The comparison between subjective and objective free-living physical activity in women with diverse weight loss histories

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Declarations

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Abstract

Introduction: Weight regain following weight loss is a universal concern for successful obesity management strategies. The tendency evident in reduced-weight women to overestimate physical activity may be one of the causes of unsuccessful weight loss maintenance in the long term. The current study aimed to 1) identify differences in objective (accelerometry) and self-reported (GPAQ) free-living physical activity in women who experienced weight loss, and 2) determine whether over-or-underestimation of physical activity was related to time at goal weight.

Methods: Reduced-obese women (n = 19) were recruited for this study. The reduced-obese condition consisted of women who had lost a minimum of 10% of their body weight 18-6 months before testing. Prior to visiting the laboratory, participants were telephonically questioned to determine their inclusion or exclusion status for the study. During the first visit, participants completed physical assessments (BMI, body fat percentage), the Global Physical Activity Questionnaire (GPAQ), and underwent the accelerometer fitting. The accelerometer was worn for a period of 7 days and was used to measure free-living daily activity. Means ± SD were used to analyse parametric data and medians and interquartile range were used to assess non-parametric data. Pearson correlations were used to measure the association between the two methods. Paired sample t-tests, Chi-square tests and Effect sizes using Cohen's *d* were run. Finally, we visually inspected and statistically tested the results using Bland-Altman plots and simple liner regressions.

Results: On average, participants lost 23.3 ± 9.1 percent of their weight over an average period of 7 ± 2.8 months. Participants underestimated their sedentary time and time spent in moderate-intensity activity and overestimated their vigorous-intensity activity. Bland-Altman plots revealed a proportional bias for time spent per day in sedentary time, vigorous-intensity activity, and MVPA. MVPA showed a statistically significant positive correlation between the two measures, $r = 0.72$, $p = 0.0006$. Time spent in moderate activity showed the best agreement between the self-reported measure and accelerometry, revealing no proportional bias (mean ± SD bias of -61.8 ± 38.2 min per day). Chi-squared results revealed that 11 participants (of which 9 were at their goal weight for 6 months and 2 were at their goal weight for longer than 6 months) underestimated their MVPA. Chi-squared results also revealed that 7 participants (of which 6 were at their goal weight for 6 months and 1 was at their goal weight for longer than 6 months) overestimated their vigorous-intensity activity.

Discussion and conclusion: Underestimation of sedentary time and overestimation of vigorous-intensity exercise put the group of reduced-obese women at risk for weight regain in the long term. The moderate-intensity activity was largely underreported, which requires further investigation. It is imperative that research on reduced-weight women make use of objective measures for the measurement of free-living activity, for self-reported measures will lead to a misinterpretation of this specific population's physical activity status.

List of abbreviations

Abbreviation	Meaning
ACSM	The American college of sports medicine
BIA	Bioelectrical impedance analysis
BMI	Body mass index
DLW	Doubly labelled water
EB	Energy balance
EE	Energy expenditure
GPAQ	Global physical activity questionnaire
MVPA	Moderate to vigorous physical activity
n	Number
PA	Physical activity
PSQI	Pittsburgh sleep quality index
SB	Sedentary behaviour
TEE	Total energy expenditure
WC	Waist circumference
WHO	World Health Organization

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Chapter 1: Literature Review

1.1 Introduction

The global prevalence of overweight and obesity continues to rise at an alarming rate, such that it is now considered a pandemic (Meldrum et al., 2017; Ryan et al., 2021; The Lancet Gastroenterology, 2021; Villalobos, 2016). While many approaches have been tried to address obesity, global overweight and obesity prevalence continue to rise and are recognised as one of the world's major public health challenges (Ryan et al., 2021; Varkevisser et al., 2019). Obesity is controversial as some consider it to be a "sin", "a crime against humanity", "an aesthetic crime", and "a self-inflicted disability" (Karasu, 2016). Obesity is a multifactorial condition with complex associations among individual variability, environmental factors, and psychological factors that lead to behaviours that indirectly cause initial weight gain or weight regain after weight loss (Hill & Peters, 1998; Lee et al., 2019; Puhl et al., 2008). Weight loss maintenance is critical in preventing weight regain (Hall & Kahan, 2018). Varkevisser and colleagues (2019) postulate that weight loss maintenance is reliant on the behavioural determinants engaging in energy balance and the determinants promoting it (Varkevisser et al., 2019).

Therefore, this literature review will elaborate and focus on obesity and the role of physical activity (PA) in weight loss and weight loss maintenance. Further, it will investigate the importance of measuring PA and the various methods for PA measurement. It will describe the risks associated with estimating the energy balance model incorrectly. Moreover, it will examine the predictors of discordance between the various methods of PA measurement and the characteristics associated with causing discordance between device-measured and reported PA.

1.2 The problem of obesity

Obesity is a significant health concern as it predisposes individuals to several comorbidities, including hypertension, dyslipidemia, coronary heart disease, type 2 diabetes, stroke, cancer, osteoarthritis, and a shortened life expectancy while impairing the individual's quality of life (Blomain et al., 2013; Cercato & Fonseca, 2019; Greenberg, 2013; Greenway, 2015; Mayoral et al., 2020; Ogden et al., 2013; V. H. Taylor et al., 2013; Velapati et al., 2018; Zhou et al., 2014). The most recent statistics reported by the World Health Organization (WHO) on global obesity were in 2016. The report stated that more than 1.9 billion adults aged 18 and older were overweight. Of these, over 650 million adults were obese. It went on further to state that 39% of adults aged 18 and over (39% of males and 40% of females) were overweight (WHO, 2021).

Overall, approximately 13% of the world's adult population (11% of males and 15% of females) were reported to be obese (Cercato & Fonseca, 2019). This indicates that the worldwide prevalence of obesity has nearly tripled between 1975 and 2016 (https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight). Obesity is among the most common and costly chronic disorders worldwide (Schwartz et al., 2017). Substantial evidence shows that obesity is one of the major causes of non-communicable diseases (NCDs), and this condition itself contributes to 9% of all medical expenses in the U.S. (worldometers.info/weight-loss/). In the United States alone, it is estimated that more than $60 billion is spent on weight loss efforts per year.

According to the WHO, the fundamental cause of obesity is an energy imbalance between calories consumed and calories expended. Globally, this can be attributed to an increased intake of energy-dense foods that are high in fats and sugars and an increase in physical inactivity due to the increasingly sedentary nature of many forms of work, changing modes of transportation, and increasing urbanisation (WHO, 2021). The WHO noted further that changes in dietary and PA patterns are often the result of environmental and societal changes associated with the development and lack of supportive policies in sectors such as health, agriculture, transport, urban planning, environment, food processing, distribution, marketing, and education (WHO, 2021). Furthermore, Ford and co-authors (2017) stated that within the past three decades, global overweight has increased from 28.8% to 36.9% in men and from 29.8% to 38.0% in women (Fleming et al., 2014; Ford et al., 2017).

Within a South African context, the latest South African National Health and Nutrition Examination Survey (SANHANES-1) published in 2013 reported that more than 65% of women and 30% of men are either overweight or obese in South Africa (https://hsrc.ac.za/uploads/pageNews/72/SANHANES-launch%20edition%20(online%20version).pdf). The obesity epidemic among South

Africans can be attributed to the globalisation of urban settings and the epidemiological transition from rural to urban settings. The rapid urbanisation of South Africa created a change in diet from traditional foods to foods rich in fat and sugar and a change in PA from physical work to sedentary work and physical inactivity (Kruger et al., 2005). Statistics show that NCDs account for 39% of total deaths in South Africa, and that an increase in NCD-related mortalities is a result of urbanisation and an increase in overweight and obesity (Nojilana et al., 2016; Peer et al., 2014; Reddy & Yusuf, 1998). Combating the rise in overweight and obesity figures in South Africa is part of the National Strategic Plan for the Prevention and Control of Non-Communicable Diseases 2022-2027 (https://bhekisisa.org/wp-content/uploads/2022/06/NCDs-NSP-SA-2022-2027-1.pdf). The objective set by the Department of Health is to halt the rise in the number of individuals diagnosed with diabetes and obesity by 2027. These alarming statistics describe the need for effective and successful obesity management programmes to combat obesity in the country.

1.3 The problem of weight loss and weight loss maintenance

Despite the global obesity epidemic and the high cost of its consequences, efforts to maintain weight loss are frequently regarded as ineffective. Weight loss can be achieved through a variety of strategies and modalities; however, long-term maintenance of lost weight proves to be much more challenging, and weight regain is common (Hall & Kahan, 2018; Loveman et al., 2011; Wing & Phelan, 2005; Wu et al., 2009). There are various weight loss strategy interventions, including lifestyle modification programmes such as Weight Watchers, food replacement programmes such as Jenny Craig, pharmaceutical products such as orlistat, lorcaserin, and liraglutide, intragastric balloon systems such as Orbera, and surgical interventions such as gastric bypass and bariatric surgery (Finkelstein & Verghese, 2019; Possmark et al., 2020).

The most common weight loss strategies currently are lifestyle interventions targeting dietary modification, PA, and behavioural change strategies. These weight loss strategies typically result in early rapid weight loss, which is followed by a weight plateau and eventually progressive weight regain (Hall & Kahan, 2018; Loveman et al., 2011). Notably, only 50% of individuals attempting weight loss succeed in losing 5-10% of their initial weight, while the rest are unsuccessful. Of those who are successful, almost 30-50% of them will regain the weight lost within one year, and by five years, more than 80% of the lost weight will be regained (Appelhans et al., 2016; Blomain et al., 2013; Hall & Kahan, 2018). Another statistic reveals that only 13-20% of obese individuals who lose at least 10% of their initial weight are able to maintain the weight lost after 5-10 years post-weight loss (Anderson et al., 2001; Wing & Phelan, 2005).

1.4 Compensatory responses to weight loss and the problem of weight loss maintenance

Compensatory physiological changes that occur with weight loss help explain the near-ubiquitous weight loss time course: early rapid weight loss that reaches a plateau after several months, followed by progressive weight regain (Franz et al., 2007; Hall & Kahan, 2018). Different weight loss strategies ultimately result in the same unfortunate circumstance, i.e., as people progressively lose more weight, they are faced with an increasing battle against the biological responses that oppose further weight loss (Hall & Kahan, 2018). It has been postulated that appetite changes likely play a more important role than a slowing metabolism in explaining the weight loss plateau due to the feedback circuit responsible for long-term calorie intake having greater overall strength than the feedback circuit responsible for calorie expenditure (Hall & Kahan, 2018). Specifically, Hall and colleagues (2018) state that it is estimated that for each kilogram of lost weight, calorie expenditure decreases by approximately 20-30 kcal/d, whereas appetite increases by approximately 100 kcal/d above the baseline level prior to weight loss (Hall & Kahan, 2018; Polidori et al., 2016). This can therefore account for weight regain as the lower total daily energy expenditure can easily be exceeded by total daily energy intake. This can lead to a positive energy balance resulting in weight regain over time. The latter takes place while the individual follows the same diet that yielded successful results during the initial phase of weight loss (Freedhoff & Hall, 2016; Hall & Kahan, 2018).

