventilation, (VE) were assessed without interruption on a breath-by-breath basis. The facemask used in the study was the model 7600 V2 (Hans Rudolph inc, Canada). The VO_2 data was collected on-line by a personal computer laptop using the PC software (JLAB 4.61.1, CareFusion GmbH, Hoechberg Germany). Collection sample was set to use 10 second intervals with each data point as a mean value of the interval. Steady state oxygen consumption (VO_2/kg/ml/min/kg) was used to work out oxygen consumption for each speed/walking test.

Walking test

Participants were invited to participate in the test at three-time points in pregnancy: in early pregnancy (14-15 weeks), second trimester (24-28 weeks), and third trimester (35 weeks). The different devices (four accelerometers, heart rate monitor and spirometry) were placed on the participants. They would get a 15 minutes rest sitting on a chair. A walking incremental test would start with the participant moving at a speed of 3 km/h while increasing a speed of 0.5 km/h at each 50 m /10 m beep. A 400-m meter track was marked by cones distanced 10 m apart and a red cone was used as an indication that 50 m has been reached. An audio recording was used to alert the participant by a beep at each 10 m to increase speed every 50 m. The participants would increase their walking speed to reach 8 km/h, or when they asked to discontinue or stop and then complete 10 minutes active cool down. After the cool down participants would walk at different speeds lasting 5 minutes each. They would start by a speed of 3 km/h, 5 km/h and then end with free speed fast walking. Each 5-minute speed was followed by a 3 minutes active cool down (Appendix A).

3.6 Ethics

The Human Research Ethics Committee (HREC) of the University of the Witwatersrand Ethical gave ethics approval for the study (M160532) (Appendix G). Safety measures and sufficient professional supervision were provided during the testing; this was to ensure a non-hazardous environment where the participant feels safe to perform exercise. Confidentiality of the patient's medical history, data collection and any other personal or health related information was maintained at all times. This was achieved by allocating a numerical code to each participant. Each participant received a participant information document (see Appendix D) that explained exactly what is expected from each participant throughout the duration of the study, including how long they needed to exercise for, and what type of exercise they were required to do. This document was to notify the participants of any potential risks and benefits associated with participation in the study. In addition, after being informed a consent form (see Appendix E) was signed by each participant prior to the start of the study.

3.7 Analysis

Stata/SE 15.1 was used for data analysis. Descriptive statistics for all variables were calculated to describe characteristics of the pregnant and non-pregnant participants and energy expenditure values for each accelerometer and Oxycon outputs during the walking protocol. Histograms and Shapiro-Wilk tests indicated non-normality for 51 of 55 continuous physical activity variables, as a result, non-parametric tests were used for the analysis. The non-normally distributed continuous variables were presented as medians and interquartile range (IQR) and the categorical variables as frequencies and percentages. The level of significance was set at $p < 0.05$ for all analyses.

For the comparison between accelerometers and the Oxycon, average Vector Magnitudes (VM) for each accelerometer (ActiGraph-hip, ActiGraph-wrist, Axivity and GENEActiv) which are a proxy to METs and Oxygen consumption (VO_2/kg) for the Oxycon were calculated for the complete walking protocol test and at each stage. Fifty five outcome variables were taken into account for the analysis, namely TEE Oxycon (VO_2/kg), TEE ActiGraph-wrist (VM), TEE ActiGraph-hip (VM), TEE Axivity (SVM), GENEActiv (SVM), 15 min rest Oxycon (VO_2/kg), 15 min rest ActiGraph-wrist (VM), 15 min rest ActiGraph-hip (VM), 15 min rest Axivity (SVM), 15 min rest GENEActiv (SVM), 3 min rest Oxycon (VO_2/kg), 3 min rest ActiGraph-wrist (VM), 3 min rest ActiGraph-hip (VM), 3 min rest Axivity (SVM), 3 min rest GENEActiv

(SVM), Incremental test Oxycon (VO_2/kg), Incremental test ActiGraph-wrist (VM), Incremental test ActiGraph-hip (VM), Incremental test Axivity (SVM), Incremental test GENEActiv (SVM), 10 min rest Oxycon (VO_2/kg), 10 min rest ActiGraph-wrist (VM), 10 min rest ActiGraph-hip (VM), 10 min rest Axivity (SVM), 10 min rest GENEActiv (SVM), 3km/h Oxycon (VO_2/kg), 3km/h ActiGraph-wrist (VM), 3km/h ActiGraph-hip (VM), 3km/h Axivity (SVM), 3km/h GENEActiv (SVM), 3 min rest Oxycon (VO_2/kg), 3 min rest ActiGraph-wrist (VM), 3 min rest ActiGraph-hip (VM), 3 min rest Axivity (SVM), 3 min rest GENEActiv (SVM), 5km/h Oxycon (VO_2/kg), 5km/h ActiGraph-wrist (VM), 5km/h ActiGraph-hip (VM), 5km/h Axivity (SVM), 5km/h GENEActiv (SVM), 3 min rest Oxycon (VO_2/kg), 3 min rest ActiGraph-wrist (VM), 3 min rest ActiGraph-hip (VM), 3 min rest Axivity (SVM), 3 min rest GENEActiv (SVM), free-speed Oxycon (VO_2/kg), free-speed ActiGraph-wrist (VM), free-speed ActiGraph-hip (VM), free-speed Axivity (SVM), free-speed GENEActiv (SVM), 3 min rest Oxycon (VO_2/kg), 3 min rest ActiGraph-wrist (VM), 3 min rest ActiGraph-hip (VM), 3 min rest Axivity (SVM), 3 min rest GENEActiv (SVM).

Convergent validity or the association between the Oxycon and accelerometers was assessed by four different methods: summary statistics were used to describe EE estimates by the Oxycon and accelerometers at each stage of the walking protocol; Energy expenditure at each stage of the walking protocol for the pregnant and non-pregnant participants was compared using the Wilcoxon rank-sum test. Pairwise correlation was used to compare placement position (wrist and hip) of the accelerometers and comparison of PAEE values of the Oxycon and accelerometers during the walking protocol test. In addition, box plots and Pairwise correlations were used to demonstrate the total energy expenditure differences of the whole walking protocol between the Oxycon and accelerometers. In this study, Pairwise correlations were considered as small from 0 to less than 0.30, as moderate from 0.30 to less than 0.40, and greater than 0.5, as a strong correlation (Cohen, 1988), however, numerous results in this study were in the 0.4-0.5 range.

Chapter 4: Results

4.1 Demographics of the participants

Participant's demographics are presented in Table 3 below. Prior to analysis, 3 participants were excluded from the recruited sample of 35 participants because they had incomplete data. Thirty two female participants (22 pregnant and 10 non-pregnant) completed the walking protocol test and were included in the final analysis. From the 22 pregnant participants only 2 were followed up until the third trimester (longitudinal), 9 of them participated during their second trimester and 7 during the third trimester of pregnancy (cross-sectional). The median age for the pregnant participants was 28 years (range 27-33 years) and 24 years (range 21-25 years) for the non-pregnant women. The median BMI for the pregnant participants was 27.1 kg/m^2 (range 23.3-30.2 kg/m^2) and 23.4 kg/m^2 for the non-pregnant participants (range 21-27.6 kg/m^2) respectively. Three pregnant participants (13.64%) reported to be current smokers. The pregnant participants also reported that they had at least four days without enough sleep in the previous month. Furthermore 31.8% of the pregnant participants were unemployed, with 36.4% of them been single and 54.6% of them were having at least one child.

Table 3: Participants demographics for pregnant and non-pregnant women

	Pregnant woman median (IQR)/ % (n=22)	**Non-pregnant woman** median (IQR)/ % (n=10)	**p-value**
Age (yrs.)	28 (27-33)	24 (23-25)	**0.014**
Height (cm)	160 (155-162.5)	160 (157.5-165)	0.463
Weight (kg)	67.3 (60-73.7)	61.7 (55.5-70.9)	0.309
BMI (kg·m^{-2})	27.1 (23.3-30.2)	23.4 (21-27.6)	0.160
Smoking	3 (13.6%)	0%	
sleeping hours	8 (8-9)	7.5 (7-8)	**0.021**
Days without enough sleep	4 (0-5)	5 (3-6)	0.320
Level of education			
Secondary	9 (40.9%)	1 (10%)	
Technical	3 (13.6%)	3 (30%)	
University	10 (45.5%)	6 (60%)	
Occupation			

Full-time	11 (50%)	6 (60%)
Part-time	1 (4.6%)	
Student	3 (13.6%)	3 (30%)
Unemployed	7 (31.8%)	1 (10%)
Marital status		
Married	13 (59.1%)	1 (10%)
Cohabiting	1 (4.6%)	
Single	8 (36.4%)	9 (90%)
Number of children		
None	12 (55.56%)	10 (100%)
One	5 (27.3%)	
> One	5 (27.3%)	

Values are presented as median and Inter-Quartile Range; frequencies and percentages. Significant results are presented in bold ($p<0.05$)

4.2 Summary statistics of total energy expenditure for the Oxycon and accelerometers during the walking protocol test

Table 4 shows summary statistics of the Oxycon and accelerometers used to estimate the total energy expenditure (EE) and a comparison between the pregnant and non-pregnant participants for the whole walking protocol. No significant differences were observed during the comparison of the total energy expenditure estimates between the pregnant and non-pregnant participants while measuring physical activity using the Oxycon, ActiGraph-wrist worn, and Axivity accelerometers after completing the whole walking protocol test. However, there were significant differences observed when comparing the total energy expenditure estimates between the pregnant and non-pregnant participants while using the hip worn ActiGraph and GENEActiv accelerometers ($p<0.05$). In addition, figure 1 shows the differences in total energy expenditure measured by the Oxycon, and accelerometers for both pregnant and non-pregnant participants during the walking protocol test.

