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Utility of the SenseWear Pro 3 armband monitor and the Weight Management System for evaluating energy balance in adults

by

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DEDICATION

Dedicated to Jesus Christ, my Lord and Savior.

And whatever you do, whether in word or deed, do it all in the name of the Lord Jesus, giving thanks to God the Father through him.

Colossians 3:17

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ABSTRACT

The progression of the obesity epidemic stems directly from the inability of individuals to achieve a balance between energy expenditure (EE) and energy intake (EI). To enhance research on obesity prevention it is important to develop and validate instruments that can facilitate monitoring of energy balance (EB) under free-living conditions. The SenseWear Pro 3 armband (SWA) monitor and associated weight management system (WMS) offer promise as a non-invasive method suitable for energy balance research. The primary purpose of the study was to evaluate the utility of the SWA and WMS to assess EB during a week of free-living activity. A total of 68 healthy adult participants (31 male and 37 female) wore the SWA monitor for a week while recording a detailed 7-day dietary food record. Estimates of EE were obtained directly from the SWA software. Estimates of EI were obtained by entering the dietary food records into both the Nutritionist Pro and the SenseWear WMS dietary assessment systems. The estimated EB (EI-EE) was compared with the observed EB (obtained from fasted weight measures taken at the beginning and ending of the study). Differences in EB values (observed – estimated) were statistically tested using standard t-tests. A secondary purpose was to compare the assessed EI between Nutritionist Pro and SenseWear WMS. A mixed model analyses of variance was used to evaluate the difference between EI values as well as macronutrient intakes of carbohydrate, fat, and protein. Results indicated that participants lost weight during the week long protocol (mean weight loss = -0.5 ± 1.6 lbs) without an apparent intention to lose weight. Similarly, estimated EB was significantly different than zero, indicating a negative EB (weight loss). Difference in weight difference (observed – estimated) was positive (difference = 0.9 lbs ± 2.0), indicating a significant overestimation of weight loss ($p < 0.001$). Supplemental analyses indicated that individuals completing more detailed dietary records had a significantly higher weight loss than those providing less detailed records. More interestingly, individuals providing high quality dietary records had a small (non-significant) average EB difference (difference = -0.03 ± 1.4 lbs, $p = 0.09$) while individuals providing poor quality records had large EB differences (difference = 2.0 ± 1.0 lbs,

$p < 0.001$). Collectively, this suggested that the estimates of EB from the WMS are accurate when participants provided detailed dietary records. Correlations between nutrient intake (EI, protein, carbohydrate, and fat) assessments (SenseWear WMS vs. Nutritionist Pro) were high for all comparisons (range: $r = 0.93$ to 0.99). The estimates of EI from the two dietary assessment systems were not significantly different ($p = 0.07$) and the gender by method interaction was also not significant ($p = 0.32$). Similar results were noted for macronutrient comparisons; however, a significant gender by method interaction was evident for protein ($p = 0.048$). In conclusion, the SWA monitor with its integrated WMS demonstrated promising attributes for assessing EB in free-living individuals.

Key Words: activity monitors, energy balance assessment, dietary assessment system

CHAPTER 1. GENERAL INFORMATION

Introduction

The obesity epidemic is one of the leading health challenges facing the nation. Within the last 10 years, the prevalence in the United States of overweight (37.4%) and obesity (27.7%) has increased by 36% (BRFSS, 2007). Basic principles of energy balance suggest that weight gain will occur when energy intake through the diet exceeds the amount of energy expenditure through physical activity (Dietz, 1983; Uauy, 2005; Hill, 2006). To enhance obesity prevention efforts, it is important to investigate the utility of devices capable of assessing energy balance. One of the challenges in this line of research is that it is difficult to accurately assess energy intake and energy expenditure.

There are a variety of instruments to assess the consumption of energy intake, but self-report instruments are the most common and widely used in research. Other than direct analysis of food consumed, weighed diet records theoretically provide the most accurate assessment of intake, but are not feasible with most research studies. Participants typically recall or record foods that were eaten and the data are entered into dietary assessment systems to estimate energy intake. Research has demonstrated many limitations in energy intake assessment methods. One consistent limitation is the underestimation of energy intake using weighed diet records (Livingstone et al., 1990; Bathalon et al., 2000), dietary intake records (Hoidrup et al., 2002; Mahabir et al., 2006), 24-hour recalls (Tran et al., 2000), and food frequency questionnaires (Mahabir et al., 2006). This may be due to a variety of issues such as respondent fatigue (Bathalon et al., 2000), variations in BMI and age (Hoidrup et al., 2002), and incomplete records (Smith et al., 1991).

There are also numerous instruments available for assessing energy expenditure. Self-report instruments are among the most common, but researches have increasingly relied on the use of objective accelerometers to obtain more accurate measures. Doubly labeled water is considered the gold standard to assess energy expenditure, but it is expensive, quantifies energy expenditure over a period of days (Welk, 2002), and does not provide information about specific activities throughout the measurement-period. Accelerometers have evolved and been validated against doubly labeled water to provide objective daily energy expenditure assessment during free-living conditions. Although these devices are promising, there has been a consistent demonstration that these devices underestimate energy expenditure (Leenders et al., 2001; Welk, 2002), especially during time spent in light intensity activities (Strath et al., 2003).

The inherent challenges associated with assessing energy intake and energy expenditure have made it particularly difficult to accurately assess energy balance. Integrated tools that assess both energy intake and energy expenditure offer promise for improving the understanding of energy balance. A commercially available device known as the SenseWear Pro 3 armband (SWA) monitor (Bodymedia Inc.) offers considerable promise for advancing energy balance research in free-living individuals. The SWA monitor is a comfortable, non-invasive physical activity monitor that is worn on the upper arm. An advantage of the SWA monitor is that it automatically detects non-wear time and can provide accurate estimates of free-living physical activity and energy expenditure when worn over multiple days. A unique aspect of the SWA monitor is that, in addition to estimating energy expenditure, it has an associated software tool called the Weight Management System (WMS). This software integrates energy expenditure data with a comprehensive dietary assessment system to provide information about energy intake and energy balance. The ability to track and monitor energy balance over time may help individuals learn to modify dietary and physical activity habits to facilitate weight maintenance or weight loss. Previous research has demonstrated the validity of the SWA monitor during rest and exercise against indirect calorimetry (Fruin & Rankin, 2004; Malavolti et al., 2007) and DLW (St-Onge et al., 2007; Calabro & Welk, in press). However, to date no study has examined the utility of the SWA monitor integrated with the WMS software tool for assessing energy balance.

The purpose of this study is to examine the agreement between estimated and actual energy balance during a 7-day period using the SWA monitor and WMS. A secondary goal is to compare the energy intake (and macronutrients) assessment from the WMS with associated estimates from a more established dietary assessment system called Nutritionist Pro. In this project, healthy adult participants wore an SWA monitor for 7-days while completing a detailed 7-day dietary record. Estimates of energy expenditure were obtained directly from the SWA software and estimates of energy intake were obtained by entering dietary records into the WMS and Nutritionist Pro software. Body weight (collected following an overnight fast) was measured at the beginning and end of the week to obtain weight change and energy balance during the 7-day period. Simple t-tests were used to examine differences between estimated and actual energy balance. A mixed model analysis of variance was used to directly compare energy intake and macronutrient consumption estimates from the WMS and Nutritionist Pro. It was hypothesized that energy intake and energy expenditure would vary on a daily basis, but would average out during the week for individuals who remained weight stable during the 7-day period. It was also hypothesized that the WMS and Nutritionist Pro would yield similar estimates of energy (and macronutrients) intake.

Thesis Organization

This thesis contains a general introduction, a literature review focusing on energy balance, assessment of energy intake, and assessment of energy expenditure while focusing on a specific accelerometer, the SenseWear Pro 3 monitor. The paper entitled "Utility of the SenseWear Pro 3 monitor and the Weight Management System for evaluating energy balance in adults" will be submitted to *The American Journal of Clinical Nutrition*. A general conclusion follows the paper.

CHAPTER 2. REVIEW OF LITERATURE

This literature review provides key statistics and trends related to energy intake and energy expenditure that cause positive energy balance – a direct contributor to overweight and obesity. It also provides a summary of current knowledge related to assessment of energy intake and energy expenditure. The inherent complexity of assessing energy intake and energy expenditure creates additional challenges for examining energy balance. The SenseWear Pro 3 (SWA) monitor and the associated Weight Management System (WMS) offer promise for applied energy balance research. To date, the utility of this device to assess energy balance has not been evaluated.

Overview of Obesity

The obesity epidemic is one of the leading health challenges facing the nation. In the United States (U.S.) the prevalence of obesity has increased over the past years. In 2007, 37.0% of the nation was neither overweight nor obese, 36.6% were overweight, and 26.3% were obese (BRFSS, 2007). Iowa is one of the 50 states that continues to face the obesity epidemic. Within the last 14 years, the prevalence of overweight and obesity in Iowa has increased by an alarming 36.8%, which is higher than the national rate. In the year 2007, 35.3% of Iowans were neither overweight nor obese, 37.0% were overweight, and 27.7% were obese (BRFSS, 2007). This indicates that a greater portion of Iowans are overweight or obese rather than maintain a healthy weight, illustrating the importance of enhancing obesity prevention efforts.

Since 1985, there has been a dramatic increase in the prevalence of obesity in the U.S. In 1990, 10 states had a prevalence of obesity less than 10% and no states had a prevalence equal to or greater than 15% (BRFSS, 2007). Unfortunately, by the year 1998, no states had a prevalence less than 10% and 7 states had a prevalence rates between 20-24% (BRFSS, 2007). Continuing to increase in the year 2007, 30 states had a prevalence of obesity equal to or greater than 25% (BRFSS, 2007). Colorado was the only state that had a prevalence of obesity less than 20% (BRFSS, 2007). On the other hand, Alabama, Mississippi, and Tennessee had an alarming obesity prevalence equal to or greater than 30% (BRFSS, 2007). The range of obesity prevalence was 18.7% in Colorado to 32.0% in Mississippi, with an average of 25.6% nationwide (BRFSS, 2007).