Blomain and co-authors (2013) stated that the concept of weight loss leading to a decrease in energy expenditure (EE) is known as “adaptive thermogenesis”, which results in increased hunger and therefore promotes weight regain (Blomain et al., 2013; Leibel et al., 1995; Catia Martins et al., 2020). In addition to an increase in hunger, individuals will experience compensatory responses related to altering levels of essential satiety hormones and hypothalamic-pituitary neuroendocrine axes, which may promote weight regain (Blomain et al., 2013; Catia Martins et al., 2020).

King and colleagues (2007) noted the concept of homeostasis and stated that each individual has a "body weight set-point" and that, after any alterations, body weight will attempt to return to baseline (King et al., 2007; Catia Martins et al., 2020). Their review focused on the behavioural and metabolic compensatory responses that serve as barriers to exercise-induced weight loss. The authors noted that behavioural responses to compensate for changes in energy balance (EB) will be more influential than metabolic responses (e.g., the energy content of a snack would have a more significant effect on EB than a metabolic adaptation such as a reduction in resting EE), as PA does not contribute to EB as much as food intake does (PA accounts for 20-60% of EE, whereas behaviour accounts for 100% of energy intake) (King et al., 2007). Therefore, while metabolic adjustments in response to weight loss contribute to resisting an energy deficit, the behavioural compensatory responses could play a detrimental role in the weight loss process (King et al., 2007). Interestingly, Catia Martins and colleagues (2020) stated that when looking at the success of weight loss maintenance, it is imperative to distinguish between the following: 1) the physiological characteristics of individuals that make them prone to obesity; 2) the adaptation of the gut microbiota; and 3) a decline in self-monitoring adherence. All of these factors are possible reasons for weight loss relapse (Burke et al., 2011; Laitner et al., 2016; Catia Martins et al., 2020; Milsom et al., 2011; Peterson et al., 2014; van de Wouw et al., 2017; Zheng et al., 2016).

In addition, it is important to consider the physiological regulation of appetite, which causes an increase in appetite in certain regions of the brain that operate below an individual's conscious awareness (Berthoud et al., 2017; Hall & Kahan, 2018). Therefore, when considering whether someone is successful in their weight loss maintenance attempts, it is important to note that the reduced obese state is associated with a significantly reduced total energy expenditure (TEE), attributable to both a reduction in resting and non-resting EE (Leibel et al., 1995; C. Martins et al., 2020). Consequently, individuals wanting to use exercise as a mechanism to maintain weight loss would have to increase their exercise duration and intensity; however, within each individual, the type and extent of behavioural and metabolic compensatory responses will play a pivotal role in the success of exercise to promote weight loss (Cox, 2017; Hopkins & Blundell, 2016; King et al., 2007; Swift et al., 2014).

A lack of effective options for long-term weight reduction magnifies the enormity of this problem; individuals who successfully complete behavioural and dietary weight loss programmes eventually regain most of the lost weight (Schwartz et al., 2017). Therefore, one of the leading challenges in the management of obesity is the prevention of weight regain after successful weight loss (Busetto et al., 2021; Swencionis et al., 2019; van Baak & Mariman, 2019b). Most studies show that, on average, the weight loss attained during a weight loss intervention period is not fully maintained during a 1-year follow-up (Ochner et al., 2013; van Baak & Mariman, 2019a). The vast majority of individuals who attempt to lose weight are not able to achieve and maintain a 10% reduction over a period of 12 months (MacLean et al., 2015; Stubbs et al., 2021).

Weight regain following weight loss can often be attributed to a lack of compliance with food habits and exercise (Busetto et al., 2021). Additional factors contributing to weight loss relapse include physiological resistance to weight loss, the obesogenic environment, individual experiences of stress and life events, and a general lack of knowledge among individuals on how to effectively manage EB behaviours, dietary intake, and PA (Hall & Kahan, 2018; Stubbs et al., 2021). Elfhag and Rössner (2005) identified characteristics that relate to greater individual success in weight loss maintenance. They are as follows: 1) individuals who had substantial weight loss during initial treatment; 2) individuals who reach a self-determined weight loss goal; 3) individuals who lead an active lifestyle; 4) individuals who engage in leisure time activities; 5) individuals who continue to monitor their weight and eating behaviour; 6) individuals who correct weight regain quickly and prove to be self-sufficient and autonomous; 7) individuals who suffered less from psychological and emotional instability; 8) individuals who suffer less from binge eating and weight cycling; and 9) individuals who use support from a social context (family and friends) (Elfhag & Rössner, 2005; Varkevisser et al., 2019).

1.5 The measuring of physical activity for weight loss

Regular PA has been shown to be essential for healthy ageing and chronic disease prevention: it aids in maintaining one's physical function and performance while improving one's overall health and quality of life (CDC, 2020; Domingos et al., 2021; Kononova et al., 2019; Langhammer et al., 2018; Mercer et al., 2016; WHO, 2022). As noted by Cox and colleagues (2017), the terms PA and exercise are often used interchangeably; however, PA is defined as all movement that results in EE and exercise is structured, planned PA (Cox, 2017). Exercise is frequently identified as a predictor of weight maintenance following elective weight loss and has been considered a stronger determinant than diet for long-term weight loss maintenance (Jeffery et al., 2003; Mekary et al., 2010; Schoeller et al., 1997; Varkevisser et al., 2019; Wier et al., 2001). It was postulated by King and colleagues (1997) that engaging in an increased amount of PA could have an influence on food selection (i.e. energy reserves used during exercise would estimate a drive for a particular nutrient) (King et al., 1997) . Blundell and co-authors (2015) noted that exercise has the potential to drive the sensation of hunger; however, favourable adjustments to postprandial satiety may occur via an interaction with food composition that may cause an individual to make better food choices following the completion of exercise (Blundell et al., 2015). The authors went on to note that individual variability may make this difficult to predict (Blundell et al., 2015). In a study conducted by Catenacci and colleagues (2014), the authors found that individuals who reported engaging in high levels of PA per week tended to consume fewer processed meals and breakfast more frequently (Catenacci et al., 2014). This could indicate that highly active individuals are more in tune with their hunger and how their hunger equates to EE and therefore influences their EI.

The main aim of measuring PA is to accurately identify the frequency, duration, intensity, and types of behaviours performed over a specified period of time (Ainsworth et al., 2015). This means that one needs to utilise the appropriate measurement tool to ensure that what is required to be measured is actually measured. Various self-report and objective methods to measure PA exist. These methods include behavioural observations, questionnaires, PA diaries, direct and indirect calorimetry, doubly labelled water (DLW) and motion sensors such as accelerometry, and pedometers (Butte et al., 2012; Prince et al., 2008; Skender et al., 2016).

The ideal PA assessment tool would be highly versatile, easy to evaluate, accurate in its estimation of intensity, volume, duration, and frequency of the exercise performed, capable of measuring individuals' PA in free-living environments, and not limited to measurement in a confined clinical space (Ainsworth et al., 2015; Dowd et al., 2018). As previously mentioned, various methods exist for assessing PA and EE. Each method has both advantages and limitations; however, having an understanding of these methods is important when deciding which method to use for a specific study context (Ndahimana & Kim, 2017). These constraints include, but are not limited to, financial constraints, time constraints, recall bias, and equipment requirements (Ndahimana & Kim, 2017; Prince et al., 2008; Skender et al., 2016)

Self-report questionnaires and tools are considered to be the most cost-effective, and they provide important contextual information about PA; however, due to the long timeframes they may cover, they are limited by recall bias and variation in reporting accuracy for different intensities and domains (Colley et al., 2019; Ekelund et al., 2011; Helmerhorst et al., 2012; Skender et al., 2016). In addition, some individuals may not have a device that indicates time and therefore are unable to accurately report the time frame in which they engaged in PA (Sylvia et al., 2014). There are a multitude of self-report tools available that require reporting of PA over various timeframes such as "a typical week", "the last 7 days", "usual activity", "over the last year", "over the last month", "a typical week during the last month", "usual activity over the last 3 months", and "during the current trimester" (Helmerhorst et al., 2012). The ambiguity of some of these statements opens room for misinterpretation and bias (Colley et al., 2019). This can be due to misreporting intentionally caused by social desirability bias or because of cognitive limitations related to recall or comprehension (recall bias); this further explains why estimates vary so much between methods (Colley et al., 2019; Durante & Ainsworth, 1996; Helmerhorst et al., 2012; Jobe & Mingay, 1989).

Furthermore, it is important to understand the differences between these various self-reporting tools. Global questionnaires are short, one-to-four-question PA assessment tools. They provide a classification of an individual's PA status across various domains, such as, "occupation", "leisure", "transportation", or a combination of domains (Ainsworth et al., 2015). A major advantage of these types of questionnaires is their ease of administration; however, they do not accurately represent the amount of PA an individual is engaging in, which poses difficulties in measuring the individual's compliance with PA guidelines (Ainsworth et al., 2015; Physical Activity Guidelines Advisory, 2008).

Additionally, short-term recall questionnaires (e.g., the Physical Activity Recall Survey (PAR), Activities Completed Over Time in 24 Hours (ACT24), and the Yale Physical Activity Survey) typically include seven to twenty questions that require individuals to recall the frequency, duration, and intensity of specific types of PA performed in the past week or month (Ainsworth et al., 2015; Matthews et al., 2019). Moreover, quantitative history recall questionnaires (e.g., the Baecke physical activity questionnaire, the modified Baecke physical activity questionnaire, and the Tecumesh questionnaire) may have more than sixty questions for individuals to answer regarding the frequency, duration, and intensity of multiple types of activities across various domains completed over the preceding year up to and including one's entire lifetime (Ainsworth et al., 2015). In addition, subjective PA monitoring includes the use of PA logs and diaries. PA logs include checklists of specific activities that are completed at the end of the day or during allocated time periods (e.g., 15-20 minutes) during the course of the day (Ainsworth et al., 2015). PA diaries, on the other hand, contain detailed information about various aspects of PA and may include information regarding the domains, specific activities, body positions while performing the activities, and the duration of each PA performed (Ainsworth et al., 2013).

In 2002, the WHO launched its STEPwise approach for the surveillance of risk factors for non-communicable chronic diseases (Rudolf et al., 2020). In line with this approach, the

WHO developed the Global physical activity questionnaire (GPAQ) to assess the PA differences in various settings and cultures around the world, and subsequently, it has been recommended for the international tracking of PA (Alkahtani, 2016; Mumu et al., 2017; Rudolf et al., 2020). To date, as a global instrument, the GPAQ has been translated into nine languages, has been validated in more than 20 countries, and has been used as a PA surveillance measure in over 100 countries (Keating et al., 2019; Metcalf et al., 2018; Rudolf et al., 2020).

The GPAQ consists of 16 questions designed to estimate an individual's level of PA in 3 domains (work, transport, and leisure time) as well as time spent in sedentary behaviour (SB) (Bull et al., 2009; Cleland et al., 2014; Kolbe-Alexander et al., 2015; Rudolf et al., 2020; Singh & Purohit, 2011; Tomaz et al., 2020). The GPAQ has been used extensively in low-to-middle income countries and has been validated for use in South African populations (Bull et al., 2009; Kolbe-Alexander et al., 2015; Tomaz et al., 2020). It has been reported that overall, the GPAQ provides reproducible data and is a suitable and acceptable instrument for the monitoring of PA in population health surveillance systems (Bull et al., 2009; Mumu et al., 2017). The GPAQ has shown moderate-to-good concurrent validity with other PA questionnaires and self-report measurement tools (Bull et al., 2009; Jakicic et al., 2015). Furthermore, it has been observed that the self-reported GPAQ may be used appropriately to estimate levels of moderate-to-vigorous physical activity (MVPA) and, therefore, monitor change in MVPA in a population sample (Cleland et al., 2014).