Table 4: Total energy expenditure comparison between the pregnant and non-pregnant participants for the complete walking protocol test.

	Pregnant woman median (IQR)	**Non-pregnant woman** median (IQR)	p-value
TEE Oxycon (VO_2/kg)	70.1 (64.3-78.2)	80.4 (49.6-85.6)	0.371
TEE ActiGraph-wrist (vm)	506.1 (339.4-586.3)	532.8 (392.8-618.5)	0.515
TEE ActiGraph-hip (vm)	272.6 (186.9-329.7)	330 (309.8-373.9)	**0.025**
TEE Axivity (svm)	0.7 (0.6-0.8)	0.8 (0.6-0.9)	0.393
TEE GENEActiv (svm)	304.4 (278.9-346.7)	366.7 (336.6-441.6)	**0.051**

Significant results are presented in bold ($p < 0.05$), TEE: total energy expenditure, VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine.

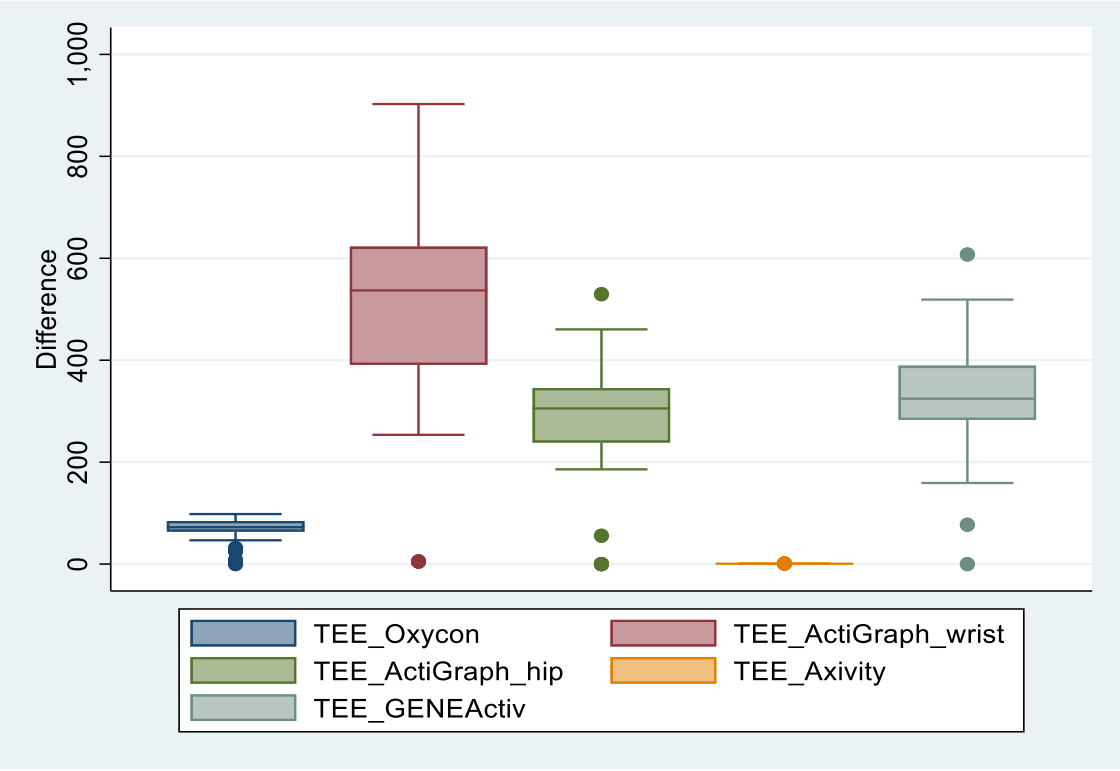

Figure 1: Differences in total energy expenditure between the Oxycon and accelerometers for pregnant and non-pregnant participants.

Table 5 and 6 are summary descriptive statistics of energy expenditure estimates by the Oxycon, ActiGraph-wrist, ActiGraph-hip, Axivity and GENEActiv used in this study. The summaries are of each stage of the walking protocol test for the pregnant and non-pregnant participants. Estimates of energy expenditure varied across the different accelerometer devices and the Oxycon for both the pregnant and non-pregnant participants. Estimates of energy expenditure ranged from 8.6-11.3 VO_2/kg during the incremental test, 6.6-7.9 VO_2/kg at 3km/h, 8.8-11.9 VO_2/kg at 5km/h and 9.7-17.1 VO_2/kg at free speed for the Oxycon when measuring the pregnant participants. For the non-pregnant participants EE estimates ranged from 10-11.9 VO_2/kg during the incremental test, 7-9.7 VO_2/kg at 3km/h, and 7.2-12.8 VO_2/kg at 5km/h and at free speed 12-18.7 VO_2/kg respectively. There were no significant differences observed between the pregnant and non-pregnant participants at the different stages of the walking protocol test while using the Oxycon mobile.

Using the ActiGraph-wrist-worn accelerometer, EE estimates ranged from 40.4-90 VM for the pregnant participants while performing the incremental test, 26.1-140.9 VM when walking at 3km/h, 75.6-100.9 VM at 5km/h and 63.1-106.2 VM at free speed during pregnancy. However, for the non-pregnant participants estimates ranged from 72.8-100.1 VM during the incremental test, 44.2-108.8 VM at 3km/h, 41.1-111.6 VM at 5km/h and 19.9-83.9 VM during the free speed test. Additionally, there was also no significant differences observed between the pregnant and non-pregnant participants at the different stages of the walking protocol test while using this device.

Estimates from the hip-worn-ActiGraph accelerometer ranged from 17.2-67.2 VM during the incremental test, 26.1-140.9 VM at 3km/h, and 9.6-55.3 VM while walking at 5km/h and 18.4-65.4 VM at free speed from the pregnant participants. Across the non-pregnant participants estimates ranged from 40.4-64.4 VM when performing the incremental test, 40.1-74.9 VM at 3 km/h, 15.4-70.9 VM at 5km/h and 17.1-69.4 VM during the free speed test. Furthermore, we observed significant differences of EE estimates between the pregnant and non-pregnant participants during the 10 minutes resting period of the incremental test ($p = 0.050$), while completing 3km/h walking test ($p = 0.036$) and at 3 minutes rest after completing the 5km/h walking test ($p = 0.031$).

The Axivity accelerometer estimates ranged from 0.05-0.13 SVM during the incremental test, 0.11-0.15 SVM at 3km/h, 0.13-0.17 SVM at 5km/h and 0.11-0.16 SVM at free speed amongst the pregnant participants. Similarly, for the non-pregnant participants, estimates ranged from

0.04-0.08 SVM when performing the incremental test, 0.13-0.17 SVM at 3km/h, from 0.11-0.17 SVM at 5km/h, and ranged from 0.17-0.28 SVM at free speed. When comparing EE estimates for the Axivity accelerometer we found significant differences during the 3km/h walking test ($p = 0.017$) and the free speed walking test ($p = 0.005$) between the pregnant and non-pregnant participants.

When measuring PA using the GENEActiv accelerometer, estimates ranged from 21.8-76.1 SVM for the incremental test, 11.6-25.3 SVM at 3km/h, 15.1-35.1 at 5km/h and 14-41.9 SVM at free speed from the pregnant participants. EE estimates ranged from 72.8-103.2 SVM for the incremental test, 13-14.9 SVM at 3km/h, 18.3-34.2 SVM at 5km/h and 31.5-60.9 SVM at free speed for the non-pregnant participants. We observed significant differences of the GENEActiv energy EE estimates between the pregnant and non-pregnant participants during the incremental test ($p = 0.010$) and free speed walking test ($p = 0.016$).