Iowa displays the same obesity characteristic trend as our national prevalence rates. In 1995, 17.5% of Iowans were considered obese (BRFSS, 2007). As the years have progressed, the prevalence of obesity in Iowa has increased at a steady rate. Within 12 years, the prevalence of obesity increased 10.2% resulting in 27.7% of Iowans being obese in 2007 (BRFSS, 2007). It is evident that the Iowa obesity epidemic along with the national obesity epidemic, continues to increase and will not be abated unless contributing factors are addressed.

A) Assessment of Overweight and Obesity

Obesity specifically refers to a state of expanded body fat stores (Dietz, 1983). There have been numerous instruments and methodologies developed to estimate body composition, such as hydrodensitometry, isotope dilution, and dual-energy x-ray absorptiometry. All of these methods are precise; however, they are time-consuming, inconvenient, and costly (Wagner & Heyward, 1999). Simpler and less expensive methods include skinfold thickness measurements and bioelectrical impedance analysis (BIA). In this literature review there will be a focus on the BIA, which is a field based instrument that estimates total body water (TBW), which can be used to estimate fat free mass (FFM). This device is based on the principle that lean tissue is a good electrical conductor because it contains primarily water and electrolytes, whereas fat is relatively anhydrous and hence is a poor conductor. The BIA sends a small electrical current (800 microamperes) through the body and measures the impedance (Z) to the voltage produced between two electrodes. The higher TBW and FFM, the less resistance to the electric current and lower Z value, translating into a lower body fat percentage.

The BIA is a simple and attractive device because it is quick, non-invasive, and easy to administer by the technician. Similar to all devices, there are limitations to the BIA device. The state of hydration is an underlying factor, contributing to the inaccuracy of the device because it can affect the Z value (Kushner, 1992). Kushner (1992) also demonstrated that the coefficient of variation for R (resistance) measurements for the same participant, ranged from 0.3% to 2.8% during the course of a day and during the course of the week ranged from 0.9% to 3.6%. Similar results were displayed in a study of 14 men during 5 consecutive days, with 2.0% precision for Z measurements obtained from BIA (Lukaski et al., 1985). Overall, the BIA is a quick, easy, yet crude device to assess body composition. Based on NIH/WHO guidelines, the recommended body fat percent age for females 20-39 years old is 21-33% and for males 20-39 years old is 8-20% (Gallagher et al., 2000).

Body mass index (BMI) is a simple calculation based upon anthropometric measures that is often used as a proxy for body composition. BMI is calculated by dividing an individual's weight in kilograms by his/her height in meters squared. The World Health Organization (WHO) classifies individuals according to the following BMI (kg/m^2) ranges: normal is 18.5 to 24.9; overweight is 25 to 29.9; obese is ≥ 30. Research has indicated that a BMI ≥ 25 kg/m^2 is linked to greater risk for comorbidities, such as diabetes, hypertension, hypercholesterolemia, asthma, arthritis, and poor overall health status (Mokdad et al., 2003). The utility of BMI is not without controversy. BMI does not distinguish between lean and fat tissue (Prentice & Jebb, 2001). It should be used with caution when assessing the elderly (Cook et al., 2005), children, and athletes (Prentice & Jebb, 2001) and does take racial differences into account (Prentice & Jebb, 2001). However, there is an importance of documenting an individual's BMI is important. Used in conjunction with other observations, BMI is a quick, noninvasive, and easy measurement to assess the weight status of a population.

B) Health Risks of Obesity

Many physiological and psychosocial risks are associated with obesity. Obesity increases the risk of morbidity and mortality related to heart disease, diabetes mellitus, gallbladder disease, high blood pressure, and cancer (Bray, 1996). The risk of developing comorbidity is influenced by the extent of obesity, location of excess body fat, and degree of weight gain during the adult years. Morbidity and mortality caused by obesity increase in direct proportion to the increase in BMI (Calle et al., 1999; Rimm et al., 1995). The location of excess body fat storage is critical in the risk assessment of chronic disease. Those individuals with androidal adiposity (upper body) are at an increased risk of cardiovascular disease, dyslipidemia, hypertension, and type 2 diabetes mellitus. Excess androidal fat content may result in dyslipidemia and insulin resistance, in addition to high ambulatory 24-hour systolic blood pressure (Seppala-Lindroos et al., 2002). Among adolescents, excess fatty acids stored in the skeletal muscle may cause insulin resistance within the skeletal muscle (Sinha, 2002). In addition, obesity causes premature death, especially among younger adults who are obese ($BMI \geq 30$ kg/m^2) (Fontaine et al., 2003). In the United States in 2005, approximately 365,000 deaths were associated with obesity (Mokdad et al., 2005).

Energy Balance

Weight maintenance requires energy balance, a condition in which energy intake and energy expenditure are equivalent. Energy intake is the total amount of calories consumed either by enteral or parenteral routes. These calories are provided predominately by macronutrients: protein, carbohydrate, and fat. Energy expenditure is composed of three main components: basal energy expenditure (BEE), thermic effect of food (TEF), and energy expenditure of physical activity (EEPA). Positive energy balance results when energy intake exceeds energy expenditure and net body energy gain occurs (Dietz, 1983; Uauy & Diaz, 2005; Hill, 2006). Conversely, negative energy balance occurs when energy expenditure exceeds energy intake and net body energy is lost. Humans' body weight seems to be more stable over long periods of time than suggested by the wide variations in daily energy intake and energy expenditure (Tarasuk & Beaton, 1991). Variations in day-to-day energy balance are due to both energy intake and energy expenditure patterns. Individuals in Western cultures repeatedly have demonstrated a positive energy intake through the diet that exceeds the amount of energy expenditure through physical activity (Uauy & Diaz, 2005). Energy balance is a major determining factor of chronic weight gain and accurate assessment methods are needed to assess energy balance.

A) Energy Intake Patterns

Energy intake patterns vary for many reasons. An individual's energy consumption is not from a single nutrient and hence it is a challenge to investigate the contributing nutrients. Also, energy intake patterns change regularly, because they are influenced by the environment, family, culture, and religion. Despite these challenges, research has demonstrated the role of an individual's overall energy intake pattern in developing obesity. Diets containing high energy dense foods and dietary intake patterns that skip breakfast have been shown to be contributing factors to the development of obesity (Drewnowski, 2007; Alexander et al., 2009). From 1977 to 2001, the amount of energy intake from sugar-sweetened beverages consumed per individual increased by 135% (Nielsen & Popkin, 2004). This is of great concern, because sweetened beverages, such as soda and fruit drinks, are high in calories, but do not provide a sense of satiety. Thus, sugar-sweetened beverages tend to increase energy consumption, contributing to weight gain (Malik et al., 2006; Vartanian et al., 2007).

Other energy intake patterns have been shown to protect against developing obesity. Diets low in fat, the intake of low glycemic foods, and meals high in whole grains and legumes appear to protect against obesity (Drewnowski, 2007). Also, an energy intake pattern high in vegetables and fruits seem to decrease the risk of obesity (Sartorelli et al., 2008). During the past 11 years, the national statistics of individuals consuming five or more of fruits and vegetables per day has remained at a steady state. In 1996, only 23.7% of the nation was consuming five or more servings/day of fruits and vegetables (BRFSS, 2007). Throughout the years this percent has remained unchanged at 24.4% in 2007 (BRFSS, 2007). This is a greater concern in Iowa, because in 1996, only 15.1% of Iowans were consuming five or more servings/day of fruits and vegetables (BRFSS, 2007). This percent increased to 19.9% in 2007, but it is still lower than the national average (BRFSS, 2007). Dietary fiber intake may also decrease the risk of obesity. Dietary fiber has a unique characteristic of increasing the volume of food and decreasing the energy density leading to earlier satiety. Dietary fiber has been shown to increase post-meal satiety, thus promoting weight loss (Howarth et al., 2001). Calcium and dairy products have also been shown to influence adiposity in some (Zemel et al., 2000), but not all (Jensen et al., 2002) studies. High calcium diets have been demonstrated to reduce weight gain, particularly with calcium sources from dairy products (Sun & Zemel, 2004). This issue is not at all settled and has sparked fierce debate.

B) Energy Expenditure Patterns

Energy expenditure through physical activity represents the most variable component of total daily energy expenditure. Low levels of physical activity are a likely contributor to the increase prevalence of obesity. Surveillance data from the Center for Disease Control and Prevention suggest that about 49.5% of adults achieve the recommended physical activity per day. A slightly lower percent of Iowans (48.4%) met the guidelines. Only 28.3% of the nation and 25% of Iowans achieved 20 minutes or more of vigorous activity three or more days per week (BRFSS, 2007).

The amount of energy expended during physical activity is a major contributing factor to the obesity epidemic. Individuals who are more physically active and less sedentary are at lower risk of weight and fat gain (Must & Tybor, 2005). Also, the amount of body fat reduction due to energy expenditure through physical activity has been shown to be dose-dependent. An increase in duration, intensity, and frequency leads to a higher total body fat reduction (Ross & Janssen, 2001). Sedentary lifestyles characterized by physical inactivity energy expenditure patterns may be a link to the obesity epidemic.

Assessment of Energy Intake

Since energy intake is a component of energy balance, the assessment of energy intake is necessary to evaluate energy balance. Dietary assessment also may be used to identify nutrients that may be under or over consumed and to identify intake patterns. A variety of methods have been developed over the years, but there is still debate about which assessment techniques is most reliable, accurate and precise when used in the community.