In a study conducted by Adıgüzel and colleagues (2021), the authors concluded that the GPAQ can be used as a valid and reliable tool in the Turkish population. The authors went on further to state that the WHO's international use of the GPAQ to scan for risk around the world is an advantage for comparison between countries (Adıgüzel et al., 2021). In addition, a study conducted by Trinh and co-authors (2009) concluded that the GPAQ is suitable for the surveillance of PA among adults in Vietnam (Trinh et al., 2009). Moreover, an additional study concluded that the GPAQ is an effective tool for measuring PA in females and people with high levels of education (Mumu et al., 2017). In a study conducted by Nashandi and colleagues (2021), the authors concluded that the GPAQ is valid for group or population measures of MVPA (Nashandi et al., 2021). Finally, in a study conducted on Chinese young adults, it was concluded that the GPAQ is a recommended instrument for measuring MVPA and SB among college students (Gao et al., 2022).

When compared to objective measurement tools, self-report questionnaires are relatively easy to administer, inexpensive, pose a low burden on participants, and are more convenient to implement within large population health surveillance systems, according to multiple studies (Ainsworth et al., 2015; Celis-Morales et al., 2012; Colley et al., 2019; Domingos et al., 2021; Helmerhorst et al., 2012; Lagerros & Lagiou, 2007; Martins et al., 2017; Ndahimana & Kim, 2017; Prince et al., 2008; Terwee et al., 2010). However, the primary concern when using these self-report methods to assess PA is related to the accuracy of recall and reporting bias as individuals may overestimate or underestimate their true EE and rates of both PA and inactivity (Ainsworth et al., 2015; Burchartz et al., 2021; Celis-Morales et al., 2012; Durante & Ainsworth, 1996; Helmerhorst et al., 2012; Jekauc et al., 2013; Jobe & Mingay, 1989; Martins et al., 2017; Martorell et al., 2020; Nocon et al., 2008; Prince et al., 2008; Slootmaker et al., 2009; Wijndaele et al., 2015). Additionally, some authors believe that accurately measuring PA using self-report tools may be challenging as individuals may not accurately estimate the amount and type of PA completed in the survey time or precisely report the intensity of PA (Quinlan et al., 2021; Sallis & Saelens, 2000; Timperio et al., 2003). The risk involved is that inaccurate measurements of activity variables may result in a reduction of the apparent effects of activity on health-related outcomes due to regression dilution bias (random errors in measuring a risk factor that may introduce a downward bias of an estimated association to a disease or a disease marker), which may eventually result in weight loss relapse (Berglund, 2012; Celis-Morales et al., 2012; Frost & Thompson, 2000).

Objective PA measurement tools may overcome some of the limitations that self-reporting tools pose. Objective measures are believed to offer more accurate estimates of EE and dim the occurrence of response and recall bias (Prince et al., 2008). In the age of technological advances, there are numerous tools available for the objective measurement of PA and EE; however, they do not come without their own set of limitations.

The gold standards for objectively measuring EE are indirect calorimetry in laboratory settings and the DLW method for field testing (Haugen et al., 2007; Ndahimana & Kim, 2017; Park et al., 2014; Schoeller & van Santen, 1982; Speakman et al., 2021). The use of

DLW for the assessment of free-living EE in humans was first reported by Schoeller and van Santen (1982) (Schoeller & van Santen, 1982). The DLW method provides insight on the total energy expended by a free-living individual for a period of four to twenty days as this timeframe is likely to indicate the usual energy requirement of the individual (Ainslie et al., 2003). The DLW method is highly accurate, noninvasive in nature, and has limited burden on individuals as they can carry out their usual daily activities during the measurement period (Krumbiegel, 2010; Ndahimana & Kim, 2017; Wong et al., 2014). However, this gold-standard method is not cost-effective. It requires expensive equipment and highly qualified expertise to complete the data analysis (Ainslie et al., 2003; Ndahimana & Kim, 2017; Park et al., 2014; Speakman et al., 2021). Furthermore, the DLW method only provides an overall measurement of averaged daily total EE but does not provide any specific details about the type of physical activities performed (Ndahimana & Kim, 2017).

The direct calorimetry technique is the most precise method to measure energy expenditure. It measures the rate of total heat loss from the body using a calorimeter within a clinical setting (Ainslie et al., 2003; Ndahimana & Kim, 2017). However, it cannot give an indication of free-living EE as the individual undergoing the measurement is confined to a small clinical space (Kaiyala & Ramsay, 2011; Ndahimana & Kim, 2017). Subsequently, the indirect calorimetry technique was developed to measure total energy production by the body by measuring the concentration of carbon dioxide produced and oxygen used over a period of time (Ainslie et al., 2003; Leonard, 2012; Ndahimana & Kim, 2017). Indirect calorimetry is accurate, noninvasive, and provides individuals with information regarding substrate utilisation (Kaiyala & Ramsay, 2011; Ndahimana & Kim, 2017).

The area of PA assessment is constantly evolving, and the use of wearable monitors to directly measure the various components of PA is becoming more common (Ainsworth et al., 2015; Butte et al., 2012). In comparison to self-report methods, wearable monitors offer more accurate assessments of the physiological or mechanical factors that correspond with PA (Ainsworth et al., 2015; Westerterp, 2009). However, it is important to note that there is no single "gold standard" wearable monitor to objectively measure free-living PA (Ainslie et al., 2003; Freedson et al., 2012; Oliveira et al., 2017; Prince et al., 2008). One needs to consider the following factors when deciding which type of wearable monitor is suitable for the outcome one wants to achieve: 1) the specific factor of PA interest; 2) the target populace of interest; 3) the cost involved and the logistics involved when taking the measurement; and 4) the component of PA of interest (e.g., vigorous intensity PA) (Ainsworth et al., 2015; Oliveira et al., 2017). There are various wearable monitors available for objective PA assessment. These include pedometers, accelerometers, and heart rate monitors (Ainsworth et al., 2015; Anastasopoulou et al., 2014; Butte et al., 2012; McClung et al., 2018; Oliveira et al., 2017; Torres-Castro et al., 2017).

Pedometers measure the steps taken by an individual, and the basic output variable is step count. Step counts cannot provide PA intensity estimations, and they have a tendency to underestimate the number of steps taken when walking at a low speed, therefore limiting the validity of EE estimations that can be derived from the number of steps taken (Ainslie et al., 2003; Ainsworth et al., 2015; Beets et al., 2010; Butte et al., 2012; Melanson et al., 2004; Ndahimana & Kim, 2017; Oliveira et al., 2017). Moreover, the Actiheart, a combined heart rate and movement sensor has been developed for the assessment of PA at a population level (Brage et al., 2005). Brage and colleagues (2005) concluded that the device is technically reliable and valid; however, further investigation is required to determine whether the reliability and validity of the device extends to free-living conditions (Brage et al., 2005).

Additionally, technological advances have allowed for the development of accelerometers as one of the most frequently used methods for PA energy and expenditure measurement (Ndahimana & Kim, 2017). Accelerometers are small, lightweight, noninvasive wearable monitors that record motion in one or more planes (vertical, horizontal, and perpendicular) and provide information on the frequency, duration, and intensity of the PA being completed (Ainsworth et al., 2015; Butte et al., 2012; Chen & Bassett, 2005; Corder et al., 2008; Kavanagh & Menz, 2008; Vanhees et al., 2005). The device is commonly attached to the hip, calves, or wrist in order to measure the frequency, intensity, and duration of PA through direct measurements of body accelerations and decelerations (Bouten et al., 1994; Crouter et al., 2010; Ndahimana & Kim, 2017; Oliveira et al., 2017). Accelerometers can monitor and record PA for long periods (several days to several weeks) of time within a free-living environment (Ainsworth et al., 2015; Butte et al., 2012;

Oliveira et al., 2017), collect large amounts of PA data, and differentiate among exercise intensities (McClung et al., 2018). The expense of the method, its inability to provide contextual information and differentiate between physical activities participated in, and its limited capacity to accurately measure non-ambulatory activities such as bicycle riding, load bearing, weightlifting, or swimming are all limitations of the use of accelerometers. Most devices are not waterproof and thus must be removed during such activities, potentially leading to misclassifications of an individual's PA profile (Ainsworth et al., 2015; Butte et al., 2012; Colley et al., 2019; McClung et al., 2018; Oliveira et al., 2017; Skender et al., 2016; Troiano et al., 2014).

All measurement tools, whether subjective or objective, for the analysis of PA have limitations. Consequently, there is no single best method that can assess all aspects of PA and EE (Ainsworth et al., 2015). The choice of assessment instrument is multifaceted due to many factors, including the specific PA component of interest, the sphere of evolving technology, the characteristics of the target population, the validity and reliability of the method, and practical considerations including the ease of use, cost, and logistics (Ainsworth et al., 2015; Dowd et al., 2018; Martins et al., 2017; Ndahimana & Kim, 2017; Oliveira et al., 2017; Torres-Castro et al., 2017; Troiano, 2009).

Accelerometers are widely used as an alternative for the objective measurement of PA as they are relatively less expensive when compared to DLW, feasible, show a good level of reliability, and have been validated against DLW (Cleland et al., 2014; Mumu et al., 2017).

The intra- and inter-instrument reliability has been studied for a wide range of accelerometer makes and models and, of these monitors, the ActiGraph monitors are the most used and studied and have shown favourable reliability in comparison to other monitor brands (Aadland & Ylvisåker, 2015; Esliger & Tremblay, 2006; Vanhelst et al., 2012; Welk et al., 2004). Accelerometry has become one of the most popular and frequently used techniques for assessing daily free-living PA (Liu et al., 2022; Warren et al., 2010). They utilise the recorded acceleration for classifying postures, identifying types of daily activities, and measuring the number of steps taken (Butte et al., 2012). Furthermore, they translate the body's accelerations into PA variables, which aids them in classifying the time spent being active as time spent in moderate-intensity or vigorous-intensity PA (Imboden et al., 2018).

1.6 Comparison of quantification of physical activity methods within different populations

In isolation, both self-report and objective measurements of PA show moderate-to-strong validity and reliability; however, when used concurrently, the literature reveals a level of discordance. In a study conducted by Herrmann and co-authors (2013), they found that self-reported measures demonstrated an overestimation of MVPA when compared to accelerometer data (Herrmann et al., 2013). In addition, in a study with a cohort of Americans, it was found that participants with higher education levels and better self-reported health status were more likely to overestimate their moderate-vigorous activity using self-reported measures (Liu et al., 2016). Moreover, Alkahtani (2016) stated that the

GPAQ is reliable; however, it demonstrated low agreement with accelerometry for estimated MVPA and very low agreement with accelerometry for estimating sedentary time amongst college-aged Saudi men (Alkahtani, 2016). In addition, Domingos and colleagues (2021) found that there is a large difference, low correlation, and absence of agreement between self-reported and accelerometer-based estimates of PA (Domingos et al., 2021).