Table 5: Summary statistics of energy expenditure by the Oxycon and accelerometers for the pregnant participants at each stage of the walking protocol test

	Oxycon (VO_2/kg) median (IQR)	**ActiGraph wrist (vm)** median (IQR)	**ActiGraph hip (vm)** median (IQR)	**Axivity (svm)** median (IQR)	**GENEActiv (svm)** median (IQR)
15 min rest	3.4 (3.2-3.9)	23.6 (10.8-31.8)	1.7 (7.9-22)	0.03 (0.01-0.08)	25.9 (13-59.7)
3 min rest	4.6 (3.4-5.6)	29.6 (14.5-58.2)	6.5 (0.21.8)	0.02 (0.01-0.09)	20.1 (12.6-34.4)
Incremental test	9.6 (8.6-11.3)	54.4 (40.4-90)	43.3 (17.2-67.2)	0.75 (0.05-0.13)	50.9 (21.8-76.1)
10 min rest	4.7 (4-5.7)	20.6 (10.9-57.2)	11.9 (3-22.6)	0.02 (0.01-0.02)	25.3 (19.5-33.6)
3km/h	7.4 (6.6-7.9)	65.1 (26.1-140.9)	39.9 (27.8-52.6)	0.12 (0.11-0.15)	17.2 (11.6-25.3)
3 min rest	4.7 (3.9-5.4)	13.2 (5.7-21.7)	5.7 (1.7-16.4)	0.02 (0.01-0.03)	21.9 (7.5-26.3)
5km/h	10.5 (8.8-11.9)	90.1 (75.6-100.9)	32.9 (9.6-55.3)	0.14 (0.13-0.17)	20.1 (15.1-35.1)
3 min rest	5.5 (4.8-6.3)	15.4(10.7-25.9)	5.9 (2.3-13.9)	0.03 (0.02-0.05)	20.9 (7.1-39.7)
Free-speed	12.1 (9.7-17.1)	89.1 (63.1-106.2)	32.6(18.4-65.4)	0.15 (0.11-0.16)	21.6 (14-41.9)
3 min rest	6.1 (5-7.8)	27.4 (11.3-41.3)	15.3 (2.2-36.6)	0.04 (0.02-0.07)	23.5 (11.6-34.4)

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, IQR: interquartile range.

Table 6: Summary statistics of energy expenditure estimates by the Oxycon and accelerometers for the non-pregnant participants during each stage of the walking protocol test

	Oxycon (VO_2/kg) median (IQR)	**ActiGraph wrist (vm)** median (IQR)	**ActiGraph hip (vm)** median (IQR)	**Axivity (vm)** median (IQR)	**GENEActiv (vm)** median (IQR)
15 min rest	3.9 (3.3-4.4)	36.2 (14-17.1)	19.5 (13.4-24.8)	0.07 (0.04-0.08)	43.5 (10.5-69.3)
3 min rest	4.7 (4.3-5.2)	57.1 (26.4-77.2)	20.3 (12.8-54.4)	0.03 (0.01-0.04)	27.7 (16.3-43.3)
Incremental test	10.6 (10-11.9)	89.3 (72.8-100.1)	45.5 (40.4-64.4)	0.07 (0.04-0.08)	84.9 (72.8-103.2)
10 min rest	4.5 (3.4-5.6)	38.3 (10.2-74.4)	27.3 (10.9-49.7)	0.01 (0.01-0.02)	22.7 (21.9-34.2)
3km/h	8.10 (7-9.7)	59.3 (44.2-108.8)	58.6 (40.1-74.9)	0.15 (0.13-0.17)	13.7 (13-14.9)
3 min rest	4.9 (3.5-5.2)	17 (7.26-22.1)	9.9 (5.4-19.4)	0.02 (0.01-0.03)	20.9 (18.3-34.2)
5km/h	11.7 (7.2-12.8)	52.4 (41.1-111.6)	62.3 (15.4-70.9)	0.15 (0.11-0.17)	18.8 (16.2-20.4)
3 min rest	5.5 (3.7-6.5)	15.7 (14.2-27.2)	21 (10.9-33.8)	0.02 (0.01-0.03)	29 (20.3-58.5)
Free-speed	17.7 (12-18.7)	43.1 (19.9-83.9)	47.3 (17.1-69.4)	0.20 (0.17-0.28)	38.7 (31.5-60.9)
3 min rest	70.1 (4.4-7.7)	20.5 (14.8-48.5)	19 (6.7-23.9)	0.03 (0.02-0.04)	28.7 (24.4-41.1)

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, IQR: interquartile range.

4.3 Comparison between placement positions of accelerometers for pregnant and non-pregnant participants

4.3.1 Relationship between wrist accelerometers in measuring PA

When comparing the three wrist worn accelerometers used to measure PA of the pregnant participants (Table 7), the findings show a moderate significant correlation between the Axivity and GENEActiv accelerometers (r =0.428) at 15 minutes rest. Furthermore, while completing the 5km/h walking test, moderate significant correlations were found between the ActiGraph-wrist and GENEActiv accelerometers (r =0.394). No any other significant correlations were observed in the pregnant participants during the other stages of the walking protocol.

For the non-pregnant participants (Table 8), our study results indicated a strong significant correlation between the ActiGraph wrist and the Axivity accelerometer (r =0.659), and between the ActiGraph wrist and GENEActiv accelerometer (r =0.617) at 3 minutes rest after completing the 5km/h walking test. Additionally, at 3 minutes rest after completing the free speed walking test, we also found strong significant correlations between the ActiGraph wrist and Axivity (r =0.727), and between the GENEActiv and Axivity accelerometers (r =0.809) in the non-pregnant participants respectively.

Table 7: Pairwise correlations between wrist worn accelerometers for pregnant participants at each stage of the walking protocol test

	ActiGraph-wrist (vm) R-value	**Axivity (svm)** R-value
15 minutes rest		
Axivity (svm)	-0.249	
GENEActiv (svm)	-0.264	**0.428**
3 minutes rest		
Axivity (svm)	-0.026	
GENEActiv (svm)	-0.229	0.079
Incremental test		
Axivity (svm)	-0.154	
GENEActiv (svm)	-0.054	0.021
10 minutes rest		

Axivity (svm)	0.032	
GENEActiv (svm)	0.281	0.182
3km/h		
Axivity (svm)	0.229	
GENEActiv (svm)	-0.214	-0.044
3 minutes rest		
Axivity (svm)	-0.251	
GENEActiv (svm)	-0.019	-0.000
5km/h		
Axivity (svm)	-0.037	
GENEActiv (svm)	0.394	0.184
3 minutes rest		
Axivity (svm)	-0.018	
GENEActiv (svm)	0.235	0.141
Free speed		
Axivity (svm)	-0.009	
GENEActiv (svm)	0.230	0.336
3 minutes rest		
Axivity (svm)	0.160	
GENEActiv (svm)	-0.246	-0.283

Significant results are presented in bold ($p < 0.05$), vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 8: Pairwise correlations between wrist worn accelerometers for non-pregnant woman at each stage of the walking protocol

	ActiGraph-wrist (vm) R-value	Axivity (svm) R-value
15 minutes rest		
Axivity (svm)	-0.340	
GENEActiv (svm)	0.457	-0.049
3 minutes rest		
Axivity (svm)	-0.600	
GENEActiv (svm)	-0.472	0.599
Incremental test		

Axivity (svm)	-0.297	
GENEActiv (svm)	-0.228	-0.033
10 minutes rest		
Axivity (svm)	0.032	
GENEActiv (svm)	0.281	0.182
3km/h		
Axivity (svm)	-0.080	
GENEActiv (svm)	-0.233	0.498
3 minutes rest		
Axivity (svm)	0.000	
GENEActiv (svm)	0.022	0.221
5km/h		
Axivity (svm)	-0.240	
GENEActiv (svm)	-0.037	0.198
3 minutes rest		
Axivity (svm)	**0.659**	
GENEActiv (svm)	**0.617**	0.450
Free speed		
Axivity (svm)	-0.299	
GENEActiv (svm)	0.334	-0.031
3 minutes rest		
Axivity (svm)	**0.727**	
GENEActiv (svm)	**0.944**	**0.809**

Significant results are presented in bold ($p < 0.05$), vm: vector magnitude, svm: support vector machine, R-value: correlation.

4.3.2 Relationship between measuring PA on the hip and wrist

When comparing the wrist-worn and hip-worn-ActiGraph accelerometer (Table 9) between the pregnant and non-pregnant women, strong significant correlations were found during the 10 minutes rest ($r = 0.557$) for the pregnant participants and a moderate correlation while walking at 3km/h ($r = 0.406$) followed by strong significant correlation during the 3 minutes rest after completing the 3km/h walking test ($r = 0.626$). In addition, strong significant correlations where observed when participants were completing the 5km/h walking test ($r = 0.763$). However, only moderate correlations were observed from the non-pregnant participants when performing the

5km/h walking test (r =0.441), no correlations were observed during the other stages of the walking protocol test.