A) Background and History of Methods

Since the 19th century, scientists have been researching and developing techniques to estimate energy intake. There is limited information available about how these techniques were developed. The number of calories of heat that one pound of a given material yields upon combustion seems to be the major technique for determining the energy content in food. This technique has been used to create food composition databases for analyzing weighed dietary records, 24-hour recalls, and dietary records.

In 1864, Henneberg proposed a method with weak acid and alkali digestions, known as the Weende method, to investigate the nutrient value of food (Atwater & Woods, 1896). The nutrient values that were obtained by this long and tedious method were the following: protein, fat, carbohydrate, ash or mineral materials, and total energy. Protein was determined by multiplying the total nitrogen content by 6.25. Fat was determined by total ether extraction. Carbohydrate was obtained by the differences. Energy intake represents the number of calories of heat that one pound of a given material would yield upon combustion. The first analysis in the U.S. was completed on a series of Indian corn (Atwater & Woods, 1896).

Interest in the current problems related to nutrient intake caused the United States Department of Agriculture, the State of Connecticut, and several other institutions to investigate the nutrition composition of foods. The first series of investigations were for fish, vertebrates, and meat that was completed by Professor Atwater in the years 1878-1881 (Atwater & Woods, 1896). In 1886, Carroll D. Wright completed the first accurate investigation of chemical and economic statistics of nutrient composition (Atwater & Woods, 1896). In addition, many other analyses were completed. Combining all of these results, a database consisting of the chemical and nutrient composition of American foods was published in Bulletin 21 (Atwater & Woods, 1896). Analysis continued over the years with the most extensive analysis directed by Professor Atwater. A total of 2,600 food items, excluding milk and butter, were analyzed and compiled during this time of investigations (Atwater & Woods, 1896). Jenkins and Winton's "Compilation of Analyses of American Feeding Stuffs" was published in 1891, including analysis of grains and vegetables (Atwater & Woods, 1896).

Previous methods to assess energy intake were tedious and there was a need to develop a method that was more reliable. The bomb calorimeter determines the energy content of a substance by combustion. In 1912, Fery (Miller & Payne, 1959) proposed a method using a light bomb casing to measure heat quality ballistic, which measures the peak temperature as an accurate indication of heat released upon combustion of a food item. This method has been termed "ballistic bomb calorimeter". In 1957, Raymond, Canaway, and Harris began to use the adiabatic method. This method measures the heat produced by a small rise in temperature of a large mass of material. The advantage of this method is that its procedure is less time consuming. However, the equipment is complicated and expensive. Research has shown that the ballistic bomb calorimeter method of measuring the peak temperature is an accurate indication of heat released that can then be used to determine the amount of kilocalories in a specific food item (Miller & Payne, 1959).

B) Assessment Methods

Over the years, assessment of energy intake has evolved into a two step process. The first step requires obtaining the food and beverages consumed and the second step involves converting these records into estimates of energy intake measured in kilocalories and a myriad of nutrients. There are several methods available to obtain the food and beverages consumed. The choice of the method depends upon the primary objectives of the study and the characteristics of the study group. Although weighed dietary records theoretically provide the most accurate assessment of intake, they are not realistic with large sample sizes. Thus, assessments of energy intake rely mainly on self-report methods and are based either on recall or estimated records. Converting the food and beverages consumed into energy intakes rely on dietary assessment systems that have been created over the years. There are numerous dietary assessment systems, but this literature review will focus on the Nutritionist Pro and Nutrition Data System for Research (NDSR).

a) Methods for Assessing Intake

There are four major methods for assessing intakes (weighed dietary record, dietary record, 24-hour recall, and food frequency questionnaires). Each method will be briefly reviewed.

i. Weighed Dietary Record

A weighed dietary record consists of measuring or weighing food that will be consumed and recording the household measure or weight in ounces, grams, or pounds. It is often regarded as the “gold standard” for assessing energy intake, because of its relative precision and hence is frequently used to validate other dietary assessment methods (Gibson, 2005). However, the weighed dietary record has been challenged as the “gold standard” for energy intake assessment. Research has demonstrated that underreporting is common using this method and may be due to incomplete recording (Bathalon et al., 2000). Similarly, weighed dietary records compared to double labeled water have demonstrated that the mean energy intake reported was significantly lower than the assessed energy expenditure in both men and women (Livingstone et al., 1990). Other limitations include heavy respondent burden, likelihood of poor compliance, and cost of data entry.

ii. Dietary Record

A dietary record is a common method to assess dietary intake during a designated period of time. Duration of recording may last three to seven days or longer depending upon the study requirements. The individual is required to record both food and beverage consumption. Theoretically, recording is to be completed at the time of consumption. The amount of intake can be recorded in terms of household measures (cups, tablespoons), scale (ounces, grams), or through models and pictures. In theory, if accurate intakes are recorded, an accurate assessment of energy intake can be obtained. Individuals should be trained carefully at the level of detail needed to adequately describe the amounts of food and beverage. Additional information is critical related to the name of the food, brand names, preparation method, recipes, and portion size complete a descriptive dietary record. After completing the desired days of dietary recording, a trained interviewer reviews the record with the individual to clarify entries and probe for unreported food or beverages. The dietary record is then analyzed through a dietary assessment system to examine energy intake, macro-, and micronutrients.

The dietary record provides reasonably accurate assessment of dietary intake (Bingham et al., 1987). However, there are many limitations to this method. Dietary records involve self-monitoring and hence may affect the individual’s habitual eating patterns, thus limiting the ability to accurately assess the true dietary intake. Numerous research studies have indicated an underreporting of energy intake when using the dietary record compared to assessing actual energy expenditure. On average participants reported a 37% underestimation of energy intake compared to energy expenditure obtained by doubly labeled water in postmenopausal women (Mahabir et al., 2006). Another research study demonstrated a 20% underestimation of energy intake using records in adults and found that it is dependent on age and BMI (Hoidrup et al., 2002). Since there is high respondent burden, the reliability of the records decreases over time due to respondent fatigue. There is still debate about the number of days needed to adequately obtain habitual energy intake. It is known that weekend days and weekdays should be in proportion to each other (Tarasuk & Beaton, 1992) to a given assessment. In 1988, Bingham et al. (1988) recommended a minimum of three days to obtain energy intake consumption. Jula et al. 1999 recommended a 5-day food record consisting of Friday, Saturday, Sunday, and two of the weekdays from Monday to Thursday to accurately assess energy intake of working men and women. Conversely, other research studies have demonstrated that a dietary record consisting of all days of the week is essential to reduce the sampling bias (Maisey, 1995). Also, if the respondent is not compliant in recording at the time of consumption, the number of omitted foods or other faults will decrease the accuracy and the number of days need to be increased (Smith et al., 1991).

iii. 24-hour Recall

The 24-hour recall was originally attributed to Wiehl (1942). The protocol involves an interview procedure to collect dietary information of food and beverages consumed within the preceding day or 24-hours. The individual is required to remember and the interviewer must be trained to effectively facilitate recalls through probing questions. Time, serving size, preparation, and brand are all components that enhance the dietary assessment. Due to variation of daily energy intake, multiple 24-hour recalls should be collected during a period of time to characterize an individual’s usual intake. After analyzing a 24-hour recall through a dietary assessment system, it provides an estimation of a typical energy intake for that individual for one day.

Multiple 24-hour dietary recalls can provide excellent detail and have low respondent burden compared to other assessment methods. The correct number of 24-hour recalls is controversial. Several studies have attempted to answer this question. Many have indicated that 3, 4, 5, or 7 days are adequate (Nelson et al., 1989). One research study demonstrated that the average of energy intake from the first two 24-hour recalls was better approximation of energy expenditure in comparison to that obtained by doubly labeled water than the first 24-hour recall, and the average of the first three 24-hour recalls further improved the estimate of energy expenditure (Yunshen et al., 2009). However, additional 24-hour recalls beyond the initial three did not improve the estimate of energy expenditure (Yunsheng et al., 2009). Also, other research studies have demonstrated that the required number of recalls necessary depends upon demographic groups (Wassertheil-Smoller et al., 1993) and nutrients that are being examined (Basiotis et al., 1987). There seems to be little difference in whether the interviewer meets with the person or completes the recall through a telephone interview (Tran et al., 2000). Since the 24-hour dietary recall is completed after the person has eaten, it does not alter energy or nutrient intake patterns. A disadvantage is that they can be costly and require multiple contacts with participants to acquire a typical energy intake. The respondents' recall is dependent on memory making it harder to estimate accurate portion sizes. Along with other assessment methods, the 24-hour recall has also been prone to underreporting error when examined against energy expenditure assessment by doubly labeled water (Tran et al., 2000).

iv. Food Frequency Questionnaires

Food frequency questionnaires (FFQ) display the typical frequency of energy intake of each food group from a list of foods for a specific period of time. Thus, memory of past dietary patterns may influence present dietary patterns that the individual is assumed to be reporting. Little detail is provided related to preparation methods, brand name, and portion size. Many FFQ now incorporate questions revealing portion size (small, medium, large). The additional of portion size estimates and improved computerized self-administered questionnaires, FFQ become semi-quantitative, providing estimates of daily energy and nutrient intakes. The FFQ provides overall nutrient intake by summarizing the response of each food group and the amount of nutrients in that specific food group. FFQ are the most common dietary intake assessment tool used in large epidemiologic studies of diet and health. The National Health and Nutrition Examination Survey is one surveillance survey that utilizes the FFQ to obtain usual dietary intake over a large sample population.