Cleland and co-authors (2014) discovered that the GPAQ was valid for measuring MVPA but not for measuring sedentary behaviours in Northern Irish adults (Cleland et al., 2014). Furthermore, Troiano and co-researchers (2014), stated that because the two measures are not equivalent and thus not perfectly interchangeable, the relationship demonstrated between self-reported PA and accelerometry-based PA is frequently of low to moderate strength (Troiano et al., 2014). However, Wunsch and co-authors (2021) found that both self-reported and accelerometer-based measurements of PA showed a weak but significant correlation (Wunsch et al., 2021). In additional studies, it was reported that in adults, self-reported measures of PA tend to have low correlations with objective measures (Banda et al., 2010; Bassett et al., 2021; Prince et al., 2008; Quinlan et al., 2021; Schuna et al., 2013).

Multiple studies have shown that the level of PA assessed by self-report tools is often overestimated (Burchartz et al., 2021; Jekauc et al., 2013; Slootmaker et al., 2009; Wijndaele et al., 2015). Rudolph and colleagues (2020) found that self-reported PA showed an overestimation when compared to accelerometry and an underestimation of SB in female university students (aged 28.3 ± 12.2) which was in line with previous systematic reviews conducted by several research teams (Copeland et al., 2017; Dowd et al., 2018; Harvey et al., 2015; Lee et al., 2011; Prince et al., 2008; Rudolf et al., 2020). Moreover, the results of a study conducted on overweight and obese young adults found that the objective and subjective measures of MVPA do not provide comparable results, especially on an individual basis, and that wide variability exists between the two measures (Jakicic et al., 2015).

A systematic review of peer-reviewed research papers from Asia, Europe and the United States discovered that participants across the board tended to overestimate their MVPA and underestimate their sedentary behaviour (Keating et al., 2019). The latter study did not mention whether participants were healthy, diseased, obese, overweight or normal weight. Additionally, in a study conducted by Maddison and colleagues (2007), it was noted that self-reported measures demonstrated a bias toward the underestimation of PAEE at higher levels of PA when compared to DLW in a sample of males and females (aged 18-64) (Maddison et al., 2007). However, the authors indicated that appropriate calibration factors could be implemented to correct the measurement error in PA questionnaires, and through this, the estimation of activity-related EE should improve (Maddison et al., 2007).

Metcalf and co-authors (2018) stated that calibrating PA questionnaires to objective measures of PA is a good way to denoise self-reported data (Metcalf et al., 2018). They went on to conclude that their research regarding the calibration of GPAQ data to 7 days of accelerometer-measured PA provides an understanding of the divide between objective and subjective measures and provided a means to make use of the two methods as a unified measure (Metcalf et al., 2018). Furthermore, Prince and colleagues (2020) discovered that individuals from chronic disease populations tend to underestimate their sedentary time to a greater degree than apparently healthy populations (Prince et al., 2020). However, within this study, both men and women had a tendency to underestimate their sedentary time to the same degree (Prince et al., 2020).

Gorzelitz and co-authors (2018) investigated the characteristics associated with greater levels of discordance in PA measurement. The authors investigated a large population-based sample of adults and discovered that approximately 75% of the sample self-reported meeting PA guidelines; however, only 19% of the participants met the guidelines when assessed via accelerometry (Gorzelitz et al., 2018). The authors discovered that individuals with a higher education attainment and those who were married or partnered demonstrated significantly lower discordance when reporting their PA levels (Gorzelitz et al., 2018). In addition, Martorell and co-authors (2020) found that obese subjects tend to overreport their PA when compared to “normal weight” subjects (Martorell et al., 2020). Moreover, researchers investigating PA in individuals post-weight loss surgery discovered that patients significantly overestimated their reported MVPA at post-surgery measurement compared to pre-surgery (Berglind et al., 2016; Bond et al., 2010; Ouellette et al., 2020; Possmark et al., 2020). A study conducted by Lichtman and colleagues (1992) noted similar findings in obese individuals who had undergone no surgical weight loss intervention (Lichtman et al., 1992).

1.7 Conclusion

From the previous paragraphs, we have an understanding that obesity has reached pandemic status and has become an increasing public health problem worldwide (Cercato & Fonseca, 2019; Mayoral et al., 2020; Meldrum et al., 2017; Ryan et al., 2021; Villalobos, 2016). Obesity requires a cure and can be cured by incorporating lifestyle adaptations that will result in successful weight loss (Loveman et al., 2011; Wing & Phelan, 2005). However, despite weight loss attempts, long-term weight loss maintenance is a rare event (Appelhans et al., 2016; Blomain et al., 2013).

In addition, weight loss results in behavioural and physiological compensatory responses that contribute to weight loss relapse and can account for weight loss maintenance only being possible in a small percentage of individuals (Blomain et al., 2013; King et al., 2007; Catia Martins et al., 2020). It is of critical importance that obesity research identifies and establishes successful weight loss intervention strategies to fight the most substantial problem in obesity management therapies, which is not just weight loss itself but successful weight loss maintenance (Hall & Kahan, 2018). The key to successful weight loss maintenance may be rooted in the successful tracking of EB (energy consumed and energy expended). The literature shows that adherence to regular PA is seen as one of the best behaviours for the promotion of weight loss maintenance (Mekary et al., 2010; Varkevisser et al., 2019). However, the problem with being in a reduced-obese state is that it is associated with a significantly reduced TEE (C. Martins et al., 2020). In addition, due to behavioural compensatory responses to weight loss, individuals may begin to overestimate the amount of PA they are engaging in due to social desirability bias or recall bias (Colley et al., 2019; Helmerhorst et al., 2012).

Further, the literature has stated that all people overestimate their PA; however, there is a larger over-reporting among individuals with overweight and obesity compared with the "normal-weight" population (Martorell et al., 2020; Possmark et al., 2020). In addition, the overestimation of PA has been noted in individuals who have achieved weight loss through both surgical and non-surgical interventions (Berglind et al., 2016; Lichtman et al., 1992; Ouellette et al., 2020; Possmark et al., 2020). Thus, it is imperative that we measure and understand this discordance in order to find appropriate solutions that promote long-term weight management (Varkevisser et al., 2019). Therefore, the use of activity tracking may play an essential role in assisting patients with understanding and, hopefully, increasing their PA behaviours (Possmark et al., 2020). As there is no single procedure for the optimal detection of all facets of PA, multimodal, combined approaches of self-report and device-based methods of PA tracking are recommended to fully understand PA and sedentary behaviours (Burchartz et al., 2021).

1.8 Aims and Objectives

As there is limited research in the area of PA tracking in reduced-obese women, the purpose of this study was to determine whether there are differences between subjective and objective free-living PA in women who have diverse weight loss histories.

1.8.1 Aims of the Study

1.8.1a The primary aim of this study was to determine possible differences between subjective and objective free-living physical activity in women who have lost substantial weight over time.

1.8.1b The secondary aim of the study was to determine if the discordance between objective and subjective PA was related to the duration at goal weight.

1.8.2 Research hypotheses

1.8.2a There will be a significant difference between the subjective and objective reporting of physical activity in women who have lost substantial weight over time.

1.8.2b It is stated that individuals who have reached their goal weight and maintained it for more than a year will overreport their PA level to a greater extent.

Chapter 2: Methods and Materials

2.1 Study Design

This study incorporated a cross-sectional, descriptive study design. Participants visited the laboratory for testing on two occasions. Prior to baseline testing, participants were screened using an online questionnaire. They were also telephonically briefed on the testing procedures. Medical history and reproductive health questionnaires were completed to exclude participants who were on any chronic medication or suffered from any conditions that would affect energy expenditure as well as individuals who had any injuries which would limit or impair their ability to engage in physical activity. In addition, a diet and weight-loss history questionnaire was completed to confirm that participants were eligible for the study and to exclude those who did not meet the criteria. Additionally, participants completed questionnaires addressing demographics, education levels, socio-economic status, and employment.

Following the screening process, participants were informed that they were selected for the study and were requested to agree to online consent for further assessments. The first visit was used to provide participants with an in-depth explanation of the study and to obtain informed consent. In addition, anthropometric measures were taken, and the participants completed the Global Physical Activity Questionnaire (GPAQ). During this visit, the Actigraph activity monitor (GT3X +, Actigraph, Pensacola, FL) was also fitted. The accelerometer was worn for a period of 7 full days and was used to measure free-living daily activity. Following the fitting of the accelerometer, the participants were given the following instructions: 1) They were to remove the accelerometer when bathing, showering, or performing activities in which they would come into contact with water; 2) They were to sleep with the accelerometer on, but they were allowed to remove it if it was uncomfortable; 3) They were instructed about the proper placement of the accelerometer on their right hip and were given a picture as guidance to ensure that the accelerometer was securely and properly placed at all times; 4) They were encouraged to keep a log of any planned or unplanned physical activity (PA), which included cycling (stationary or other) or swimming during the 7-day wear period.

Prior to visit 2, participants were instructed to cease the consumption of food and drink by 9pm the preceding evening. They were asked to not engage in any strenuous physical activity for 24 hours before their scheduled 2nd visit as well as to empty their bladder before testing commenced. During visit 2, which occurred after the 7 days, the accelerometer was returned and Bioelectrical impedance analysis (BIA) measurements were taken. Both of the laboratory visits were completed at the Division of Exercise Science and Sports Medicine, Sports Science Institute of South Africa, in South Africa.

The study protocol was approved by the University of Cape Town Faculty of Health Sciences Human Research Ethics Committee (HREC REF: 230/2018). All participants were briefed on the full experimental procedures before providing written informed consent. They were made aware that participation was voluntary, and that they were allowed to withdraw from the study at any stage at their own discretion.

2.2 Study Population

Nineteen participants with a mean ± SD age of 35.6 ± 5.7 years and weighing 73.4 ± 7.7 kg who met the inclusion criteria were selected from volunteers who showed interest in participating in the study. The participants were found through various forms of advertising and the media. This included platforms such as social media, weight-loss groups, weight-loss intervention franchises, and word of mouth. Additionally, advertisements were sent out through newsletters and notice boards at schools, gymnasiums, and health lifestyle intervention centres. The criteria for participants included women between the ages of 25 and 45 who had recently achieved significant weight loss. "Recent" was defined as reaching their goal weight in the past 18 months. The participants needed to have been classified within the obese range prior to weight loss (BMI > 30 kg/m^2) and then reduced their obesity status (BMI < 32 kg/m^2) through "significant weight loss", which was defined as a minimum of a 10% reduction in body weight. Exclusion criteria included women who were pregnant, lactating, or breastfeeding; women with irregular menstrual cycle function (defined as less than 7 cycles per year or cycles with intervals greater than 35 days); individuals with any medical condition requiring chronic medication known to affect energy expenditure (e.g., B_2-agonists and Beta-blockers); women taking medication or supplements for weight loss;

individuals diagnosed with thyroid dysfunction; and individuals diagnosed as having an eating disorder (e.g., bulimia or anorexia nervosa) or mental disorder.