Table 9: Pairwise correlations between the hip and wrist worn accelerometers at each stage of the walking protocol for the pregnant and non-pregnant participants

	Pregnant woman ActiGraph-wrist (vm) R-value	**Non-pregnant woman** ActiGraph-wrist (vm) R-value
15 minutes rest		
ActiGraph-hip (vm)	-0.065	0.258
3 minutes rest		
ActiGraph-hip (vm)	0.216	0.247
Incremental test		
ActiGraph-hip (vm)	-0.029	-0.080
10 minutes rest		
ActiGraph-hip (vm)	**0.557**	0.030
3km/h		
ActiGraph-hip (vm)	0.406	-0.240
3 minutes rest		
ActiGraph-hip (vm)	**0.626**	-0.195
5km/h		
ActiGraph-hip (vm)	**0.763**	0.441
3 minutes rest		
ActiGraph-hip (vm)	0.173	-0.087
Free speed		
ActiGraph-hip (vm)	0.341	0.344
3 minutes rest		
ActiGraph-hip (vm)	0.305	0.134

Significant results are presented in bold ($p < 0.05$), vm: vector magnitude, svm: support vector machine, R-value: correlation.

4.4 Relationship between the Oxycon and accelerometers when measuring PA for pregnant and non-pregnant participants

4.4.1 Associations when measuring the pregnant participants

The relationship between measuring physical activity using the Oxycon and accelerometers during the different stages of the walking protocol test was measured. Negative moderate and significant correlations (r = -0.445) between the Oxycon and the ActiGraph-hip accelerometer during the 3 minutes rest before commencing with the walking protocol were found (see table 11). Furthermore, moderate significant correlations were found between the Oxycon and Acti-Graph-wrist accelerometer (r = 0.410) at 10 minutes rest after completing the Incremental test (see table 13). No correlations were observed for tables 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 and 28 for both pregnant and non-pregnant participants.

Table 10: Correlations at **15 minutes rest** between the Oxycon and accelerometers of the walking protocol test for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.158
ActiGraph-hip (vm)	0.255
Axivity (svm)	0.262
GENEActiv (svm)	0.151

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 11: Oxycon and accelerometers correlations at **3 minutes rest** of the walking protocol test for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.112
ActiGraph-hip (vm)	**-0.445**
Axivity (svm)	-0.370
GENEActiv (svm)	0.100

Significant results are presented in bold ($p < 0.05$), VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 12: **Incremental test** correlations between the Oxycon and accelerometers for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-Wrist (vm)	0.070
ActiGraph-hip (vm)	-0.173
Axivity (svm)	0.195
GENEActiv (svm)	0.234

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 13: **10 minutes standing rest after the incremental walking test** correlations between Oxycon and accelerometers for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	**0.410**
ActiGraph-hip (vm)	0.308
Axivity (svm)	-0.342
GENEActiv (svm)	0.223

Significant results are presented in bold ($p < 0.05$), VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 14: **3km/h walking test** correlations between the Oxycon and accelerometers for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.228
ActiGraph-hip (vm)	-0.059
Axivity (svm)	0.144
GENEActiv (svm)	-0.133

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 15: 3 minutes standing rest after the 3km/h walking test correlations between the Oxycon and accelerometers for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.321
ActiGraph-hip (vm)	0.198
Axivity (svm)	-0.157
GENEActiv (svm)	-0.043

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 16: **5km/h walking test** correlations between the Oxycon and accelerometers for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.261
ActiGraph-hip (vm)	0.150
Axivity (svm)	0.292
GENEActiv (svm)	0.124

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 17: **3 minutes standing rest after the 5km/h walking test** correlations between Oxycon and accelerometers for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.378
ActiGraph-hip (vm)	0.000
Axivity (svm)	-0.209
GENEActiv (svm)	-0.181

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 18: **Free speed walking test** correlations between the Oxycon and accelerometers for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.355
ActiGraph-hip (vm)	0.129
Axivity (svm)	0.149
GENEActiv (svm)	0.384

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 19: **3 minutes standing rest after the free speed walking test** correlations between the Oxycon and accelerometers for pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	-0.001
ActiGraph-hip (vm)	-0.054
Axivity (svm)	0.109
GENEActiv (svm)	0.084

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

4.4.2 Associations when measuring the non-pregnant participants

The relationship between the Oxycon and accelerometers of measuring PA was also assessed from the non-pregnant participants and our results show a significant and strong negative correlation between the Oxycon and GENEActiv accelerometer (r = -0.714) when the participants were completing the 5km/h walking test (Table 26). Similarly, strong and significant correlations were found at the 3 minutes resting period (Table 27) after completing the 5km/h walking test between the Oxycon and GENEActiv (r = 0.667). In addition, when comparing EE estimates between the Oxycon and Axivity accelerometer our studies results show a strong significant correlation during the 3 minutes resting period of the free speed walking test (r = 0.627),

we also found strong significant correlations between the Oxycon and GENEActiv accelerometer (r = 0.627) during the same stage (Table 29).

Table 20: Correlations between the Oxycon and accelerometers at **15 minutes rest** of the walking protocol for non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	-0.184
ActiGraph-hip (vm)	0.257
Axivity (svm)	-0.032
GENEActiv (svm)	-0.525

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 21: **3 minutes rest** correlations between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	-0.258
ActiGraph-hip (vm)	-0.420
Axivity (svm)	0.114
GENEActiv (svm)	0.077

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 22: **Incremental test** correlations between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.238
ActiGraph-hip (vm)	-0.146
Axivity (svm)	-0.467
GENEActiv (svm)	0.292

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 23: Correlations at **10 minutes rest of the Incremental test** between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	-0.431
ActiGraph-hip (vm)	-0.158
Axivity (svm)	-0.354
GENEActiv (svm)	0.547

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 24: **3km/h walking test** correlations between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	-0.539
ActiGraph-hip (vm)	0.341
Axivity (svm)	0.506
GENEActiv (svm)	0.091

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 25: **3 minutes rest of the 3km/h walking test** correlations between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.073
ActiGraph-hip (vm)	0.399
Axivity (svm)	0.305
GENEActiv (svm)	0.271

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 26: **5km/h walking test** correlations between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.295
ActiGraph-hip (vm)	-0.390
Axivity (svm)	0.083
GENEActiv (svm)	**-0.714**

Significant results are presented in bold ($p < 0.05$), VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 27: Correlations at **3 minutes rest of the 5km/h walking test** between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.311
ActiGraph-hip (vm)	0.296
Axivity (svm)	0.130
GENEActiv (svm)	**0.667**

Significant results are presented in bold ($p < 0.05$), VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 28: **Free speed walking test** correlations between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	-0.157
ActiGraph-hip (vm)	-0.051
Axivity (svm)	0.498
GENEActiv (svm)	0.048

VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Table 29: Correlations at **3 minutes rest of the free speed walking test** between the Oxycon and accelerometers for the non-pregnant participants

Accelerometers	Oxycon (VO_2/kg) R-value
ActiGraph-wrist (vm)	0.597
ActiGraph-hip (vm)	0.312
Axivity (svm)	**0.672**
GENEActiv (svm)	**0.642**

Significant results are presented in bold ($p < 0.05$), VO_2/kg: oxygen consumption, vm: vector magnitude, svm: support vector machine, R-value: correlation.

Chapter 5: Discussion

5.1 Introduction

The present study is the first of its kind to investigate and report on the validity of accelerometer's ability to measure PA during pregnancy while performing a field walking protocol test in South Africa. Very little evidence is available regarding physical activity measurement during pregnancy, and no regular measurement tool is currently accepted and being used to assess PA throughout pregnancy (Harrison et al., 2011).

Measuring physical activity in an accurate way especially during the pregnancy period is a multi-faceted concern and explaining the issues of validity is complex (Kelly et al., 2016). The method to examining and describing validity of physical activity measurements has been addressed in a study done by Kelly et al. (2016), this was done so that clarity can be ensured, and that there is accuracy and comparability between different validation studies of PA. In the present study, convergent validity was examined by use of four various methods, and the results indicate a poor validity of the accelerometers when compared to the Oxycon for measuring PA at each stage of the walking protocol test for pregnant and non-pregnant participants. For instance, the ActiGraph-wrist, ActiGraph-hip and GENEActiv overestimated the total energy expenditure of the whole walking test protocol for both the pregnant and non-pregnant participants when compared to the Oxycon. Furthermore, the Axivity accelerometer underestimated the total energy expenditure of both the pregnant and non-pregnant participants during the walking protocol test.

5.2 Description of the participants

Very few pregnancy PA measurement tool validation studies have looked at black or African pregnant participants from low-income households (Hesketh et al., 2018, Watson et al., 2017, Welch at al., 2014). However, in this current study ethnicity and level of income was not considered for exclusion to participate. The pregnant participants in this study were 27 years or above, with the majority of them having some tertiary education which signifies that they may read and understand the benefits of PA during pregnancy.