FFQ are the most cost effective tool for assessing usual intake. The FFQ can be self-administered and requires a relatively short amount of time from the interviewer. Respondents' immediate energy intake patterns are not affected by the questionnaire. However, they have limitations for diverse populations and recent studies have questioned their ability to assess energy intake. FFQ have also been shown to underestimate energy intake. In a study comparing FFQ to doubly labeled water, there was a 42% underestimation of energy intake in postmenopausal women (Mahabir et al., 2006). Another study demonstrated that three different FFQ estimated calcium intake reasonably well compared to a dietary record (Sebring et al., 2007).

b) Methods to Assess Energy from Intake Data

To accurately assess food and beverage consumption it must be converted to energy intake by dietary assessment systems. The National Data Laboratory (NDL) is responsible for developing the United States Department of Agriculture's (USDA) national nutrient database. This database is compiled with a comprehensive array of 7,412 food and beverage options consumed in the U.S. (2009a). Whereas, the Canadian Nutrient File (CNF) only consists of 5,500 foods (2009b). To provide up-to-date foods and beverages consumed in the U.S., these are continually evaluated and revised. The database is the foundation for most dietary assessment systems. Therefore, it is an important database that can affect many programs that assess the energy and nutrient intake of various dietary assessment methods.

i. Nutritionist Pro

Nutritionist Pro is one of many dietary assessment systems that utilize the USDA national nutrient database. It encompasses more than 18,000 foods and ingredients including more than 500 name brands from 300 manufacturers, fast foods, and ethnic foods (2009c). In addition, it provides the ability to thoroughly assess energy intake of diets, recipes, and menus. It provides a quick view and print outs of energy intake of more 90 nutrients and nutrient factors that can be used in a variety of settings (2009c).

ii. NDSR

Thirty years ago, the Nutrition Data System for Research (NDSR) was developed by the Nutrition Coordinating Center (NCC) at the University of Minnesota. Its primary use is to investigate the relationship between dietary intake and health. The NDSR encompasses approximately 2,700 non-recipe foods and 7,000 brand names providing a total of 153 nutrients. The USDA national nutrient database serves as the primary resource for this nutrient database. An optional dietary supplement assessment module (DSAM) may be used, which is a modified version of the NHANES dietary supplement database.

Assessment of Energy Expenditure

Since energy expenditure is a component of energy balance, the assessment of energy expenditure is necessary to evaluate energy balance. It also may be used to identify physical activity patterns within individuals. A variety of methods have been developed over the years, but there is still a debate about which assessment technique is most reliable, accurate, and suitable for various populations.

Total energy expenditure refers to an individual's entire energy output. It is mainly composed BEE, TEF, and EEPA. This total amount of energy expenditure is measured in kilocalories (kcal) or kilojoules (kJ). Physical activity has been defined as “any bodily movements produced by skeletal muscles that result in caloric expenditure” (Caspersen et al., 1985). Physical activity can increase or decrease the total energy expenditure and varies greatly among individuals. There are many different methods used to assess energy expenditure, but each of them has both advantages and inherent disadvantages (Welk, 2002). This section will review these methods and describe the advantages of the SenseWear Pro 3 armband monitor for the present study.

A) Background on Methods

There are many methods available for assessing physical activity, but emphasis here is on indirect calorimetry, doubly labeled water, and accelerometry. Indirect calorimetry is used for laboratory measurements and cannot be used to estimate energy expenditure over extended periods of time. A biochemical method known as doubly labeled water is often used as the “gold standard” for assessing free-living energy expenditure. However, it is expensive to perform and only quantifies overall energy expenditure during a period of days without providing estimates for particular activities. Accelerometers have been created and validated against indirect calorimetry and doubly labeled water to minimize these disadvantages. Accelerometry-based activity monitors have emerged as a compromise between accuracy and feasibility.

B) Methods for assessing energy expenditure

There are three methods for estimating expenditure (indirect calorimetry, doubly labeled water, and accelerometry) that will be addressed in this literature review. Each method will be briefly reviewed, followed by an in depth review of a specific accelerometer, the SenseWear Pro 3 activity monitor.

a) Indirect Calorimetry

It has been known for many years that breathing is required by living mammals to remain alive. However, the physiological function remained unclear until in the 1600s when scientists began to investigate the importance of respiration. In 1757, Joseph Black discovered carbon dioxide and in 1774 Joseph Priestly discovered oxygen. Lavoisier and Seguin then discovered that animals and humans consume oxygen and produce carbon dioxide. They continued to investigate this issue by confining humans in a chamber to measure their oxygen consumption and carbon dioxide expiration. They discovered that larger people consume more oxygen, at rest one consumes less oxygen than those standing, and oxygen consumption increases after ingesting a meal (Speakman, 1998). These discoveries lead to the method of indirect calorimetry that has been continually enhanced throughout the years and has made it possible to validate other energy expenditure assessment methods that are used today to assess free-living individuals.

Indirect calorimetry measures oxygen consumption and carbon dioxide production using respiratory gas analysis to ultimately estimate energy expenditure. In the past, a closed-circuit design was used to measure the rates of oxygen consumption and carbon dioxide production by the change in pressure within the closed apparatus. Later, the open-circuit design became more common in clinical and research settings. New devices have recently been created to replace expensive, cumbersome traditional devices. This method is based upon the relationship that expending one kilocalorie requires 208.06 milliliters of oxygen. This in turn can be used to calculate resting metabolic rate (RMR) and TEF.

In 1911, Douglas created a method to determine the respiratory exchange in men with the use of a rubber-lined cloth (Douglas, 1911). Similar to previous results, Shephard (1995) revealed that the Douglas bag technique suffered from carbon dioxide seeping out of the bag due to the solubility through the pores. This device illustrates limitations that may arise with this technique, a method of validating other calorimeter devices and provided the beginning to new indirect calorimetry devices.

To validate indirect calorimetry, artificial ventilation was used where combustion of a weighed solvent, such as butane (Nunn et al., 1989) or methanol (Miodownik et al., 1998), is burned downstream. The closed-circuit method has been shown to produce no significant difference in oxygen consumption or carbon dioxide output measurements (Nunn et al., 1989). In 2000, Miodownik and his colleagues developed a device upon the Douglas bag technique that measured gas exchange continuously and, compared to artificial ventilation of methanol, it was shown to precisely measure carbon dioxide production (Miodownik et al., 2000). Another method to validate indirect calorimetry is by comparing the newer devices to older valid calorimetery methods, such as the Douglas bag technique. The Douglas bag technique is occasionally referred to as the "gold standard" indirect calorimeter, because it measures each variable independently through calibrated instruments (McDoniel, 2007). One example of this is the new handheld MedGem/BodyGem. This device was examined against the Douglas bag technique and was not significantly different displaying an average mean RMR difference of 1% in adults over a range of studies (McDoniel, 2007). Over the years there have been improvements related to the design of indirect calorimeters. Despite the availability of portable "backpack" units, there are still limitations in using this technique for assessment of free-living individuals.

b) Doubly Labeled Water

In the 1920s and 1930s, isotopes were discovered for hydrogen and oxygen that could be used to outline their behaviors within the body. As scientists continued to investigate these isotopes, they came to the conclusion that the difference between these two isotopes, giving rise to its name doubly labeled water (DLW), could estimate the amount of carbon dioxide (CO_2) elimination and ultimately energy expenditure. Several years passed before Lifson and his colleagues (1955) introduced an effective DLW method in 1955. Lifson et al. demonstrated a 7% ± 7 difference between CO_2 calculated from DLW and CO_2 obtained via a metabolism chamber in mice (Lifson et al., 1955). When taken into account algebraically, the average difference was -3% ± 10. Overall, Lifson (1995) concluded that the DLW method provided a reasonable assessment to calculate the rate of CO_2 production and ultimately energy expenditure (MJ/day).

The DLW technique requires individuals to ingest two isotopes, deuterium (^2H_2O) and $H_2{}^{18}O$. As the individual continues normal living activities, these isotopes equilibrate with bodily fluids and are eliminated from the body in proportion to CO_2 production. Urine collections are obtained throughout the designated length of time to assess energy expenditure, which is typically 7-14 days. The difference in loss between the two isotopes is analyzed in the obtained urine, blood, or saliva samples and measured by mass spectrometry, which provides a direct measurement of the rate of CO_2 production and an indirectly an accurate assessment of energy expenditure (MJ/day).

While the first DLW study was conducted in 1955, DLW was not used in humans until the late 1970’s. Schoeller and van Saten (1982) investigated the validity of DLW against assessed energy intake plus change in body composition and water output in 4 human adults during a 13 day period, demonstrating an average difference of 2.1% in energy intake and 1% in water output. Two years later Schoeller published another study related to the validity of the DLW method against respiratory gas exchange and reported a 6% greater energy expenditure for the DLW method (Schoeller & Webb, 1984). The DLW method during this time was also shown to be an accurate method during low and high activity levels (Westerterp et al., 1988).

Over the years, DLW has become a highly valuable and valid energy expenditure assessment method. For this reason many scientists refer to DLW as the “gold standard” for assessing energy expenditure in free-living individuals (Schoeller & van Saten, 1982; Welk, 2002). With its ability to assess energy expenditure in free-living individuals, DLW has been used in numerous studies to validate other energy expenditure assessment methods and energy intake methods. DLW is not without limitations. A review article, Speakman (1998), found the average precision to be ~10% overestimation between the validations comparisons of DLW and indirect calorimetry between the years 1982 and 1996. Also, it requires expensive stable isotopes, highly trained laboratory staff, and expensive mass spectrometry equipment, all of which are all highly expensive. Therefore, DLW is typically only utilized with small sample sizes. In addition, DLW only has the ability to assess extended amounts of periods, 7 or 14 days. A primary limitation of DLW is that it cannot provide energy expenditure for individual activities. Overall, the DLW method is not perfect, but it provides a reliable and accurate assessment of energy expenditure.

c) Accelerometry

Over the years, accelerometers have become a popular and effective method for assessing physical activity and energy expenditure. They can detect the intensity of physical activity and store minute by minute data over days and even weeks. In 1959, Schulman and his colleagues developed one of the first accelerometers. This accelerometer used a wristwatch rotor that changed in position based on vertical acceleration (Schulman & Reisman, 1959). As years past, accelerometers became more advanced using sensors that consisted of piezo-resistive or piezo-electric sensors. Accelerometers have made it possible to assess energy expenditure patterns during free-living conditions. These devices have become popular, because they are objective and have the ability to indicate body movements, intensity, frequency, and duration of the activity.