2.3 Detailed Experimental Measures

2.3.1 Anthropometric Measures

All participants underwent measurements of height (cm) with a self-developed stadiometer, weight (kg) with a digital body mass scale (SECA, Hamburg, Germany), and two waist circumference measurements with a CESCORF © (Porto Algegre, Brazil) anthropometric tape. The smallest girth between the iliac crest landmark and the 10th rib, and the girth at the level of the umbilicus was used. Measurements were taken after the removal of excess clothing and were taken according to the standardised regulations of the International Society of the Advancement of Kinanthropometry (ISAK, NZ). Calibrated equipment was used to determine these indices. Height and weight were used for the calculation of body mass index (BMI) (kg/m^2). Body-circumference measurements were repeated until two measurements were attained that were no more than 0.5 cm apart, with the average of those two measures noted as the final measure. BIA was used to assess the body composition of all participants. BIA measures the impedance to the flow of an applied mild alternating current by body tissues and was used to determine the main outcome variable of total body water from which fat-free mass and fat mass can also be calculated. The single-frequency instrument (BIA *Quantum*, RJL Systems, Clinton Township, MI) was attached to electrodes generating an excitation current of 800 Ma at 50 kHz, while the prediction equation (TBW = 3.75 + 0.45 stature2 / resistance + 0.11 weight; FFM = 9.53 + 0.69 stature2 / resistance + 0.17 weight + 0.02 resistance) of Sun and colleagues (2003) was used for the estimate of body fat (Sun et al., 2003). Outcome variables: BMI (kg/m^2), body fat %, fat-free mass (kg), and fat mass (kg).

2.3.2 Physical Activity

Objectively measured physical activity using accelerometry: Accelerometers were used to measure free-living daily activity and the number of steps taken per day with the Actigraph activity monitor (GT3X+, Actigraph, Pensacola, FL). Accelerometry also served as an instrument to assess non-exercise activity thermogenesis in addition to planned PA. Participants received accelerometer instructions during visit 1 and were asked to wear it for a period of 7 full days and return the accelerometer at visit 2. Outcome variables: min/day spent in either sedentary, light, moderate, or vigorous PA using standardised methods (Freedson et al., 1998). The Freedson equation has been proven to be valid and reliable in apparently healthy adult populations and adolescent populations (Alhassan et al., 2012; Martín-Martín et al., 2022; Montoye et al., 2017; Rothney et al., 2010). This device has shown reliable PA measures in counts/min (Esliger & Tremblay, 2006). This has been shown in two studies which were conducted by Ozemek and Colleagues (2014) and Jarrett and co-authors (2015). The studies found an ICC of 0.94 and > 0.97 respectively for the GT3X+ Actigraph activity monitor (Actigraph, Pensacola, FL) (Jarrett et al., 2015; Ozemek et al., 2014) .

Self-reported physical activity using the Global Physical Activity Questionnaire (GPAQ): The GPAQ was used to quantify subjects' self-reported daily PA. The GPAQ is a 16-item self-reported and validated PA questionnaire (Armstrong & Bull, 2006; Bull et al., 2009; Trinh et al., 2009). The questionnaire addresses specific activities (minutes per week) for various domains in which PA can be performed. It unfortunately does not make provision for the domain of "light physical activity". Outcome variables: quantifies habitual levels (minutes per week) of PA in the transportation, occupational, leisure, and domestic domains, as well as time spent sitting. Activity in each respective domain can only be recorded if the said "bout" of exercise lasts a minimum duration of 10 minutes. The GPAQ has been shown to be a suitable tool for the surveillance of PA among adults (Trinh et al., 2009). Self-reported physical inactivity or sedentary activity has also been obtained using methods derived from the GPAQ and noted average hours of sleep per night (Cleland et al., 2014).

2.3.3 Other questionnaires

Demographic variables, medical and family histories, and dieting and weight-loss histories: We used a self-developed, in-house questionnaire that has been used in all our previously published work on obesity and pathophysiology in South African women. This questionnaire includes demographic details, personal medical and family history, and specific self-reported lifestyle behaviours. Outcome variables: age (years) and highest completed education level.

<u>Pittsburgh Sleep Quality Index (PSQI):</u> The PSQI assessed sleep quality over the past month. The 19 items are grouped into a seven-component score, each weighted on a 0-3 scale. The global PSQI score, which ranges from 0 to 21, is a summation of the seven component scores. Higher scores indicate worse sleep quality (Buysse et al., 1989). We used the PSQI to gather an estimate of how much sleep each participant achieves per night. This value was added to the "sitting" score from the GPAQ to attain total sedentary time per day.

2.4 Statistical analysis

From the predefined time categories in the self-administered questionnaire, we calculated the mean minutes per day and presented it as time spent in each activity domain. Both the self-reported variables and accelerometer data were processed and presented as minutes per day.

We conducted several tests to investigate the associations and agreement between the objective and subjective measures of PA. Prior to analysis, the data were checked for normality by means of Shapiro-Wilk's tests and for outliers using boxplot inspections. All descriptive statistics are presented as means ± SD for parametric data, median and interquartile range (IQR) for non-parametric data, or percentages (%).

We conducted Pearson correlations to measure the association between the objective and subjective measurement methods. Pearson (for normally distributed data) or Spearman rank-order (non-parametric data) correlation coefficients were used. The correlations were classified as poor (r = 0.00 – 0.20), fair (r = 0.21 – 0.40), moderate (r = 0.41 – 0.60), strong (r = 0.61 – 0.80), and almost perfect (r = 0.81 – 1.0) according to the ratings suggested by Landis and Koch (Landis & Koch, 1977).

We statistically investigated whether there were significant differences between the measurements of the two methods using the paired sample t-test (for normally distributed data) or Wilcoxon signed rank test (non-parametric data). Further, Chi-square tests were performed to determine possible differences within the categorical/dichotomous variables.

We visually inspected and statistically tested the results using Bland-Altman plots and simple linear regressions. The Bland-Altman plots with 95% limits of agreement were used to assess the agreement and bias of subjectively and objectively measured PA and sedentary behaviour (Bland & Altman, 1986). Proportional bias was determined by calculating the significance of the Beta-coefficient of a simple linear regression using the difference (GPAQ – accelerometer) as the dependent variable and the mean (GPAQ and accelerometer) as the independent variable. A significant Beta-coefficient from the regression model was considered positive for proportional bias. In addition to the Bland-Altman plots, scatterplots

(GPAQ mins/day over accelerometer mins/day) were conducted to visualise the association between subjective and objective PA measurement methods. Linear regression models were used to determine the degree to which the reported measure could explain the objective measure.

Effect sizes were calculated using Cohen's *d* to determine if any clinically meaningful agreement or differences existed between the two methods for quantifying PA (Ellis, 2009). As suggested by Ellis (2009), effect sizes were considered "no meaningful difference" if they fell within the -0.2 to 0.2 range, as this is deemed favourable for the reproducibility of the same measurement. Data were analysed using IBM SPSS statistical software (Chicago, Illinois, USA), and an α level of 0.05 was used to determine statistical significance. Bland-Altman comparisons and scatterplots with linear regressions were performed using GraphPad Prism version 8.0.0 for Windows, GraphPad Software, San Diego, California, USA. An α level of 0.05 was used to determine statistical significance.

Chapter 3: Results

3.1 Descriptive Statistics

The descriptive characteristics of the 19 reduced-obese women are presented in Table 1. All the characteristics are normally distributed, as assessed by Shapiro-Wilk's tests. Overall, the average age of the participants was 35.6 ± 5.7 years old. The participants' average percentage of weight loss was 23.3 ± 9.1.

Table 1 Descriptive characteristics of the full cohort

Characteristics				Range		Shapiro-Wilk
(n =19)	Mean	±	SD	Min	Max	P value
Age (yrs)	35.6	±	5.7	25.0	45.0	0.6
Weight (kg)	73.4	±	7.7	58.7	89.0	1.0
BMI (kg/m^2)	27.7	±	3.1	22.3	32.1	0.2
WC (cm)	83.7	±	9.4	68.9	101.6	0.7
% of weight lost	23.3	±	9.1	9.7	39.4	0.5

BMI: body mass index; WC: waist circumference

Table 2 presents the descriptive statistics of the full cohort, which are represented as frequencies. Seven of the women (37%) had achieved a diploma or undergraduate degree, and seven women (37%) had completed a postgraduate degree. The remaining women had no post-secondary or tertiary education. Fifteen (79%) of the women were acutely at their goal weight, and four (21%) were at their goal weight for longer than 6 months. All of the women completed sufficient PA according to the American College of Sports Medicine (ACSM) guidelines for the general population as well as for weight loss maintenance. Five

(26%) of the women were classified as being in the normal weight category, and five (26%) were classified as being obese. The remaining women were classified as being overweight.

Table 2: Descriptive characteristics of the full cohort represented as frequencies

Characteristics (n =19)	n	Percentage
*Acutely at goal weight	15	79%
*Longer at goal weight	4	21%
*Completed adequate PA	19	100%
*Completed adequate PA for weight loss maintenance	19	100%
*GW: Normal weight	5	26.3%
*GW: Overweight	9	47.4%
*GW: Obese	5	26.3%
High School	5	26%
Diploma/Undergraduate degree	7	37%
Postgraduate degree	7	37%

*Acutely at goal weight: defined as individuals who have been at their goal weight for less than or equal to 6 months; *Longer at goal weight: defined as individuals who have been at their goal weight for more than 6 months; *Completed adequate PA: defined as individuals who have completed 150 minutes of MVPA per week; *Completed adequate PA for weight loss maintenance: defined as individuals who have completed 250-300 minutes of MVPA per week; *GW: Normal weight: The participant's goal weight fell into the normal BMI range, which is defined as individuals with a BMI between 18.5-24.9 kg/m^2; *GW: Overweight: The participant's goal weight fell into the overweight BMI range, which is defined as individuals with a BMI between 25.0-29.9 kg/m^2; *GW: Obese: The participant's goal weight fell into the obese BMI range, which is defined as individuals with a BMI > 30.0 kg/m^2.

The descriptive statistics for the self-reported questionnaire and accelerometer are represented in Table 3, Table 4, and Table 5. Table 3 presents the various domains and intensities of PA. The participants spent the most amount of time per week in the domains "recreational vigorous" and "recreational moderate". Furthermore, participants spent twice as much time doing moderate-intensity activities as they did doing vigorous-intensity activities.

Table 3: Physical activity by domain measured by the Global Physical Activity Questionnaire (GPAQ)

Variables (n = 19)	Mean/Median	±	SD/IQR	Range Min	-	Max	Shapiro-Wilk P value
*Sedentary time (mins/day)	1018.4	±	210.4	630	-	1380	0.5
Work moderate (mins/week)	*0*		*0*	0	-	750	< 0.001
Recreational moderate (mins/week)	127.9	±	90	0	-	300	0.15
Travel (mins/week)	*0*		*80*	0	-	250	< 0.001
Work vigorous (mins/week)	*0*		*0*	0	-	0	---
Recreational vigorous (mins/week)	*45*		*150*	0	-	600	< 0.001

IQR: interquartile range; *Sedentary time (mins/day) is a combination of the reported GPAQ sitting/reclining time and the reported PSQI sleep time.

Table 4 presents the PA intensities as measured by the accelerometer. The participants spent the most time completing "light-intensity physical activity" and "moderate-intensity physical activity" daily. According to the accelerometry, participants spent three times more time being sedentary as they did engaging in physical activity. Additionally, participants spent 1.2 times more time engaging in light-intensity physical activity compared to engaging in MVPA.