Despite the wealth of evidence of published research discouraging smoking during pregnancy (Meghea, 2010), this study found that 13.6% of our pregnant participants were still smoking

which is an indication of a poor and destructive lifestyle behaviour that poses various health risks for both the mother and the baby. Similarly, Meghea et al. (2012) who assessed the prevalence and the relationship of smoking during pregnancy reported that 15% of the women in their study carried on smoking throughout their pregnancy. Smoking cigarettes during pregnancy has been linked with a number of risks such as placental abruption, placenta praevia, low birth weight and premature birth, which result in a significant high rate of morbidity and mortality in babies (Toriola et al., 2011). Smoking has also been associated with behavioural problems and respiratory diseases during infancy and into childhood (Robinson et al., 2010). Additionally, it was also reported that although signs of depression and stress were not related with smoking during pregnancy, women who did not have any social support had higher odds of continuing to smoke when compared to the non-smoking (Meghea et al., 2012). In this study, 36.4% of the pregnant participants were single; therefore not getting enough support throughout the pregnancy may have been a contributing factor to their continued smoking.

5.3 Description of energy expenditure estimates during the walking protocol test between the pregnant and non-pregnant participants

Due to the physiological changes during pregnancy, it is known that energy expended during PA is different when comparing the pregnant and non-pregnant women; therefore, assessing the differences of total energy expended during PA for pregnant and non-pregnant women is important. It has been shown by previous research that as a result of the increase in tissue mass (Butte and King, 2005), and the physiological changes that occur during pregnancy there is an increase of energy expenditure at rest and during exercise (Fernandes & Takito, 2015). However, accelerometry results from a study done by van Hees et al. (2011), indicated quite the opposite as the non-pregnant participants expended 24% more of PAEE compared to 11% of PAEE expended by the pregnant participants, but this difference was not significant. Similarly, although not significant, this study also found that non-pregnant participants expended more energy based on estimates from the criterion measure (Oxycon) as compared to the pregnant participants.

Energy expenditure is known to increase during pregnancy with an increase in gestation under resting conditions, resulting in an increase of about 16-32 % above non-pregnant controls (Lotgering et al., 1985, Lumbers, 2002). Overall, in this study some devices such as the ActiGraph-hip-worn accelerometer at 10 minutes rest of the incremental walking test and at 3 minutes rest of the 5km/h walking test, the Axivity at the 3km/h and free-speed walking test were able to

detect the differences of the energy expended during PA. Lastly, the GENEActiv accelerometer was also able to detect the difference in PAEE during the incremental and free-speed walking test. However, there was very little significant differences of total energy expenditure at each stage of the walking protocol between the pregnant and non-pregnant participants while measuring PA with the ActiGraph-hip worn, Axivity and the GENEActiv accelerometer. All in all, this study did not find any consistently different patterns of energy expended between the pregnant and non-pregnant participants which may indicate that the differences are negligible, or perhaps the accelerometers are not sensitive enough to pick up on the changes that do occur.

5.4 Relationship between different devices worn on the wrist

Wrist worn accelerometers are becoming increasingly more popular, and have been studied in different clinical and research settings (Vanhelst et al., 2012, Manini et al., 2013, Hildebrand et al., 2014, Rowlands et al., 2014, Ellis et al., 2014, Tudor-Locke et al., 2015, Vanhelst et al., 2012, Mannini et al., 2013, Ellis et al., 2014, Hildebrand et al., 2014, Rowlands et al., 2014, Tudor-Locke et al., 2015, Dieu et al., 2017), making it an important issue to determine whether measuring on the wrist is suitable placement area.

In a study done by Rowlands et al. (2017), which looked at the correlations between three commonly used accelerometer brands, namely GENEActiv, Axivity AX3 and ActiGraph GT9X, they found that the GENEActiv and Axivity accelerometers were considered equivalent, but acceleration measured by the ActiGraph was lower. Similarly, findings in the current study showed a moderate significant correlation at rest between the GENEActiv and Axivity accelerometer and no correlation to the ActiGraph-wrist worn accelerometer when measuring PA of the pregnant participants. Furthermore, Rowlands et al. (2017) also found a good agreement when comparing GENEActiv or Axivity to the ActiGraph accelerometer, based on time spent within intensity cut-points. However, since we did not use cut-points in this study, we were unable to detect overall differences of the GENEActiv and Axivity accelerometer.

Nonetheless, there was strong significant correlations between the three wrist worn accelerometers (ActiGraph, Axivity and GENEActiv) when we measured PA of the non-pregnant participants, although this was only during the resting period of the walking protocol test. These findings suggest that perhaps accelerometer devices are more sensitive to detect sedentary or recovery periods than they are for moderate to vigorous activity in this group. Similarly,

Zinkhan et al. (2014) found that wrist-worn accelerometers performed better in assessing total sedentary time and sleep estimates parameters than the hip-worn accelerometers.

Results from a study done by van Hees et al. (2011), suggests that wrist-worn accelerometers are feasible for measurement of physical activity and may be preferable for pregnant women in terms of comfort and compliance. Although previous research has indicated that wrist-worn accelerometers may be more likely to provide consistency across measurement time points as they remain in the same attachment place regardless of changes during pregnancy (Hesketh et al., 2018). Findings in the current study are not strong enough to confirm this, which warrants more studies looking at the consistency of different wrist-worn accelerometer brands during pregnancy.

5.5 Relationship between the hip and wrist worn ActiGraph accelerometers

Earlier studies indicate that most accelerometers are worn on the waist, hip or lower back, which is closer to the centre of gravity (Westerterp, 1999). However, studies that are more recent have demonstrated that accelerometers worn around the waist or at the hip have lower wear time compliance, in cases such as sleep and water activities, which results in selection bias and mis-classification of physical activity (Vanhelst et al., 2012). The positioning of activity monitors on the body is an important consideration for physical activity researchers.

Our study assessed the relationship between the hip-and-wrist-worn ActiGraph accelerometers and the findings indicated that there were strong and significant correlations between the hip-and-wrist-worn ActiGraph accelerometers at 10 minutes rest after completing the incremental test and at 3 minutes rest after completing the 3 km/h walking test during PA participation for the pregnant women. Furthermore, the results also indicated strong significant correlations between the hip-and-wrist-worn ActiGraph accelerometers during the 5km/h walking test while measuring PA for the pregnant women. However, our results did not show any significant correlations when we measured PA of the non-pregnant women. On the contrary, van Hees et al. (2011) observed high correlations between the wrist-and-hip accelerometers when looking at estimations of total daily energy expenditure using a tri-axial accelerometer for both pregnant and non-pregnant participants. Furthermore, results from the study also show that the side of the body to which the accelerometers were placed contributed significantly to the explained differences in PAEE in pregnant women but not in the non-pregnant women (van Hees et al, 2011). These results support our current study findings where differences were only observed

when measuring the PAEE of the pregnant participants and not of the non-pregnant using the hip-and-wrist worn accelerometers. However, our findings were not consistent throughout the various stages of the walking protocol and therefore more research should be done to provide evidence for the use of hip versus wrist placement during pregnancy.

5.6 Relationship between the Oxycon, ActiGraph wrist, ActiGraph hip, Axivity and GENEActiv accelerometers

Measuring PA during pregnancy still poses as a challenge, with very few pregnancy specific studies done in African populations. The use of accelerometer devices to assess PA levels has increased and very few of them have looked at the validity of these devices during pregnancy. However, validity of these devices in normal or general adult populations has being previously assessed. In a study done by Welch et al. (2014), which cross-validated a waist worn accelerometer in 139 adults reported strong correlations between the GENEActiv and the Oxycon mobile, however, the accelerometer had had a low overall accuracy rate for classifying intensity. In contrast, the main findings of this study indicate moderate significant correlations between the Oxycon and ActiGraph-hip at 3 minutes rest before completing the incremental walking test and between the Oxycon and ActiGraph-wrist accelerometers at 10 minutes rest after completing the incremental walking test for the pregnant participants. When measuring PA of the non-pregnant participants, our findings indicate strong and significant correlations between the Oxycon and GENEActiv at the 3 minutes rest after completing the 5km/h and during the free-speed walking test. Furthermore, our results also indicated strong significant correlations at 3 minutes rest after completing the free-speed walking test between the Oxycon and Axivity accelerometer.

Further analysis of the results also indicates a strong significant correlation between the Oxycon and GENEActiv during the 5km/h walking test when measuring PA of the non-pregnant participants. The GENEActiv accelerometer was the one, which consistently correlated with the Oxycon in more than one stage of the walking test protocol. However, overall, very little correlations existed between Oxycon and the accelerometers when measuring PA in the study for both pregnant and non-pregnant participants. Furthermore, the wrist-worn accelerometers strongly correlated with the Oxycon during the resting periods of the walking protocol, which further confirms that wrist-worn accelerometers were more sensitive to detect low intensity activities or sedentary time in this study. Similarly, a study done by Zinkhan et al. (2014) found that wrist-worn accelerometers performed better in assessing total sedentary time than the hip-

worn accelerometers when compared with the criterion measure. Additionally, these studies results are similar to those of a study by Hesketh et al. (2018), where the results indicated that wrist-worn accelerometers provided higher compliance in comparison to the hip-worn accelerometers throughout the measurement period. Furthermore, these findings can be an indication that perhaps wrist-worn accelerometers may be better alternatives in terms of assessing PAEE during pregnancy. However, since our sample size was small more wrist-worn accelerometer validation studies with a larger sample are warranted so that a clear conclusion can be reached.