There are numerous activity monitors available to assess free-living energy expenditure. The validity and depth of information that each provide varies, as well as their cost. In general, many of these devices have practicality and accuracy limitations. Many of these devices are unable to accurately assess non-ambulatory activities and the intensity change in activities. The computer science and applications (CSA) activity monitor is one of the most widely used. It is a uni-axial highly sensitive piezo-electric accelerometer that assesses acceleration in vertical plane. Compared to indirect calorimetry under laboratory conditions, this device accurately assesses energy expenditure (Welk, 2000). However, for field based conditions it underestimates energy expenditure by 59% compared to indirect calorimetry (Welk, 2000). Similar results demonstrated that CSA, Tritrac, and Yamax significantly underestimated free-living energy expenditure against DLW in women (Leenders et al., 2001). The Manufacturing Technology Inc. (MTI) formerly made by CSA uses counts x min^{-1} to establish regression models that derive activity cut points used to relate light, moderate, and vigorous activity to energy expenditure. Many regression equations have been used by different laboratories. All have been shown to provide different predictions in time spent in physical activity intensities, and large individual error for different devices (Strath et al., 2003). This may be due to the limitation that accelerometers cannot detect upper body work and external work, such us inclined walking. In particular, accelerometers have been shown to underestimate time spent in light intensity activities (Strath et al., 2003). Overall, accelerometers have the ability to assess free-living energy expenditure, but have some limitations.

i. Sensewear Pro 3 Activity Monitor

There are numerous accelerometers available. However, one in particular stands out among the others. Body Media Inc. has created the SenseWear Pro 3 armband (SWA) monitor to assess energy expenditure in a free-living environment that is more effective and minimizes the limitations of previous accelerometers. The SWA monitor is an advanced monitor that uses pattern recognition technology to assess physical activity and estimate energy expenditure. Its unique software program integrates energy intake with energy expenditure to allow one to assess energy balance and may play a role in self-monitoring to motivate individuals to live an active and healthy eating lifestyle.

a. How It Works

The monitor is comfortably worn on the back of the upper arm. It has a unique advantage from any other activity monitor in that when worn it simultaneously measures five different variables that collectively estimate energy expenditure in calories continuously throughout the day. These five measurements are skin temperature, near body ambient temperature, heat flux, galvanic skin response, and motion via a 2-axial accelerometer. It has a built-in thermostat based sensor to measure the surface temperature of the body. Near body ambient temperature measures the air temperature around the armband to reflect temperature changes in the environment. Heat flux measures the rate at which heat is dissipating from the body. This sensor does this by using the difference between the skin temperature and the near body ambient temperature. Galvanic skin response is measured by the electrical conductivity between two points on the individual’s arm. The skin’s conductivity is affected by sweat gland activity from physical activity and emotional stimuli. Motion is measured via a built in 2-axis microelectro-mechanical sensor (MEMS). These five measurements combined with age, gender, and body parameters are incorporated into an algorithm to calculate the output of total energy expenditure, active energy expenditure, physical activity duration, and level displayed as metabolic equivalence, and sleep duration and efficiency.

b. Weight Management System

One unique advantage of the SWA monitor is that in addition to assessing energy expenditure, it has an associated dietary assessment system called the Weight Management System (WMS). This tool has the ability to assess the amount of energy intake in kilocalories one consumes based on a self-report dietary recall. Similar to Nutritionist Pro, this program is based on the USDA national nutrition database. The WMS provides a detailed report containing each food entry related to its kilocalories, carbohydrates (g and %kcal), fat (g and %kcal), and protein (g and %kcal). The WMS creates another report that integrates the SWA energy expenditure assessment with an assessment of energy intake to evaluate one's energy balance on a daily basis and during the course of the week. This allows one to self-monitor his/her energy balance, which may ultimately create awareness and motivation to develop a healthier lifestyle and help prevent obesity.

c. Advantages

This powerful monitor is small, easily applied, risk-free, and comfortably worn on the back of the upper arm. It can be worn in virtually all environmental conditions, except water, and is non-invasive and wireless, which allows it to capture typical daily energy expenditure throughout the day without limiting activity. Unlike other accelerometers, the SWA measures heat production caused by all forms of energy expenditure ,such as various types of physical activity. This allows for the distinction between different intensities of physical activity. Most standard accelerometer-based monitors only detect body motion and hence do not provide good assessment of lower intensity activities of daily living that do not involve much motion. With this advantage, the SWA minimizes many limitations present in other accelerometers. It can assess energy expenditure related to both upper and lower energy expenditure, degree of load, and non-ambulatory energy expenditure. The SWA also contains a memory space of up to 10 days, which allows individuals to self-monitor their daily activities during a course of time and allows health care professionals to do the same and evaluate their client's compliance in wearing the armband. The enhanced functionality through the associated WMS allows the SWA monitor to function as a lifestyle-base weight management tool. Improving awareness about energy balance may help individuals make lifestyle changes and prevent unwanted weight gain. The coordinated used of the SWA and WMS, along with appropriate dietary and physical activity counseling, may provide an effective tool for coordinated weight loss programming.

d. Validity

Many research studies have supported the validity of the SWA monitor for assessing free-living energy expenditure during rest and exercise in healthy subjects. Fruin et al. (2004) demonstrated a high agreement and high correlation between the SWA and indirect calorimetry during rest and exercise in lean and overweight subjects. King et al. (2004) reported that the SWA yielded accurate assessment of energy expenditure during various treadmill speeds. Of the five physical activity monitors evaluated in the study, the SWA provided the best assessment of total energy expenditure at most speeds. However, during exercise periods, an exercise-specific algorithm should be used in order for the SWA to provide an accurate assessment of energy expenditure (Jakicic et al., 2004). The SWA has also been shown to have no significant difference and a high correlation ($r = 0.86$) in assessing resting energy expenditure in healthy individuals compared to the Sensor Medics Vmax metabolic cart (Malavolti et al., 2007). St-Onge et al. (2007) also evaluated the accuracy of the SWA compared with DLW and reported a reasonable concordance based on an intraclass correlation of 0.81 ($P < 0.01$). The SWA was also shown to have good overall agreement with the Intelligent Device for Energy Expenditure and Activity (IDEEA) during a field based study, displayed a moderate individual minute-by-minute correlation ($r = 0.76$) (Welk et al., 2007). From this study, the authors concluded that the SWA and the MTI Actigraph were the two most accurate indicators of physical activity. In the same lab two years later, Calabro and Welk (2009) reported no significant difference among the 24-hour physical activity recall, IDEAA, and SWA assessment of total energy expenditure and time percentages for physical activity intensity. Calabro and Welk (2009) also demonstrated no significant difference in assessment of energy expenditure among the SWA, SenseWear Pro minifly (Body Media Inc. newer version), and DLW in 30 healthy individuals during 14 consecutive days (Calabro & Welk, in press).

Additionally, within healthy subject, the SWA has shown promise with use in the clinical population. One study evaluated the SWA in type 2 diabetic patients and noted no significant different in energy expenditure between the SWA and DLW, a high correlation (r = 0.97, P = 0.0014) and an intraclass correlation coefficient reaching 0.96 (Mignault et al., 2005). In overweight individuals, the SWA has been shown to have very high correlation and very good agreement compared to indirect calorimetry (Papazoglou et al., 2006). In obese individuals, the repeatability of the SWA to assess energy expenditure compared to indirect calorimetry is also high ($r = 0.88$, $p < 0.001$), but the SWA generally underestimates resting energy expenditure and overestimates energy expenditure during exercise (Papazoglou et al., 2006), indicating a need to develop new algorithms specific to obese individuals. This literature demonstrates the ability of the SWA in the clinical population to assist in monitoring appropriate levels of daily energy expenditure, which is important to prevent future complications related to weight gain.

To our knowledge, the SWA integrated with the WMS to assess energy balance has not yet been examined. In addition, the WMS dietary assessment system has not yet been compared with other dietary assessment systems, such as Nutritionist Pro, or examined against energy expenditure assessment during weight stable conditions. These comparisons are important to address the utility of the SWA integrated with the WMS to assess energy balance and further improve the WMS dietary assessment system, which is a promising device to assist individuals with weight and obesity issues.

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CHAPTER 3. UTILITY OF THE SENSEWEAR PRO 3 MONITOR AND THE WEIGHT MANAGEMENT SYSTEM FOR EVALUATING ENERGY BALANCE IN ADULTS

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Abstract

The progression of the obesity epidemic stems directly from the inability of individuals to achieve a balance between energy expenditure (EE) and energy intake (EI). To enhance research on obesity prevention it is important to develop and validate instruments that can facilitate monitoring of energy balance (EB) under free-living conditions. The SenseWear Pro 3 armband (SWA) monitor and associated weight management system (WMS) offer promise as a non-invasive method suitable for energy balance research. The primary purpose of the study was to evaluate the utility of the SWA and WMS to assess EB during a week of free-living activity. A total of 68 healthy adult participants (31 male and 37 female) wore the SWA monitor for a week while recording a detailed 7-day dietary food record. Estimates of EE were obtained directly from the SWA software. Estimates of EI were obtained by entering the dietary food records into both the Nutritionist Pro and the SenseWear WMS dietary assessment systems. The estimated EB (EI-EE) was compared with the observed EB (obtained from fasted weight measures taken at the beginning and ending of the study). Differences in EB values (observed – estimated) were statistically tested using standard t-tests. A secondary purpose was to compare the assessed EI between Nutritionist Pro and SenseWear WMS. A mixed model analyses of variance was used to evaluate the difference between EI values as well as macronutrient intakes of carbohydrate, fat, and protein. Results indicated that participants lost weight during the week long protocol (mean weight loss = -0.5 ± 1.6 lbs) without an apparent intention to lose weight. Similarly, estimated EB was significantly different than zero, indicating a negative EB (weight loss).