Table 4: Physical activity intensities measured by the GT3X + accelerometer

Variables (n = 19)	Mean/Median	±	SD/IQR	Range Min	-	Max	Shapiro-Wilk P value
Sedentary time (mins/day)	1136.2	±	1270.3	1011	-	1270	0.83
Light physical activity (mins/day)	207.9	±	49	132	-	317	0.8
Moderate physical activity (mins/day)	92.5	±	33.1	36.6	-	163	0.35
Vigorous physical activity (mins/day)	*0.5*		*4.7*	0	-	8.6	0.001

Table 5 presents the outcome variables from the accelerometer. The objective measure revealed that individuals spent 32% more time being sedentary than they reported. Further, the objective measure revealed that participants spent 3 times more time engaging in moderate-intensity activities than their self-reported values. In contrast, the objective measure revealed that participants reported completing 12 times more vigorous-intensity physical activity than what was objectively measured.

Table 5: Outcome variables of physical activity intensities and domains as measured by the GT3X + accelerometer and a self-administered questionnaire

Variables	GPAQ			Accelerometer						
(n = 19)	Mean/ Median	±	SD/IQR	Mean/Median	±	SD/IQR	r	P-value of r	Diff	P-value of diff
Sedentary time* (mins/day)	1018	±	210.4	1344	±	33	0.26	0.28	-326	< 0.0001
Moderate (mins/day)	*22.86*		*20*	92.48	±	33.1	0.28	0.25	-64.9	< 0.0001
Vigorous (mins/day)	*6.43*		*21.43*	*0.5*		*4.7*	0.1	0.69	5.9	0.12
MVPA (mins/day)	46.69	±	33.36	94.84	±	33	0.72	0.0006	-77.5	0.0009

*To provide a comparator for the self-reported sedentary time from the GPAQ, we combined the sedentary and light-intensity physical activity from the accelerometry; Diff: differences between means and medians between different measurements, self-report vs. accelerometer.

3.2 Comparison of time in sedentary

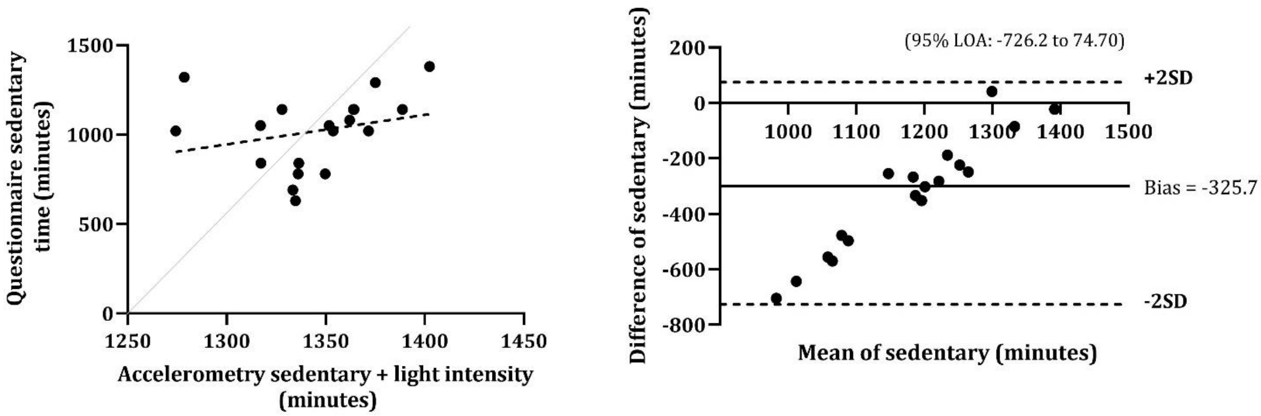

Figure 1. Scatterplot of the correlation and Bland-Altman between the self-reported and objectively measured sedentary time. Left side: Scatter plot with added 45-degree line (grey-solid) indicating perfect agreement, and linear regression line (dashed). Right side: Bland-Altman plot with 95% limits of agreement (±2SD) (dashed) and Bias (solid).

A Pearson's product-moment correlation was run to assess the relationship between self-reported sedentary time and objectively measured sedentary time. The results can be seen in Table 5. The correlation established that the two measures did not show a significant association with each other. Additionally, a linear regression was run to establish whether the objective measure could explain the values of the self-reported questionnaire. The results can be seen in Figure 1. The results from the linear regression established that it was not statistically significant (R = 0.07, p = 0.28). Moreover, the results from the paired samples t-test, as seen in Table 5, established that there was a statistically significant difference between the reported and objective measures (p = < 0.0001). The effect size (Cohen's *d* = 4.24) as depicted in Figure 3 demonstrates that there is a meaningful difference between the self-reported and objective measures.

In addition, Bland-Altman comparisons were run to determine the relationship between self-reported sedentary time and objectively measured sedentary time. The results can be seen in Figure 1. The results of the Bland-Altman test were within the limits of agreement and established that participants consistently underestimated their sedentary time compared to the objective measure. A simple linear regression revealed a proportional bias for sedentary time ($\beta = 0.52$, $t = 13.26$, $p = < 0.001$).

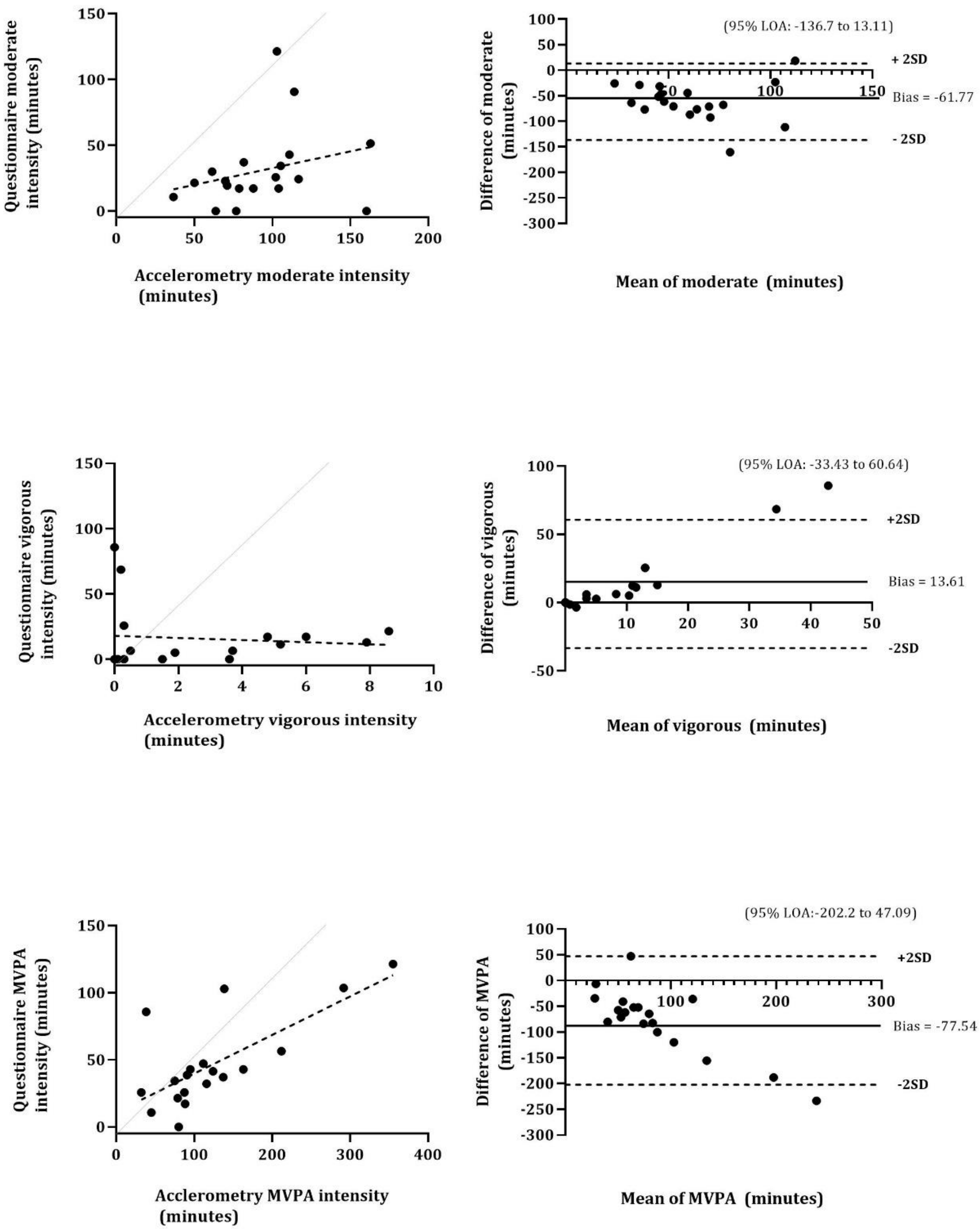

Figure 2. Scatterplot of the correlation and Bland-Altman between the self-reported and objectively measured moderate intensity, vigorous intensity and MVPA. Left side: Scatter plot with added 45-degree line (grey- solid) indicating perfect agreement, and linear regression line (dashed). Right side: Bland-Altman plot with 95% limits of agreement (±2SD) (dashed) and Bias (solid).

3.3 Comparison of time spent in physical activity

A Pearson's product-moment correlation was run to assess the relationship between the questionnaire and accelerometer in reduced-obese women. The results can be seen in Table 5. The intensities "moderate" and "vigorous" did not significantly correlate between the reported and objective measures, respectively. However, there was a statistically significant positive correlation between the self-reported MVPA intensity and the objectively measured MVPA intensity, $r (17) = 0.72$, $p = 0.0006$.

A linear regression was run to establish whether the objective measure could explain the value of the self-reported questionnaire at each intensity of physical activity. Figure 2 illustrates the linear regression results for the intensities "moderate" ($R = 0.08$, $p = 0.25$) and "vigorous" ($R = 0.01$, $p = 0.69$) and shows that the measured accelerometer exercise intensity could not significantly explain what individuals reported via recall. Moreover, the results from Wilcoxon signed-rank tests revealed that there was a statistically significant difference between the reported and objective measure for "moderate intensity" ($p = < 0.0001$) and that there was not a statistically significant difference for "vigorous-intensity" ($p = 0.12$).

In addition, the effect sizes (Cohen's *d* = 1.9 and 0.8, respectively), as indicated in Figure 3, establish that there is a meaningful difference between the self-reported and objective measurements for "moderate" and "vigorous" intensity activity. Despite the latter findings, the linear regression regarding MVPA established that the objective measure could statistically significantly explain the self-reported measure, $F(1,17) = 17.90$, $p = 0.0006$, with the objective measure explaining 51% of the variation in the self-reported measure.

Bland-Altman comparisons were run to determine the relationship between the self-reported questionnaire and the objective measurement. The results can be seen in Figure 2. Upon visual inspection, in terms of moderate intensity and MVPA, both Bland-Altman's revealed that one data point fell below the lower limit of agreement. The Bland-Altman plots show that participants consistently underreported their activity compared to the objective measure. Additionally, in terms of vigorous-intensity physical activity, the Bland-Altman revealed that two data points fell above the upper limit of agreement. The Bland-Altman analysis shows that participants consistently overreported their activity compared to the objective measure. Simple linear regressions revealed a proportional bias for vigorous intensity ($\beta = 0.47$, $t = 16.71$, $p = < 0.0001$) and MVPA ($\beta = -0.72$, $t = -6.17$, $p = < 0.001$) but no proportional bias for moderate intensity ($\beta = -0.6$, $t = -0.37$, $p = 0.71$).