5.7 Strengths and limitations

This is the first study of its kind using both cross-sectional and longitudinal design to assess the validity of accelerometers in measuring PA during pregnancy in an African population analyzing raw data rather than counts. Since the main aim of this study was to assess the validity of accelerometers in measuring PA during pregnancy in a small sample, the results found may only be applicable for this group and may not be easily generalized to other populations.

During pregnancy, each trimester has unique biomechanical and physiological changes. For example, cardiac output increases by 20% in the first 8 weeks, and then by another 10-30% by the end of gestation (Soma-Pillay, 2016). Blood pressure declines in the first and second trimesters and then rises to non-pregnant levels in the third trimester. Furthermore, while still early in pregnancy, the inspiratory reserve volume is reduced, but it then goes up again in the third trimester (Soma-Pillay, 2016). Therefore, in this study, since not all the pregnant participants were in the same trimester, there may be variation in energy expenditure and response to exercise that we did not elicit, since we were unable to compare the differences in measuring PA by trimesters.

The small sample size and the fact that that only pregnant women living in the Johannesburg area participated in the study is also a limitation. Johannesburg is a large middle-to-high-income metropolitan area with an urban lifestyle. Therefore, population groups from smaller cities, rural towns or villages may present with different findings. However, recruitment of the study participants in the Johannesburg area was more convenient as they were closer to the testing site and had easy access to transportation.

Furthermore, there are various ways of validating PA using accelerometers such as using METs or counts (Jette et al., 1990, Schutz et al., 2001, Kim et al., 2012), in this study the raw Vector Magnitude data was chosen for comparisons of PAEE between the pregnant and non-pregnant

women as it was more convenient as no conversion to METs was required. However, our results may be slightly different if a different outcome measure was used. Moreover, in a study done by Lumbers (2002), maternal exercise to the level of 82% was shown to correlate with an increase in heart rate (HR), therefore future studies should address differences in HR as well as acceleration. Additionally, since the walking protocol was a staged exercise, future studies assessing the cut points from each of the accelerometer devices, and whether they correspond with the Oxycon device are warranted.

5.8 Key take home messages

- This study found no clear differences in energy expenditure patterns between pregnant and non-pregnant women, and therefore assessing PA during pregnancy may be allowed to follow the analysis / guidelines used in the general population.
- In this study wrist-worn accelerometer devices were more sensitive to detect resting periods between walking bouts, therefore, they may be more suitable for assessing or measuring recovery time.
- More studies looking at the consistency of measuring physical activity using wrist-worn accelerometers during pregnancy are needed.
- Measuring PA using wrist-worn accelerometers may be most suitable for pregnant women, since placement position is not affected by the physiological changes that occur during pregnancy.
- More field test research with larger samples using accelerometer devices are needed especially in South Africa so that we are able to accurately assess PA and inform clinicians, communities and policy makers on the best PA recommendations in pregnancy.

5.5 Conclusion

In conclusion, accelerometers overestimated TEE and had low correlations to the Oxycon when measuring PA for both the pregnant and non-pregnant women. The wrist-worn accelerometers had a higher accuracy in measuring PA at rest when compared to the Oxycon. However, some of the accelerometer devices were only sensitive enough to detect very low activity or sedentary time. Of all the accelerometer devices, the GENEActiv had the strongest correlations to the Oxycon. There is not enough evidence from this study to say that accelerometers are suitable to assess PAEE during pregnancy, however, taking into consideration the higher accuracy of

wrist-worn accelerometers, larger cohorts are needed to confirm if devices with this placement area can accurately estimate PA's energy expenditure during pregnancy.

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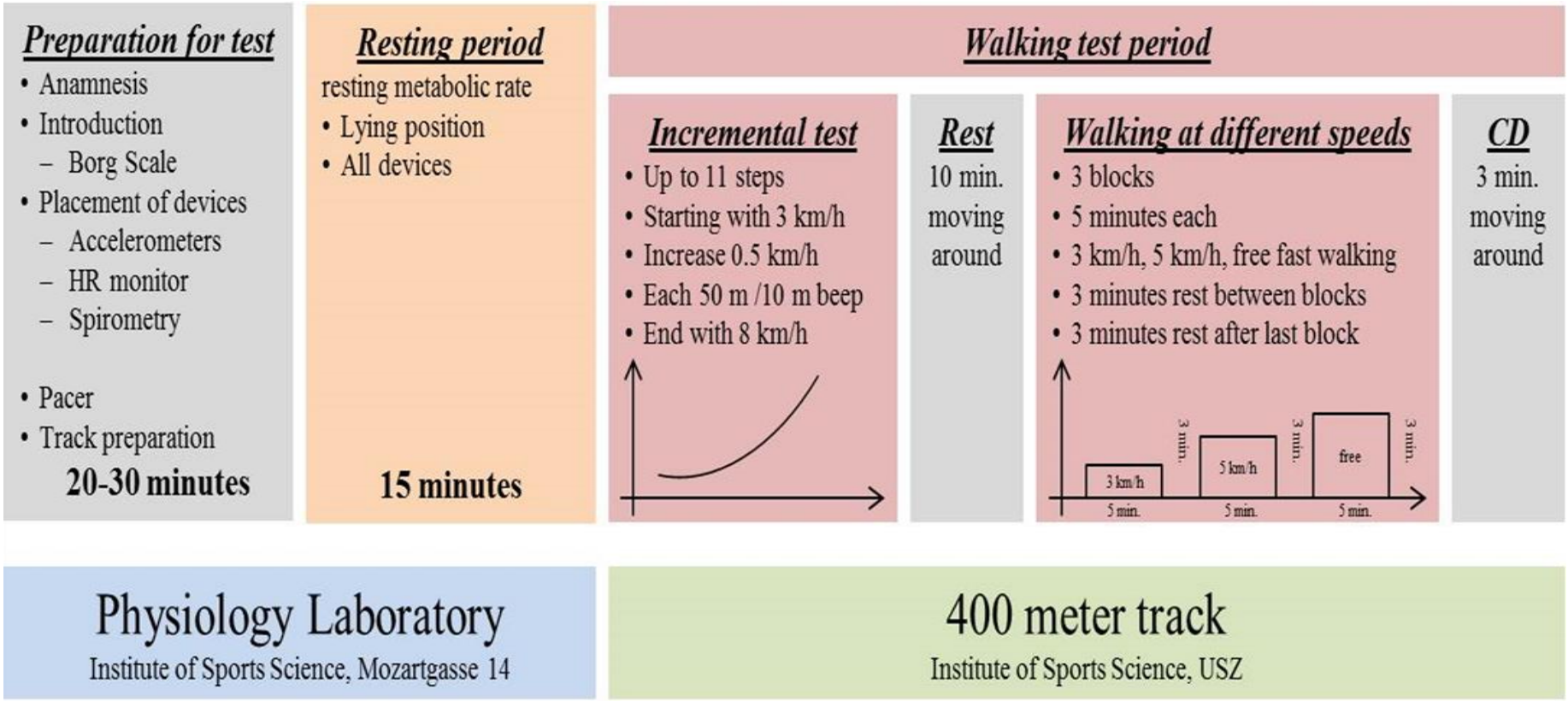
APPENDIX A: Study protocol



Data collection Form: Validation_Accelerometers Pregnancy

START		**DATE**	
ENDE		**HEIGHT**	**cm**
CODE		**WEIGHT**	**kg**
NAME		**BMI**	**kg/m²**
BIRTHDAY		**TEMPERATURE**	**°C**

STUDY: accelerometer validation pregnancy	**Walking-Tests**

Period	**Time**	**km/h**	**Borg 6-20**	**Comments:**
Preparation	20-30 min	---	---	
Resting	15 min	---	---	
Incremental test	3 min rest	**0**		
		3		
		3,5		
		4		
		4,5		
		5		
		5,5		
		6		
		6,5		
		7		
		7,5		
		8		
Resting	10 min rest			
Walking	5 min	**3**		
	3 min rest	**0**		
	5 min	**5**		
	3 min rest	**0**		
	5 min	**free speed**		distance (m): speed (km/h):
Cool down	3 min	**CD**		

HR measurement (five seconds intervals) with POLAR No. _____
HRV measurement (beat-to-beat measurement) with POLAR No._____

Actigraph hip No. _____
Actigraph wrist No. _____

Times of disconnecting accelerometers:

ActiGraph hip: __/__/__	; side of placement:	**O** left	**O** right
ActiGraph wrist: __/__/__	; side of placement:	**O** left	**O** right
GENEActive: __/__/__	; side of placement:	**O** left	**O** right
AX3: __/__/__	; side of placement:	**O** left	**O** right

Order of accelerometers on wrist:

1: ActiGraph --- GENEActive --- AX3 **O**
2: ActiGraph --- AX3 --- GENEActive **O**
3: AX3 --- GENEActive --- ActiGraph **O**
4: AX3 --- ActiGraph --- GENEActive **O**
5: GENEActive --- AX3 --- ActiGraph **O**
6: GENEActive --- ActiGraph --- AX3 **O**

APPENDIX B: PAR-Q FOR PREGNANCY

Healthy women with uncomplicated pregnancies can integrate physical activity into their daily living and can participate without significant risks either to themselves or to their unborn child. Postulated benefits of such programs include improved aerobic and muscular fitness, promotion of appropriate weight gain, and facilitation of labour. Regular exercise may also help to prevent gestational glucose intolerance and pregnancy induced hypertension. The safety of prenatal exercise programs depends on an adequate level of maternal-foetal physiological reserve. PARmed-X for PREGNANCY is a convenient checklist and prescription for use by health care providers to evaluate pregnant patients who want to enter a prenatal fitness program and for ongoing medical surveillance of exercising pregnant patients.