Difference in weight difference (observed – estimated) was positive (difference = 0.9 lbs ± 2.0), indicating a significant overestimation of weight loss ($p < 0.001$). Supplemental analyses indicated that individuals completing more detailed dietary records had a significantly higher weight loss than those providing less detailed records. More interestingly, individuals providing high quality dietary records had a small (non-significant) average EB difference (difference = -0.03 ± 1.4 lbs, $p = 0.09$) while individuals providing poor quality records had large EB differences (difference = 2.0 ± 1.0 lbs, $p < 0.001$). Collectively, this suggested that the estimates of EB from the WMS are accurate when participants provided detailed dietary records. Correlations between nutrient intake (EI, protein, carbohydrate, and fat) assessments (SenseWear WMS vs. Nutritionist Pro) were high for all comparisons (range: $r = 0.93$ to 0.99). The estimates of EI from the two dietary assessment systems were not significantly different ($p = 0.07$) and the gender by method interaction was also not significant ($p = 0.32$). Similar results were noted for macronutrient comparisons; however, a significant gender by method interaction was evident for protein ($p = 0.048$). In conclusion, the SWA monitor with its integrated WMS demonstrated promising attributes for assessing EB in free-living individuals.

Key Words: activity monitors, energy balance assessment, dietary assessment system

Introduction

The obesity epidemic is one of the leading health challenges facing the nation. Within the last 10 years, the prevalence of overweight (37.4%) and obesity (27.7%) has increased by 36% (BRFSS, 2007). Basic principles of energy balance suggest that weight gain will occur when energy intake through the diet exceeds the amount of energy expenditure through physical activity (Dietz, 1983; Uauy & Diaz, 2005; Hill, 2006). To enhance obesity prevention efforts, it is important to investigate the utility of devices capable of assessing energy balance (EB). One of the challenges in this line of research is that it is difficult to accurately assess energy intake (EI) and energy expenditure (EE).

There are a variety of instruments to assess the consumption of EI, but self-report instruments are the most common and widely used in research. Weighed dietary records theoretically provide the most accurate assessment of intake, but are not feasible in most research studies. Participants typically recall or record foods that were eaten and these data are entered into dietary assessment systems to assess EI. Research has demonstrated many limitations in EI assessment methods. One consistent limitation is the underestimation of EI using in weighed dietary records (Livingstone et al., 1990; Bathalon et al., 2000), dietary intake records (Hoidrup et al., 2002; Mahabir et al., 2006), 24-hour recalls (Tran et al., 2000), and food frequency questionnaires (Mahabir et al., 2006). This may be due to a variety of issues such as respondent fatigue (Bathalon et al., 2000), variations in BMI and age (Hoidrup, 2002) and incomplete records (Smith, 1991).

There are also numerous instruments available for assessing EE. Self-report instruments are among the most common, but researches have increasingly relied on the use of objective accelerometers to obtain more accurate assessments. Doubly labeled water (DLW) is considered the "gold standard" to assess EE, but it is expensive and quantifies EE over a period of days (Welk, 2002). Accelerometers have evolved and been validated against DLW to provide objective daily EE assessment during free-living conditions. Although these devices are promising, there has been a consistent demonstration that these devices underestimate EE (Leenders et al., 2001; Welk, 2002), especially during time spent in light intensity activities (Strath et al., 2003).

The inherent challenges associated with assessing EI and EE have made it particularly difficult to accurately assess EB. Integrated tools that assess both EI and EE offer promise for improving the understanding of EB. A commercially available device known as the SWA monitor (Bodymedia Inc.) offers considerable promise for advancing EB research in free-living individuals. The SWA is a comfortable, non-invasive physical activity monitor that is worn on the upper arm. An advantage of the SWA monitor is that it automatically detects non-wear time and can provide accurate assessments of free-living physical activity and EE when worn over multiple days. A unique aspect of the SWA is that, in addition to assessing EE, it has an associate software tool called the WMS. This software integrates EE data with a comprehensive dietary assessment system to provide information about EI and EB. The ability to track and monitor EB over time may help individuals learn to modify dietary and physical activity habits to facilitate weight maintenance or weight loss. Previous research has demonstrated the validity of the SWA monitor during rest and exercise against indirect calorimetry (Fruin & Rankin, 2004; Malavolti et al., 2007) and DLW (St-Onge, 2007; Calabro & Welk, in press). However, to date no study has examined the utility of the SWA monitor integrated with the WMS software tool for assessing EB.

The purpose of this study was to examine the agreement between reported and observed EB during a 7-day period using the SWA monitor and WMS. A secondary goal was to compare the EI assessment from the WMS with associated assessment from a more established dietary assessment system called Nutritionist Pro. It was hypothesized that EI and EE would vary on a daily basis, but would average out during the week for individuals who remained weight stable during the 7-day period. It was also hypothesized that the WMS and Nutritionist Pro would yield similar assessments of EI.

Methods

Participants

Healthy participants were recruited through internal communication and posting throughout the community. Inclusion criteria included males and females who had an age between 18 and 50 years of age and have a BMI between 18.5 and 30. Individuals using electromagnetic medical equipment or portable oxygen were excluded because of incompatibility with the SWA monitor. Other exclusion criteria included thyroid disease, postmenopausal status, or a history of anorexia nervosa or bulimia nervosa. Individuals who agreed to participate signed the informed consent documents and a total of 72 participants were enrolled in the study. Data from 4 participants were excluded due to missing data (n= 1), broken armband (n=1), or poor compliance (n=2). A total of 68 participants (31 males and 37 females) completed the study protocol and were included in the analyses. The study was conducted at the Iowa State University Nutrition and Wellness Research Center - Research Park and all procedures were approved by the Institutional Review Board.

Procedures

Participants were scheduled for individual appointments and reported to the lab in a fasted state (10 hours). Participants completed a general health history questionnaire upon arrived at the lab. Their height (cm) and weight (kg) were measured using a wall mounted (Ayrton Model S100, Prior Lake, MN) stadiometer, and laboratory scale (Cardinal/Detecto, Webb City, MO) for calculation of BMI. Body fatness was estimated with a portable Bioelectric Impedance Analyzer (Omron, Vernon Hills, IL). Resting blood pressure was measured following standard procedures using an automated monitor (Omron HEM-907XL, Vernon Hills, IL). After completing these measures, participants were instructed in how to use the SWA monitor and how to record their dietary intake using a paper and pencil food log. The SWA monitor was initialized using the Sensewear Pro WMS website and placed on the participant’s upper right arm. Participants were instructed to wear the armband at all times and record their 7-day food intake in this dietary intake record book.

At the end of the week, participants returned to the lab (once again in a fasted state) and turned in their monitor and their 7-day dietary record. Their height and weight was measured again using the same procedures and with the same type and amount of clothing (e.g. shorts and t-shirts) to minimize measurement error. Participants were asked about their week of monitoring to assess the degree of compliance with the study protocol. They were asked to provide information about times that they may have taken off the monitor. Participants were also asked to fill in gaps in their dietary intake records and to comment on their compliance in completing the dietary intake record.

Participants were provided with the opportunity return for a third visit to review summary reports of their weekly activity and dietary intake. This visit involved the project coordinator going reviewing their individual results and answering questions that participants may have had related to their physical activity or diet.

Data Processing

Participants' 7-day dietary records were entered by the same investigator into two dietary assessment systems, the WMS and Nutritionist Pro software (4.1 Version, Axxya Systems, Stafford, TX). Dietary records were first entered into the WMS and then Nutritionist Pro with standard procedures being used. If the brand was available in the dietary record, the investigator choose the food item with the same brand in both dietary assessment systems. However, not all brand names are available in these systems, so the investigator had to subjectively choose a similar generic food item. Some brand name items do not contain a complete nutrition profile and may not have a similar generic food item. In this case, the main components of the item were entered individually. For example, General Mills Gardetto's are not available in both WMS and NP and there is no similar generic food item containing all components. Thus, three main components (hard pretzels, hard sesame bread sticks, and melba toasts) were entered in the appropriate amounts to closely reflect this product. This technique has been used in other dietary assessment systems, but is very labor-intensive (Perloff et al., 1990). After entries of dietary records were completed in both dietary assessment systems, detailed reports were created that included the assessment of energy, macronutrients, and micronutrients. For the purpose of the study, only energy and macronutrient intake were evaluated, because the WMS does not assess micronutrients.

Additional analyses were conducted in the study to determine whether the quality or detail of the dietary record could impact the results. Prior to beginning the analyses, the dietary records were coded for quality using a simple 3 point scale (3= best, 1= worst). The same investigator rated all dietary records and dietary records were blinded so that the investigator was not aware of whose record was being rated. Objective rating criteria were employed to ensure consistent coding. Records rated as a 3 generally had all amounts (ie: 1, 2, 3), units (ie: ounces, cups, tablespoon), and brand names (ie: Kraft, Sunbelt, Skippy) provided with adequate details about preparation (ie: baked, fried, steamed) provided when needed. In comparison, records rated as a 1 typically provided amounts and units, but provided little or no information about brand names or preparation methods. A rating of 2 was used to code dietary records with quality between a rating of 3 and 1.

The SenseWear Pro WMS website has the advantage of merging dietary intake assessment with the assessment of EE from the SWA. The SWA monitors were uploaded to this website and the EE estimates were automatically merged with the EI estimates. This dataset was exported and merged with the separate NP dataset to produce the final dataset.