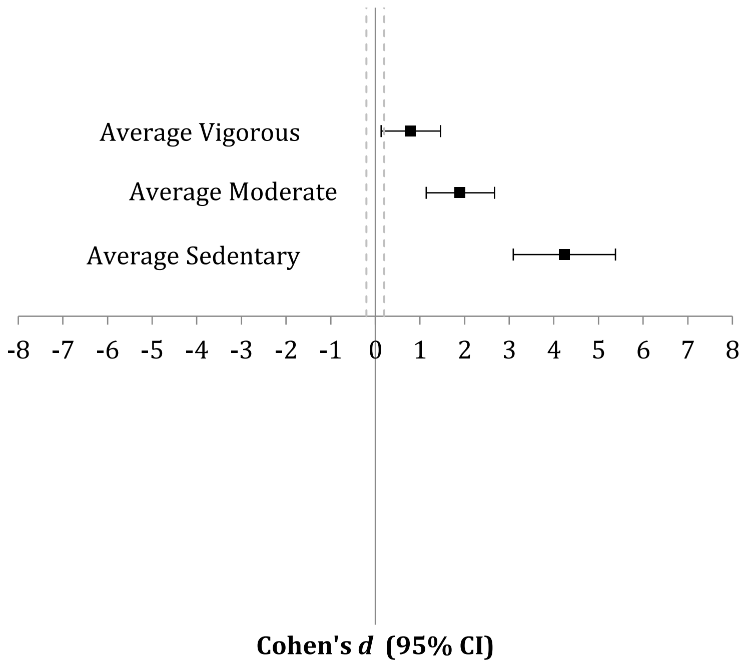

Figure 3. Effect sizes (with 95% Confidence Intervals) of the differences between accelerometer and questionnaire sedentary time, moderate and vigorous intensities.

We explored the similarities between the two measures by calculating effect sizes, which can be seen in Figure 3. In order to see that measures are similar, one would want to see an effect size of less than 0.2. The effect sizes of the difference between the accelerometer and questionnaire for sedentary time, moderate intensity and vigorous intensities were Cohen's d = 4.24, 1.9, and 0.79, respectively.

Table 6 presents the results of two Chi-squared statistical tests. In terms of MVPA, the results indicate that 11 individuals underestimated their MVPA by more than or equal to 60 minutes per day, and 8 individuals were either neutral or overestimated their MVPA by less than 60 minutes per day. 9 (82%) of the 11 people who underestimated their MVPA were acutely at their goal weight (6 months), and 2 (18%) had been at their goal weight for longer than 6 months. Additionally, out of the 8 individuals who were neutral, 6 (75%) were acutely at their goal weight and, 2 (25%) had been at their goal weight for longer than 6 months.

In terms of vigorous-intensity activity, the results indicate that 12 individuals were neutral or underestimated their vigorous-intensity activity by less than or equal to 10 minutes per day, and 7 individuals overestimated their vigorous-intensity activity by more than 10 minutes per day. Out of the 12 individuals who were neutral, 9 (75%) were acutely at their goal weight, and 3 (25%) had been at their goal weight for > 6 months. In addition, out of the 7 individuals who overestimated their vigorous-intensity activity, 6 (86%) were acutely at their goal weight and 1 (14%) had been at their goal weight for > 6 months.

Table 6: Time at goal weight vs under/overestimation of MVPA and vigorous-intensity physical activity

Variable	***Short-term at GW (n)**	**%**	***Longer at GW (n)**	**%**	**Total**	**Fisher exact**
*Neutral MVPA	6	75	2	25	8	
*Underestimation MVPA	9	82	2	18	11	0.57
Total					*19*	
*Neutral VIG	9	75	3	25	12	
*Overestimation VIG	6	86	1	14	7	0.53
Total					*19*	

*Neutral MVPA: defined as individuals who underestimated less than 60 minutes of MVPA per day; *Underestimation MVPA: defined as individuals who underestimated more than or equal to 60 minutes of MVPA per day; *Neutral VIG: defined as individuals who overestimated less than or equal to 10 minutes of vigorous-intensity activity per day; *Overestimation VIG: defined as individuals who overestimated more than 10 minutes of vigorous-intensity activity per day; *Short-term at GW: people who have been at their goal weight for less than or equal to 6 months; *Longer at GW: people who have been at their goal weight for more than 6 months.

Chapter 4: Discussion

In this study, we compared subjectively measured physical activity (PA) from a self-reported PA questionnaire with objectively measured PA from an accelerometer in previously obese women with diverse weight loss histories. The results indicate that individuals did not overestimate all their physical activity. In fact, participants underestimated their MVPA by approximately 78 mins/day and their sedentary time by more than 5 hours/day, respectively. The reduced-obese women in the study, however, overestimated their vigorous-intensity activity by 6 mins/day.

Most participants (n =15) had been at their goal weight for no longer than 6 months. This can be recognised as being at their weight loss goal for an acute/short period of time. As a result, when we refer to these participants, we are referring to reaching their goal weight as acutely. The remaining participants (n = 4) had been at their goal weight for 8 months or longer. One of the main challenges for reduced-weight individuals is the behavioural compensatory responses that accompany weight loss. These behavioural responses have been linked to individuals overestimating their activity levels over time due to social desirability bias or recall bias, which has the potential to hinder their weight loss and weight loss maintenance attempts (Colley et al., 2019; King et al., 2007). Within our study, we do not see this overestimation with moderate-intensity activity; however, we do see it with vigorous-intensity activity.

There could be many reasons for the underestimation of PA. A study conducted by Elliott and colleagues (2014) found that participants with a low measured PA level tended to overreport their activity, whereas individuals with a higher measured PA level underreported their activity using self-reported methods (Elliott et al., 2014). Within our study, participants underwent conventional weight loss, which included dietary changes and an increase in PA. As a result, having recently completed their weight loss phase, they were extremely active. Eight (42%) of the participants completed 250-600 minutes of MVPA per week, while 11 (58%) completed more than 600 minutes of MVPA per week. Therefore, the observation of Elliot and colleagues (2014) may be relevant as a possible explanation for the underestimation seen. Additionally, Watkinson and colleagues (2010) observed that individuals with higher BMIs may have a lower general perception of their health and thus tend to associate their higher BMI with insufficient activity levels (Watkinson et al., 2010). The aforementioned remark may be relevant as a possible reason for the underestimation seen by the participants in this study. Apart from the substantial weight loss (on average 23.3 ± 9.1 %) that the group of women in this study experienced, 14 (74%) of the 19 participants in this study still had high BMIs, which indicate they were still overweight or obese.

Watkinson and colleagues (2010) went on further to state that individuals who "feel" healthy may presume that they are sufficiently active, while those who perceive their overall health more negatively may assume that they are not engaging in enough PA (Watkinson et al., 2010). This observation may be true for our participants, as they have been at their goal weight for a short period of time (acutely) and have just come out of a weight loss period and therefore may still be perceiving their PA efforts as being insufficient. Clamp and colleagues (2018) stated that maintaining higher levels of moderate and vigorous activity and reducing sedentary behaviour may be key to the success of weight loss maintenance (Clamp et al., 2018). Therefore, the underestimation of PA levels for this group of individuals may be considered an advantage, as the overestimation of PA levels is considered a risk factor for weight loss relapse, and they are currently proving not to be at risk.

With regards to moderate-intensity activity, the Bland-Altman revealed no proportional bias (β = -0.6, t = -0.37, p = 0.71) between the self-reported measure and the accelerometry. The Bland-Altman plots revealed a bias and SD of bias of -61.77 to 38.10. The majority of results were within the limits of agreement (95% LOA: -136.7 to 13.11) with only one data point falling below the lower limit of agreement. Time spent in moderate activity showed the best agreement between the self-reported measure and accelerometry.

On average, participants underestimated their moderate-intensity activity by 69 minutes per day (p = < 0.0001) which is in contrast with findings from previous studies (Chu et al., 2015; Nelson et al., 2019). This may be due to their studies including both male and female participants. It was shown in the study conducted by Nelson and colleagues (2019) that male participants had a tendency to overreport PA to a greater extent when compared to female participants (Nelson et al., 2019). A similar finding was discovered in a study conducted by Dyrstad and colleagues (2014), where male participants' reported PA was 25% greater than female participants' PA (Dyrstad et al., 2014). Further, the contrast could be due to the ages of the participants (Chu and colleagues (2015) had participants aged 21–68). There is evidence to suggest that older individuals tend to overreport their PA to a greater extent when compared to younger individuals (Tomaz et al., 2016).

The Bland-Altman plots revealed a proportional bias for time spent per day in vigorous activity ($\beta = 0.47$, $t = 16.71$, $p = < 0.0001$). The Bland-Altman plots also revealed a bias and SD of bias of 13.61 to 24. Most results fell within the limits of agreement (95% LOA: -33.43 to 60.64) with two data points falling above the upper limit of agreement. The greater the amount of time participants spent in vigorous-intensity activity, the more they overestimated their vigorous activity time. Further, the agreement between the self-reported and objectively measured vigorous-intensity activity was poor and was not statistically significant ($r = 0.10$, $p = 0.69$). On average, participants overestimated their vigorous-intensity activity by 6 minutes per day ($p = 0.12$). This finding is in agreement with the findings from previous studies (Celis-Morales et al., 2012; Chu et al., 2015; Hume et al., 2015; Nelson et al., 2019; Tully et al., 2014; Walsh et al., 2004). The study conducted by Celis-Morales and co-authors (2012) on apparently healthy Chilean adults found that participants overestimated their vigorous-intensity activity by 8 minutes per day (Celis-Morales et al., 2012). The overestimation observed is very similar to what was found in our study, despite the fact that we are dealing with reduced-obese individuals.

Hume and colleagues (2015) estimated energy expenditure from self-report and accelerometer minutes per day in a study on reduced-weight individuals. The authors found that participants reported engaging in 3.7 times the amount of vigorous-intensity activity that was actually measured (Hume et al., 2015). This result is similar to the results obtained within our study focusing on the same type of population. In addition, a study conducted by Tully and co-authors (2014) found that individuals with a BMI greater than 25 kg/m^2 tended to overreport their PA levels when compared to normal-weight controls (Tully et al., 2014). An additional study conducted by Walsh and colleagues (2004) noted that reduced-weight women were prone to overestimating their energy expenditure when compared to stable-weight controls (Walsh et al., 2004). The findings from the latter two studies may provide possible reasons for the overestimation seen in our study, as 14 (74%) of our participants have BMIs greater than 25 kg/m^2, and all participants are in a reduced-weight state.