SECTION A: PATIENT INFORMATION

Participant ID: _____

Date of birth: _____

Name of clinic/gynecologist: _____

Date of last medical check: _____

SECTION B: PRE-EXERCISE CHECKLIST

PRE-EXERCISE HEALTH CHECKLIST

PART 1: GENERAL HEALTH STATUS

In the past, have you experienced: Y N

1 Miscarriage in an earlier pregnacy? ☐ ☐
2 Other pregnancy complications? ☐ ☐
3 I have completed a PAR-Q within the last 30 days. ☐ ☐

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

_____

Number of previous pregnancies: _____

PART 2: STATUS OF CURRENT PREGNANCY

Due Date: MM / DD / YEAR

During this prenancy, have you experienced: Y N

1 Marked fatigue? ☐ ☐
2 Bleeding from the vagina ("spotting")? ☐ ☐
3 Unexplained faintness or dizziness? ☐ ☐
4 Unexplained abdominal pain? ☐ ☐
5 Sudden swelling of ankles, hands or face? ☐ ☐
6 Persistent headaches or problems with headaches? ☐ ☐
7 Swelling, pain or redness in the calf of one leg? ☐ ☐
8 Absence of fetal movement after 6th month? ☐ ☐
9 Failure to gain weight after 5th month? ☐ ☐

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

_____

PART 3: ACTIVITY HABITS DURING THE PAST MONTH

1 List only regular fitness/recreational activities:

_____

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

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

Heavy lifting? ☐ ☐
Frequent walking/stair climbing? ☐ ☐
Occasional walking (> once/hr)? ☐ ☐
Prolonged standing? ☐ ☐
Mainly sitting? ☐ ☐
Normal daily activity? ☐ ☐

3 Do you currently smoke tobacco?* ☐ ☐
4 Do you consume alcohol?* ☐ ☐

PART 4: PHYSICAL ACTIVITY INTENTIONS

What physical activity do you intend to do?

_____

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

**Note: Pregnant women are strongly advised not to smoke or consume alcohol during pregnancy and during lactation.*

CONTRAINDICATIONS TO EXERCISE *To be completed by your health care provider*

ABSOLUTE CONTRAINDICATIONS

Does the patient have:	Y	N
1 Ruptured membranes, premature labour?	☐	☐
2 Persistent second or third trimester bleeding/ placenta previa?	☐	☐
3 Pregnancy-induced hypertension or pre-eclampsia?	☐	☐
4 Incompetent cervix?	☐	☐
5 Evidence of intrauterine growth restriction?	☐	☐
6 High-order pregnancy (e.g., triplets)?	☐	☐
7 Uncontrolled Type I diabetes, hypertension or thyroid disease, other serious cardiovascular, respiratory or systemic disorder?	☐	☐

RELATIVE CONTRAINDICATIONS

Does the patient have:	Y	N
1 History of spontaneous abortion or premature labour in previous pregnancies	☐	☐
2 Mild/moderate cardiovascular or respiratory disease (e.g., chronic hypertension, asthma)?	☐	☐
3 Anemia or iron deficiency? (Hb < 100 g/L)?	☐	☐
4 Malnutrition or eating disorder (anorexia, bulimia)?	☐	☐
5 Twin pregnancy after 28th week?	☐	☐
6 Other significant medical condition? Please specify: _____	☐	☐

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

PHYSICAL ACTIVITY RECOMMENDATION ☐ Recommended/Approved ☐ Contraindicated

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

PATIENTS SIGNATURE _____ DATE _____

NAME OF HEALTH CARE PROVIDER _____

ADDRESS _____

PHONE _____

HEALTH CARE PROVIDER'S COMMENTS:

_____

_____

Date:	**Signature:**

APPENDIX C: Sociodemographic questionnaire (according to the DALI study)

1. **Participant ID** ----------
2. **Date of birth** _ _ / _ _ / _ _ _ _
3. **Date of your last mentrual period** _ _ / _ _ / _ _ _ _
4. **Pre-pregnancy weight. How much did you weigh just before this pregnancy?**
5. **Do you currently smoke (cigarettes, cigars, pipe) or use any other tobacco products?**
   - o No, I have never smoked (Go to Q5)
   - o No, I used to smoke but I have stopped
   - o Yes, I currently smoke
6. **If you used to smoke, when did you quit?**
   - o Less than one year ago, exactly _____ months ago
   - o Between 1 and 5 years ago
   - o More than 5 years ago
7. **If you currently smoke, how many cigarettes/cigars/pipes do you smoke per day**
   ____ per day
8. **How many hours on average do you sleep per day?** ____ hours per day
9. **How many days in the past month did you feel you have not slept enough?**
   ____ days per month
10. **Does your work/studies involve shift work**
    - o Yes
    - o No
11. **What is your highest educational level?**
    - o No formal qualification
    - o Primary School
    - o Secondary school
    - o Technical/proffessional training
    - o University
12. **What is your occupation?**
    - o Full-time employed
    - o Part-time employed
    - o Student
    - o Housewife/stay at home mom
    - o Unemployed
    - o Other: _____
13. **Who lives in your house?**
    - o No one – I live alone
    - o Husband/partner
    - o One child
    - o Someone else's children
    - o Parents
    - o Other adult relatives

- Other adults that are not related

14. **What is your marital status?**
    - Married/living together
    - In a relationship but living apart
    - Seperated/divorced
    - Single
    - Widowed

15. **Have you been pregnant before?**
    - No
    - Yes, ___ times

16. **How many children do you have?**
    - None
    - Yes, ___ children

Appendix D: Participant Information Sheet

Good day, my name is Gudani Mukoma, and I am a Registered Biokineticist and a Masters student at the Centre of Exercise Science and Sports Medicineicineicineicine (CSSM) at the University of Witwatersrand. Together with my masters supervisor Estelle Watson would like to invite you to consider participating in our research study, entitled *"Accelerometer use to assess physical activity in pregnancy – a validation study".* Before you decide to take part, it is important for you to understand why the research is being done and what it will involve. The information leaflet is to help you decide if you would like to participate. Please take time to read the following information carefully and discuss it with others if you wish. Please ask questions if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

Study title: Accelerometer use to assess physical activity in pregnancy – a validation study

Invitation paragraph

It is well known that participating in regular physical activity leads to many health benefits. For example, it is helpful for preventing and treating diseases such as cardiovascular disease and diabetes, and is an essential tool in maintaining a healthy body weight. There are also health benefits for pregnant women. If you have an uncomplicated pregnancy, moderate exercise may help to reduce the risk of conditions such as gestational (pregnancy-related) diabetes, and pre-eclampsia. It can help to prevent excessive weight gain during pregnancy. It may also provide a protective effect against giving birth prematurely or having a low birth weight baby. Being physically active during pregnancy may also reduce the risk of obesity in your child in the future. The risks and benefits, however, depend upon the type and amount of physical activity that is done.

Where will the research be conducted?

The research will take place at the Centre for Exercise Science and Sports Medicineicineicineicine (CESSM), WITS Education Campus, Parktown. I will be assisted by my masters supervisor (Estelle Watson) and a Sport Scientist/Exercise Physiologist. We will compensate you for any travel costs incurred with coming to CESSM.

What is the purpose of the research?

The aim of this study is to assess the best way to measure physical activity during pregnancy. Because we know how important physical activity is for both the health of you, the mother, and your unborn child, it is important to public health that we can measure and assess physical activity accurately. As you know, your body undergoes many physiological changes during pregnancy. We would like to assess the effects of these changes on measuring physical activity, namely through indirect caliromtery (a way to measure how much oxygen you use during exercise) and accelerometers (a small device that measures your movement and speed of movement). This study is being done in South Africa, and Eurpoe, and will provide much needed information on the best way to measure activity during pregnancy.