Data Analysis

Descriptive statistics (mean and standard deviations) were computed to characterize the sample population. Simple t-tests were used to test for gender differences in age, height, weight, BMI, and body fat. Gender differences were also examined for three indicators of physical activity level (physical activity minutes per day, average step counts per day, and average METs per day) to characterize the activity patterns of the sample.

The primary statistical analyses involved evaluating differences between actual EB and estimated EB for both males and females. Observed EB was calculated simply by subtracting the participant’s weight at baseline from their weight at the end of the week. Estimated EB was computed by first determining the total difference in energy over the week [estimated EB = weekly EI (kcal) - total weekly EE (kcal)] and then dividing by 3500 (the calorie equivalent for a pound of fat) (2009a). The two EB equations were matched so that a negative EB value would reflect loss in body weight. Differences in EB values were computed by subtracting the estimated EB from the observed EB (differences in EB = observed EB – estimated EB). A positive difference in EB value would reflect an overestimate of weight loss. Differences in weight loss, BMI change, and body composition (%fat) change were evaluated with standard t-tests. Gender differences in BMI change, body fat change, and weight loss were examined with one-way analysis of variance (ANOVA).

A secondary goal was to evaluate possible differences in estimated nutrient intakes from the two different dietary assessment systems. Pearson product moment correlations were computed to reflect overall agreement among the key outcome measures (EI, carbohydrate intake, fat intake, and protein intake). Differences in estimates of EI (as well as carbohydrate, fat, and protein) were evaluated using a mixed model analyses of variance to account for the fact that the comparisons are based on the same raw diet log. The models (run in SAS 9.0) used participant within gender as person-level random effect terms and the residual variance was a second random effect term. The fixed effects included in the models were Gender and Method (Nutritionist Pro versus WMS) as well as the corresponding two-way interactions (gender by method). Standard F-tests were used to determine if estimates from the two versions were statistically significant from each other. Least squares means and standard errors for all effects were estimated under the model and are reported in the tables.

Results

Descriptive Outcomes

The physical characteristics and EE results for the 68 subjects (n= 31 male and 37 female) included in data analysis are shown in Table 1. Values in the table represent mean ± standard deviation for age, height, weight at visit 1 (weight-baseline), BMI at visit 1 (BMI pre), and body fat percent at visit 1 (body fat percent pre). The physical characteristics are typical for healthy adult males and females. Female subjects had significantly lower ($p < 0.05$) values for height, weight, BMI, and body fat percent. There were non-significant differences (p = 0.42) in average daily steps between males (11,066 ± 3,216) and females (11,677 ± 2,968). However, significant differences (p = 0.026) in average physical activity minutes per day were observed between males (185.1 ± 109.1) and females (137.9 ± 55.0). The average daily MET value over the entire week was 1.61 ± 0.21; males (1.64 ± 0.26) and females (1.59 ± 0.17) did not differ (p = 0.35). Figure 1 illustrates the allocation of time spent in sedentary, moderate, and vigorous physical activity levels for the combined sample (as well as separately by gender). Sedentary (1-1.5 METs) and light (1.5-3 METs) physical activity levels accounted for the bulk of the day, 58% and 31%, respectively, for all participants. This was followed by 10% of moderate (3-6 METs) and 1% of vigorous (>6 METs) physical activity for all participants. Average male and female percentages were similar.

Evaluation of Energy Balance

The observed EB value was calculated by subtracting the post-weight from the pre-weight so this value reflects the actual weight lost or gained. As shown in Table 2, participants, on an average, lost approximately a half a pound during the course of the week despite not receiving prompts, recommendations, or efforts to promote weight loss (mean weight loss = -0.5 ± 1.6 lbs). This change in weight (negative EB) was statistically significant (t = -2.35, p = 0.02). However, there was no significant changes in BMI (mean change = -0.1 ± 0.3 kg/m^2), but a significant change in percent body fat for all participants (mean change = -0.4 ± 1.5 % fat). The changes were consistent by gender, as there were no significant gender differences in either BMI change (p = 0.84) or body fat change (p = 0.39) across the week.

The estimated EB value was computed by dividing the total difference in energy [EI (kcal) – EE (kcal)] by 3500 (the calorie equivalent for a pound of fat). The estimated EB value was significantly different than zero for both males (-1.4 ± 1.1 lbs, p < 0.001) and females (-1.0 ± 1.1 lbs, p < 0.001). With males and females combined (see Table 2), the results suggested that participants on average should have lost about 1.17 pounds during the course of the week (mean estimated EB = -1.17 lb ± 1.10).

The difference in EB values was computed as the difference between the observed EB and the estimated EB values. The difference in EB value was positive (difference = 0.7 ± 1.7 lbs), indicating that the WMS overestimated weight loss compared to the actual weight loss ($p < 0.001$). This can be reflective of either an overestimation of EE or an underestimation of EI (or a combination of both). Similarly results were observed when using Nutritionist Pro software, with a significant difference in weight difference for males ($p < 0.035$) and a trend in females ($p < 0.064$), but no differences between males and females.

Supplemental analyses were conducted to evaluate the impact of dietary record quality on results. Before data analyses were completed, the investigator subjectively rated each of the participants' dietary records on a scale of 1 (worst) to 3 (best). A total of 31 participants had a rating of 3, 18 had a rating of 2, and 19 had a rating of 1. Examination of results revealed that participants with a rating of 3 had a greater average weight loss (-0.8 lbs ± 1.6), while participants with a rating of 1 had a lesser average weight loss (0.2 lbs ± 1.1). A two way (gender x diet rating) ANOVA was conducted to examine the differences. The overall F test was not significant [$F(3,64) = 2.08$, $p = 0.11$], but the main effect for diet rating approached significance ($p = 0.053$). The differences in observed weight loss across the three diet rating groups are shown in Figure 2.

More interestingly, participants who turned in high quality dietary records (rating of 3) had a small (non-significant) average difference in EB values (mean EB difference = -0.03 ± 1.42 lbs, $p = 0.09$). A two way (gender x diet rating) ANOVA was also conducted on this outcome measure. The overall F test was significant [$F(3,64) = 7.71$, $p < 0.002$] and the main effect for diet rating was also statistically significant ($p < 0.001$). The differences in EBdiff values across the three diet rating groups are shown in Figure 3. Similar results were observed when the comparisons were based on data from the Nutritionist Pro software. The pattern was also consistent for both males and females.

Plots showing the difference in EBdiff values for both dietary assessment systems are provided in Figure 4 (males) and Figure 5 (females).

There were clear gender differences in the quality of the logs. Approximately 59% of females (22 of 37) turned in high quality records whereas only 29% of males (9 of 31) were rated as high quality. To examine this in greater detail, an additional two way (gender by diet rating) ANOVA was run on the energy balance outcome. The results revealed non-significant gender main effects and no gender by diet rating interaction. The main effect for diet rating was significant [$F(2,64) = 11.29$, $p < 0.001$] and post hoc analyses revealed significant differences between group 1 and 2 and group 1 and 3. Collectively, this suggested that the difference between the EBest and EBobs was only significantly different from zero when participants turned in very poor diet records.

Comparison of Dietary Intake Estimates

Correlations between estimates of nutrient intake were high for all comparisons (range: $r = 0.93 – 0.99$). The correlation for EI estimates was high for both males ($r = 0.96$) and females ($r = 0.94$). Consistent correlations were also observed for estimates of macronutrients. The correlation for dietary protein was high for both males ($r = 0.99$) and females ($r = 0.98$). The correlations were also high for dietary fat (males: $r = 0.94$; females: $r = 0.94$) and dietary carbohydrate (males: $r = 0.94$; females: $r = 0.93$).

Direct comparisons were made between dietary intake estimates computed from the WMS and Nutritionist Pro software. Table 3 includes EI (kcal) values for both dietary assessment systems. The data were produced using the same diet records so comparisons reflect differences in the dietary assessment systems and qualification methods in each software tool. For EI, significant main effects were observed for gender [$F(1,66) = 14.09$, $p < 0.001$)]. The average EI was higher for males (2553 ± 108) than females (2004 ± 99), indicating differences in EI. However, the focus of the analyses were on the agreement between the two dietary assessment systems. Hense, emphasis was placed on method effects and gender by method interactions. The main effect for the method comparison was not significant [$F(1,66) = 3.46$, $p < 0.067$)]. Average EI values were slightly higher for the Nutritionist Pro (2300 ± 74) than the WMS (2257 ± 74), but this difference is not biologically meaningful. Importantly, there was no gender by method interaction [$F(1,66) = 1.02$, $p < 0.32$]. Figure 6 demonstrates that these results indicated that the two different dietary assessment systems worked similarly for males and females.

Additional analyses were conducted for each macronutrient to examine the agreement between the two dietary assessment systems in more detail. Similar to the EI analysis, emphasis was placed on the method effect rather than gender differences in dietary intakes. All macronutrients were assessed in grams. Table 3 includes macronutrient (g) values for WMS and Nutritionist Pro. There were no significant method effects for carbohydrate [$F(1,66) = 0.11$, $p < 0.74$], fat [$F(1,66) = 1.65$, $p < 0.20$] and protein [$F(1,66) = 0.53$, $p < 0.47$]. The gender by method interaction was not significant for carbohydrate [$F(1,66) = 0.34$, $p < 0.56$] and fat [$F(1,66) = 2.24$, $p < 0.14$], but a trend in interaction was observed for protein [$F(1,66) = 4.08$, $p < 0.05$].

Discussion

The primary purpose of this study was to evaluate the utility of the SWA monitor and associated WMS to estimate EB under free-living conditions. The design made it possible to directly compare the estimated EB from the SWA (EI-EE) with actual EB assessed by measuring body weight change. The estimated EB from the WMS (and Nutritionist Pro) suggested that participants should have lost 1.2 pounds during the course of the week, but the actual average weight loss during the course of the week was about 0.5 pounds.