The vigorous-intensity PA captured by the accelerometer was substantially lower than the PA questionnaire, which may be attributed to the discrepancy of intensity between the perception of the participants and the criterion of the question in the PA questionnaire (Gao et al., 2022). Thus, individuals may perceive their activity as vigorous-intensity; however, the activity performed may not have reached the expected intensity, resulting in overreported vigorous-intensity PA in the PA questionnaire (Freedson et al., 1998; Gao et al., 2022). Moreover, Ferrari and colleagues (2020) postulate that differences observed between objective and subjective PA measurement methods could be due to a misinterpretation of intensities combined with difficulties in remembering the frequency and duration of activities completed (Ferrari et al., 2020). However, as previously stated, reduced-weight individuals are influenced by their behavioural compensatory responses as a result of weight loss, which may also influence the amount of overestimation observed.

The results demonstrated a strong positive correlation between the self-reported MVPA and the objectively measured MVPA ($r = 0.72$, $p = 0.0006$). MVPA is comprised of a combination of moderate and vigorous-intensity activity. Within our study, participants engaged in significantly more moderate than vigorous-intensity activity. Therefore, the underestimation of moderate-intensity activity contributed greatly to the finding of MVPA.

In contrast to our other findings, the agreement between the self-reported and objectively measured MVPA was moderate and statistically significant ($r = 0.72$, $p = 0.0006$). In addition, the Bland-Altman plots revealed a proportional bias for time spent per day in MVPA ($\beta = -0.72$, $t = -6.17$, $p = < 0.001$). The Bland-Altman plots revealed a bias and SD of bias of -77.54 to 63.58. The majority of results fell within the limits of agreement (95% LOA: -202.2 to 47.09) with only one data point falling below the lower limit of agreement. Therefore, the agreement demonstrated for vigorous-intensity and MVPA were not as consistent as for moderate-intensity. On average, participants underreported their MVPA by 78 minutes per day ($p = 0.0009$) which is largely in line with previous reports by Gao and colleagues (2022) and N. J. Taylor and co-authors (2013); however, it is in contrast with findings from Gupta and colleagues (2018) (Gao et al., 2022; Gupta et al., 2018; Keating et al., 2019; N. J. Taylor et al., 2013). A reason for this discrepancy could be the different study populations and participant occupations. The study conducted by Gupta and colleagues (2018) mainly included males, and all of the participants were blue-collar workers (Gupta et al., 2018). Therefore, the contrasts observed may be for similar reasons explained for the underestimation seen in moderate-intensity activity (i.e., including male participants and the differences in ages of the study populations). Further, the literature reveals that due to the physical nature of blue-collar work, individuals tend to overreport the amount of MVPA they engage in due to the misconception that the manual labour they complete is moderate intensity in nature (Azevedo et al., 2021).

A secondary finding of our study was that participants underestimated their sedentary time. The agreement between the self-reported and objectively measured sedentary behaviour was poor and not statistically significant ($r = 0.26$, $p = 0.28$). Compared to the objective measurement, on average, participants underreported their sedentary time by more than 5 hours per day ($p = < 0.0001$) which is in agreement with the findings of previous studies (Clark et al., 2009; Cleland et al., 2014; Clemes et al., 2012; Dyrstad et al., 2014; Gupta et al., 2018; Nelson et al., 2019; Prince et al., 2020). In the study conducted by Nelson and colleagues (2019), they found that their participants (undergraduate students) underreported their sedentary time by over 2 hours per day (Nelson et al., 2019). Similarly, in a study conducted on apparently healthy adults by Dyrstad and co-authors (2014), the authors discovered that participants underestimated their sedentary time by over 2 hours per day (Dyrstad et al., 2014). Furthermore, in the systematic review conducted by Prince and colleagues (2020), the authors stated that within the literature, self-report tools underestimated sedentary time by approximately 1.74 hours per day, with underestimations of approximately 6 hours per day being noted within individual studies (Prince et al., 2020). Additionally, the Bland-Altman plots revealed a proportional bias for time spent in sedentary behaviour per day ($\beta = 0.52$, $t = 13.26$, $p = < 0.001$). The Bland-Altman plots revealed a bias and SD of bias of -325.7 to 204.3. The results revealed that all data points fell within the limits of agreement (95% LOA: -726.2 to 74.70). The Bland-Altman plots also revealed that the more sedentary time participants engaged in, the less they underestimated their sedentary time.

As previously mentioned, one of the major challenges reduced-weight individuals face is the behavioural compensatory responses that accompany weight loss. These behavioural compensatory responses may cause individuals to underreport their sedentary activity due to social desirability and the belief that they are more active than they truly are (Catia Martins et al., 2020). This underestimation of sedentary time may place them at risk for weight loss relapse (Cox, 2017). Moreover, it has been postulated that when a self-report measure of sedentary time was comprised of a single sedentary behaviour item (which is true for the GPAQ), it significantly underestimated sedentary time in comparison to accelerometer data (Cleland et al., 2014; Clemes et al., 2012; Prince et al., 2020). An additional consideration is that underestimation of sedentary time may be a consequence of recall ability or social desirability error, and since sedentary behaviour is not a structured activity (it occurs persistently in periods throughout the day), it is likely that recall ability is substantially compromised (Kastelic & Šarabon, 2019). An important consideration for the population of our study is that if individuals consider themselves to be less sedentary than they are in real-life, it places them at a greater risk for weight loss relapse (Cox, 2017).

In addition, the American College of Sports Medicine (ACSM) and the World Health Organization (WHO) recommend that adults engage in more than or equal to 150 minutes of MVPA per week for the promotion of overall health and a reduction in chronic disease risk (Donnelly et al., 2009; Silfee et al., 2018; World Health, 2020). However, for the prevention of weight regain and weight loss maintenance following weight loss, 250-300 minutes of MVPA per week is recommended by the ACSM (Donnelly et al., 2009; Unick et al., 2017).

According to these guidelines, an additional outcome of our study was that all the participants were sufficiently active according to the WHO and ACSM guidelines for the general population. All the participants also met the cut points for being sufficiently active for weight loss maintenance. However, when looking at the upper limit of the PA range for weight loss maintenance (300 minutes of MVPA per week), 89% of the participants (n = 17) met the criteria of more than or equal to 300 minutes of MVPA per week. A study conducted by Wadden and co-authors (2012) found that the maintained weight loss of individuals who exercised ≥ 300 minutes per week was nearly three times as great compared to individuals whose PA was < 150 minutes per week (Wadden et al., 2012). Additionally, a study conducted by Jakicic and colleagues (1999) found that engaging in MVPA for > 200 minutes per week has proven to be beneficial for weight loss maintenance (Jakicic et al., 1999; Wadden et al., 2012). Therefore, based on the latter two studies, we can state that the majority of participants in this study are currently engaging in sufficient exercise for successful weight loss maintenance (n = 17 are completing more than or equal to 300 minutes of MVPA per week).

The majority of our participants reached the higher guideline of minutes per week of MVPA for weight loss maintenance, despite using relatively high thresholds for moderate and vigorous exercise intensities derived from the GT3X+ accelerometer, namely the thresholds by Troiano and co-authors (2008). Within these thresholds, activity represented as counts per minute (cpm) were classified as follows: Sedentary activity (< 100cpm), light PA (100-2019 cpm), moderate PA (2020-5998 cpm), and vigorous PA (≥ 5999 cpm) (Troiano et al., 2008). We were aware that our study population was physically active due to emerging from a period of diet- and exercise-induced weight loss. Therefore, we made use of these cut points as they are the weighted average of the cut points set by Brage, Freedson, Leenders, and Yngve for physically active adult populations (Brage et al., 2003; Freedson et al., 1998; Leenders et al., 2001; Watson et al., 2014; Yngve et al., 2003).

4.1 Strengths and limitations

The strength of the present study is the high compliance with accelerometer wear and adherence to the study protocol. We used the GT3X+ accelerometer as a reference rather than the DLW method, the gold standard for measuring energy expenditure. The DLW method is expensive, requires specialised equipment, determines total energy expenditure but does not measure the intensities of PA (Strath et al., 2013). However, Chomistek and colleagues (2017) tested the validity of the GT3X+ accelerometer and found excellent correlations with the DLW method, indicating the high validity of accelerometer-measured PA (Chomistek et al., 2017; Gao et al., 2022) for measuring energy expenditure. Furthermore, Aadland and Ylvisåker (2015) tested the reliability of the GT3X+ accelerometer and found it to be a reliable tool for measuring PA in adults under free-living conditions (Aadland & Ylvisåker, 2015). It is critical to understand the intensity of the PA that individuals engage in to establish its significant impact on weight loss and weight loss maintenance (Cox, 2017).

However, it is important to note that the present study was not without limitations. There are issues related to the use of accelerometers that can also contribute to the discrepancy between objective and subjective approaches (Chu et al., 2015). Chu and colleagues (2015) stated that while accelerometers are the most widely used objective tool to measure PA, they are known to underestimate certain activities (Chu et al., 2015; Robertson et al., 2011). The authors went on to state that activities such as housework and cycling, which involve limited movement, are poorly detected by accelerometers, and activities such as swimming are often not captured because participants are advised to remove devices during such activities, which can partly contribute to the discrepancies between self-reported and accelerometry-derived estimates of activity (Chu et al., 2015; Cleland et al., 2014; Prince et al., 2008; Zult et al., 2020). In addition, the chosen accelerometer, the Actigraph (GT3X +, Actigraph, Pensacola, FL) was not able to track heart rate. An additional limitation was that we encouraged the participants to keep a log of planned activities; however, no activity logs were received from any of the participants, therefore we were unable to track activities such as stationary cycling or swimming.

Further, to truly examine the agreement between the GPAQ and accelerometer, a larger sample size would have been beneficial. The average achieved power calculated by G*Power version 3.1.9.6 based on the correlation between the two methods for time spent in sedentary, moderate, vigorous, and ,MVPA was 0.63 (Erdfelder et al., 1996). An additional limitation of the study is that we did not have a control group. Finally, despite being carefully controlled, recall bias and the modification of behaviour by participants in response to their knowledge that they were being observed (the Hawthorne effect) could not be eliminated (Chasan-Taber et al., 2002; Clemes et al., 2008).

4.2 Conclusion

Within the present study, we have discovered that individuals who have acutely lost weight and reached their goal weight largely underestimate their sedentary time and overestimate their vigorous-intensity activity. This miscalculation of their estimated total daily energy expenditure places them at risk for weight loss relapse in the long term. Despite the latter two findings, objectively, participants with acute weight loss (participants were at their goal weight for a mean ± SD of 7 ± 3 months) are sufficiently active for weight loss maintenance. The reduced weight group of women consistently (no proportional bias) underestimated moderate-intensity activity by more than an hour per day. The literature is not clear on this, and we postulate that this could be due to the participants being acutely at their goal weight; however, further investigation is required.

To conclude, the discordance between subjective and objective measures of sedentary and vigorous-intensity activity has the potential to lead to unfavourable compensatory behaviours for weight loss, which will eventually lead to weight loss relapse. Future research should investigate possible strategies to prevent the behavioural compensatory responses that lead to the overestimation of PA levels, as it is placing individuals at risk for weight loss relapse. Currently, there are factors that may contribute to weight loss relapse; however, at 6 months post weight loss, these individuals are still highly active. This provides evidence that reduced-obese women require disciplined exercise regimes to maintain weight loss and promote weight loss maintenance. Additionally, it is imperative that research on obese reduced women make use of objective measures for the measurement of free-living activity, for self-reported measures may lead to the misinterpretation of this specific population's physical activity status.

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