Patient selection

If you are pregnant (any trimester) and are healthy (not been told by your doctor that you have any conditions that would prevent you from exercising) then you are eligable to participate in the study.

Do I have to take part?

Your participation is voluntary. We would like you to consent to participate in this study as we believe that you can make an important contribution to the research. If you decide to take part you are still free to withdraw at any time. Your withdrawal will not affect your access to other medical care.

What would I be asked to do if I took part?

If you are happy to participate in the research we will ask you to read this information sheet and sign the consent form. You will then be asked to come in for one assessment, which should take between 90-120 minutes. First, we will start by filling out some questionnaires. Then we will place the accelerometers on you (two on the wrist and one on the hip). You will also be asked to wear a heart rate monitor and the oxygen-mask. The assessment will consist of walking around the track at a light to moderate pace. The fastest you will be asked to walk is a speed that is comfortable for you.

Risks or side effects

There are no side effects for taking part in this study. You may experience some tiredness from walking, but this would not be more than your usually walking fatigue, and there is no risk to you or your baby.

Benefits

There are no direct benefits to participating in this research project. We will provide you feedback on your fitness levels after the assessment, as well as a guide on what exercises are safe to do during pregnancy.

What happens to the data collected?

All information you provide to us will be kept confidential. Only members of the research team will have access to it. Information gained during the research will be used as part of a larger sample, and will remain

anonymous. The outcomes of the research will be available in one or more of the following sources: scientific papers in peer reviewed academic journals, presentations at a regional conference, local seminars.

Ethical approval

This clinical study protocol has been submitted to the University of the Witwatersrand, Human Research Ethics Committee (HREC) and written approval has been granted by that committee. For further information regarding this, contact the HREC chairman Professor Peter Cleaton-Jones on 011 717 2635 or email peter.cleaton-jones@wits.ac.za

Doctor notification

Please indicate below, whether you want me to notify your personal doctor or your specialist of your participation in this study:

- ○ **YES**, I want you to inform my personal doctor / specialist of my participation in this study.
- ○ **NO**, I do not want you to inform my personal doctor / specialist of my participation in this study.
- ○ **I do not have** a personal doctor / specialist

Who to contact?

If you have any questions, you may ask them now or later, even after the study has started. If you wish to ask any questions, you may contact the following persons

Gudani Mukoma
(Cell) 079 9037 819 (Email) mukomagudani@gmail.com

Estelle Watson
(tel) 011 717 3227 (fax) 011 717 3379 (Email) estelle.watson@wits.ac.za

Did the participant raise any questions? O**YES /** O **NO** **If YES** – What where they:

Appendix E: Participant Informed Consent

- I hereby confirm that I have been informed by the researchers, Gudani Mukoma and Estelle Watson about the nature, conduct, benefits and risks of the study called ***" Accelerometer use to assess physical activity in pregnancy – a validation study"***
- I have also received, read and understood the above written information (Participant Information Leaflet and Informed Consent) regarding the clinical study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by Gudani Mukoma and Estelle Watson or on their behalf.

- I may, at any stage, without prejudice, withdraw my consent and participation in the study.

- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.

PARTICIPANT:

Printed Name Signature / Mark or Thumbprint Date and Time

RESEARCHER:

I, _____, herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

Printed Name Signature Date and Time

WITNESS (If applicable):

Printed Name Signature Date and Time

Appendix F: Advert Example

Attention ladies !

Are you pregnant or do you know Someone who is?

We are recruiting pregnant women to participate in our research study looking at how to best measure physical activity during pregnancy. In return of participating we will provide you with exercise and healthy eating guidelines during pregnancy.

Who can take part?

All women in the first to third trimester of pregnancy, aged 18 to 40, living in Johannesburg are invited in our study. We will only need about 60-90 minutes of your time to do a walking assessment (only as fast as you can go). We will measure your breathing, heart rate and movement during this walking test. ☺

For more information, please:

SMS or Call: Gudani Mukoma (079 9037 819)

Email: gudanimukoma@gmail.com/gudani.mukoma@wits.ac.za

Appendix G: Ethics Certificate

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

R14/49 Dr E Watson, Mr G Mukoma, et al

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M160532

NAME: (Principal Investigator)	Dr E Watson, Mr G Mukoma, et al
DEPARTMENT:	School of Therapeutic Sciences Centre for Exercise Science and Sports Medicine Faculty of Health Sciences University
PROJECT TITLE:	Accelerometer use to assess physical activity in pregnancy - a validation study
DATE CONSIDERED:	27/05/2016
DECISION:	
CONDITIONS:	Re-issued on 14/11/2018 to include named co-investigator (Mr Mukoma)
SUPERVISOR:	Not applicable
APPROVED BY:	Dr CB Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	08/08/2016

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

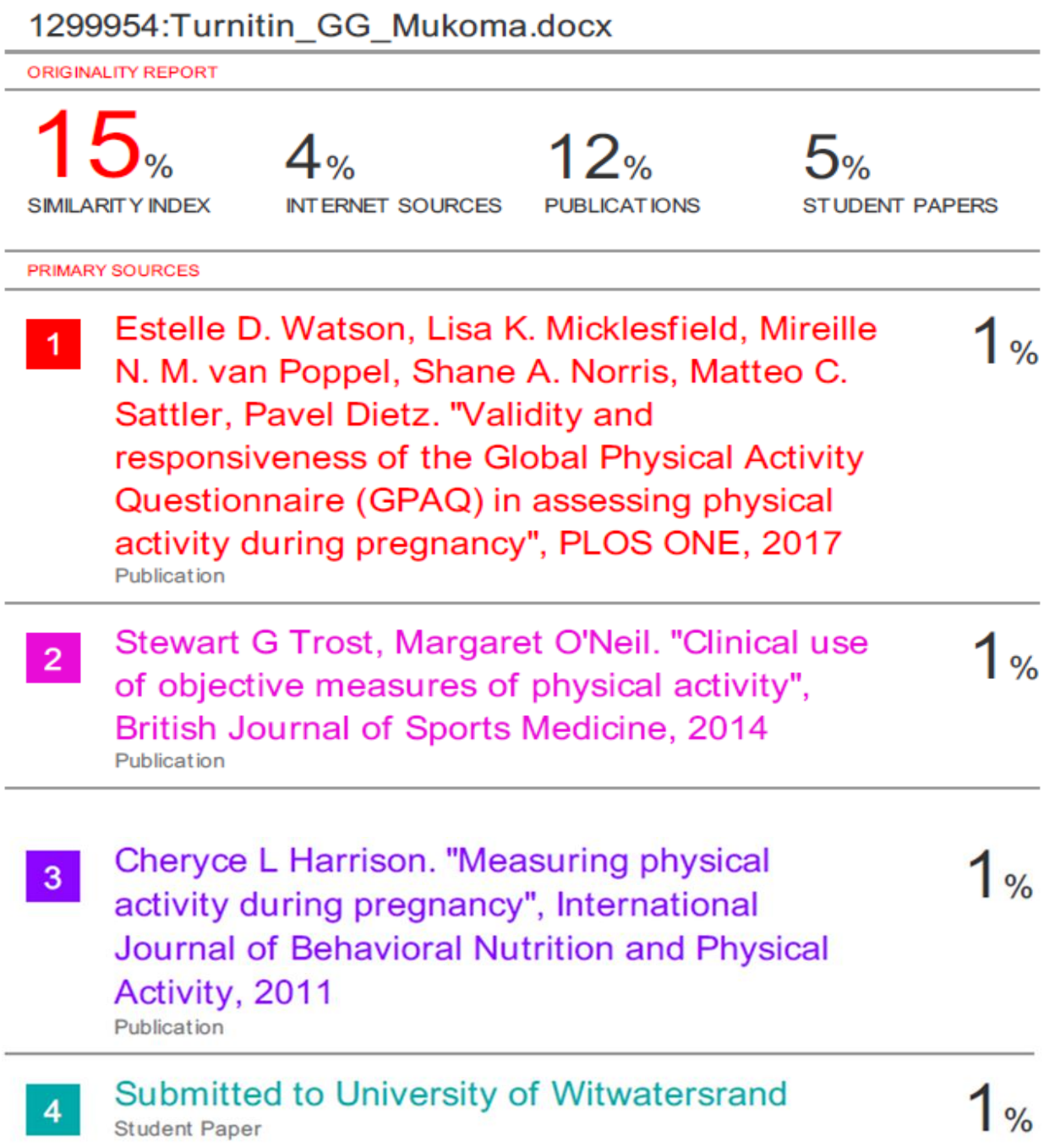
To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary on 3rd floor, Phillip V Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.
I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date of the meeting when the study was initially reviewed. In this case, the study was initially reviewed in **May** and will therefore reports and re-certification will be due early in the month of **May** each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

14/11/2018
Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix H: Turnitin report



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ORIGINALITY REPORT

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