This difference can be explained in a variety of ways, but the error can be categorized as either random or systematic error. The observed EB difference could result from an overestimate of

EE, an underestimate of EI, or a combination of both. It is not possible to determine the relative source of error, but a number of validation studies have supported that the validity of the SWA to assess free-living EE. Fruin et al. (2004) demonstrated good measurement agreement between the SWA and indirect calorimetry during rest and exercise in lean and overweight subjects. The SWA has been shown to provide accurate estimates of resting energy expenditure in healthy individuals (Malavolti et al., 2007). St-Onge et al. (2007) evaluated the accuracy of the SWA compared with DLW and reported a reasonable concordance for estimates of total EE based on an intraclass correlation of 0.81 ($P < 0.01$). Calabro and Welk recently demonstrated that the SWA yielded accurate estimates of total EE compared with corresponding estimated from DLW. While there is still considerable individual variability, the results of these studies support the validity of the EE estimates from the SWA.

In contrast, the literature on EI assessment indicate that sources of random and systematic error typically result in an underestimation of EI relative to weighed dietary records (Livingstone et al., 1990; Bathalon et al., 2000), dietary intake records (Hoidrup et al., 2002; Mahabir et al., 2006), 24-hour recalls (Tran et al., 2000), and food frequency questionnaires (Mahabir et al., 2006). Research has demonstrated that a variety of issues can cause this underestimation. It is may be evident that physical and psychological characteristics of individuals play a key role in the underestimation of EI (Trabulsi and Schoeller, 2001). Factors that have been shown to contribute to underestimation or incomplete recording include respondent fatigue (Bathalon et al., 2000), higher BMI values (Hoidrup et al., 2002), and poor compliance with record keeping to track consumption as well as simply forgetfulness (Smith et al., 1991).

Previous studies documenting underestimation have demonstrated that there is a wide range of percent underestimation. The Observing Protein and Energy Nutrition (OPEN) study (Subar et al., 2003) has shown through biomarkers of energy expenditure using DLW that men underestimated EI by 12-14% using 24-hour recalls and 31-36% using a food frequency questionnaire. Slightly higher, women underestimated EI by 16-20% using 24-hour recall and 34-38% using a food frequency questionnaire. Similarly, in another study women underestimated EI by 37% using a 7-day dietary record and by 42% using a food frequency questionnaire compared to DLW (Mahabir et al., 2006). Our study demonstrated underestimation toward the lower end of these ranges. If the EE estimates are presumed to be accurate the results indicated that men underestimated EI by 21% as assessed by both WMS and Nutritionist Pro and women underestimated EI by 20% as assessed by WMS and 18% using Nutritionist Pro when compared to the SWA. Thus, our results are consistent with previous studies reporting underestimation of EI using self-report methods.

A novel aspect of this present study is that we demonstrated that underestimation may be associated with the degree of detail provided in the dietary record used to record food intakes. The accuracy of the estimated EB was directly dependent on the quality or detail of the dietary record provided by the individual. For both males and females, individuals who submitted dietary records coded with a rating of 1 (worst) exhibited a significant difference in EB values. In contrast, individuals submitting dietary records coded with a rating of 2 or 3 (best) did not exhibit a significant difference in EB values. This indicates that higher quality dietary records yielded estimates of EB that were very close to the observed EB. This demonstrated a promising attribute of the SWA monitor for assessing EB within the free-living individuals. Interestingly, the results also revealed that participants who record more accurately also had greater weight loss during the study. No recommendations were made by the researchers to lose weight so these results suggested that a subsample of the participants became more aware of their eating habits and restricted intake. This was not a focus of the study, but it merits additional research.

A secondary goal was to compare estimates of EI from the WMS with estimates obtained from the more established Nutritionist Pro. The same dietary records were used to complete estimates with both dietary assessment systems, so the comparisons reflect internal calculations or assumptions used in the two systems to estimate EI. The results revealed good agreement as there were high correlations and non-significant differences in reported EI, as well as agreement in reported consumption of protein, carbohydrate, and fat. This supports the relative validity of the WMS and its ability to analyze dietary record intakes compared to the more established Nutritionist Pro dietary assessment system.

The SWA and associated WMS offer potential to facilitate self monitoring of both EI and EE. Research has demonstrated that self monitoring can aid in weight loss and weight management (Shay, 2008). Consistent self-monitoring has been shown to be related to increased weight loss compared to inconsistent self-monitoring (Baker and Kirschenbaum, 1993; Boutelle and Kirschenbaum, 1998). Results from a behavioral weight loss program also indicated that consistent self-monitoring of exercise contributed to greater weekly exercise participation and increased weight loss (Carels et al., 2005). Self-monitoring of dietary intake has been demonstrated to be associated with adherence to dietary measures (Schnoll and Zimmerman, 2001). However, as stated previously, underestimation is common in dietary assessment methods. Our results indicated that the SWA and associated WMS provided a way to monitor both EI and EE simultaneously to examine energy balance. Results demonstrated that the WMS provided accurate estimates of EB when participants provided accurate dietary records. The results also demonstrated that the WMS yielded similar estimates of EI compared to a more established dietary assessment tool. The ability of the SWA and WMS to facilitate monitoring of EI and EE could be useful for facilitating weight loss and weight maintenance.

The results presented here are novel since there are presently no commercially available monitor devices capable of assessing both EE and EI in a cost-effective manner. Our findings suggest that the SWA and associated WMS may offer promise for assessing EB. A unique aspect of this study was the ability to capture usual activity as the participants went about their daily lives. Participants were allowed to eat what they wanted and were under no constraints regarding physical activity, so the results capture free-living EB. Another unique feature is that we compared the WMS against a more established dietary assessment software, Nutritionist Pro, rather than only using estimated EI based on weight change during the course of one week in relation to assessed EE. In addition, supplemental analyses evaluated the impact of dietary record quality on the utility of the SWA to assess EB, providing interesting and distinctive results. Most notable is the observation that the WMS yielded accurate estimates of free-living EB when participants provided accurate dietary records. To our knowledge our, study is the first and only study to evaluate the utility of the SWA and associated WMS to assess EB.

While the results are promising it is important to consider some limitations of the design. One limitation of the study was the narrow characteristics of the participants. The average age was 26.5 years (18 to 49) old and included participants who were generally healthy. Because of this, future studies should examine the utility of this device to assess EB in more representative samples and perhaps in obese individuals where it might have the most utility. Another limitation is that the study relied on the use of a 7-day dietary record. The burden required to complete daily entries could have led participants to put less effort into the records. More accurate results could be with weighed dietary records since this method is considered the “gold standard” assessment for EI (Gibson, 2005). The use of Nutritionist Pro as a comparison measure could also be viewed as a limitation. The Nutrition Data System for Research is considered the “gold standard” system for diet analyses, but it was not possible to obtain at this time. These limitations do not threaten the internal validity of the study, but additional work is clearly needed to further evaluate the potential of the SWA and associated WMS.

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Tables

Table 1. Descriptive Statistics for participants at baseline values

	Male	Female	All
Age (yrs)	26.1 ± 5.3	26.9 ± 7.9	26.5 ± 6.8
Height (cm)	181.2 ± 7.8[b]	166.8 ± 6.5[a]	173.4 ± 10.1
Weight-baseline (lbs)	173.4 ± 33.1[b]	140.8 ± 24.9[a]	155.7 ± 33.0
BMI pre (kg/m^2)	24.0 ± 3.9[b]	22.9 ± 3.1[a]	23.4 ± 3.5
Body fat percent pre (%)	15.0 ± 4.7[b]	25.0 ± 4.2[a]	20.4 ± 6.7
PA Minute	185.1 ± 110.0[b]	138.0 ± 55.4[a]	159.4 ± 87.3
Step	11,066 ± 3,216	11,677 ± 2,968	11,399 ± 3,075
Average METs	1.64 ± 0.26	1.59 ± 0.17	1.61 ± 0.21

Values reflect Means ± standard deviation

a, b indicate significant difference ($P < 0.05$) within a row between gender

Table 2. Differences in Theoretical and Observed Energy Balance for Participants

	Male	**Female**	**All**
Actual Weight difference (lbs)	-0.5 ± 1.9	-0.4 ± 1.5	-0.5 ± 1.6*
Theoretical Weight Difference (lbs)	-1.4 ± 1.1*	-1.0 ± 1.1*	-1.2 ± 1.1*
Difference in Weight difference (lbs)	$0.9 \pm 2.0^{+}$	$0.6 \pm 1.4^{+}$	$0.7 \pm 1.7^{+}$
BMI difference (kg/m^2)	-0.1 ± 0.3	-0.1 ± 0.2	-0.1 ± 0.2
Body Fat Difference	-0.6 ± 2.0	-0.3 ± 0.9	-0.4 ± 1.5*

Values reflect Means ± standard deviation
*indicate statistically significant ($P < 0.05$) decrease
+indicate statistically significant ($P < 0.05$) overestimation of weight loss

Table 3. Dietary Analysis Method Comparison

	Weight Management System	**Nutritionist Pro**
Male		
Energy intake (kcal)	2543 ± 655	2563 ± 665
Carbohydrate (g)	309 ± 99	318 ± 107
Protein (g)	116 ± 49	114 ± 48
Fat (g)	97 ± 32	91 ± 25
Female		
Energy intake (kcal)	1970 ± 551	2037 ± 573
Carbohydrate (g)	271 ± 135	269 ± 78
Protein (g)	82 ± 28	83 ± 29
Fat (g)	70 ± 31	71 ± 28

Values reflect Means ± standard deviation

Figures

Figure 1. Average Percent Allocation in Physical Activity Levels

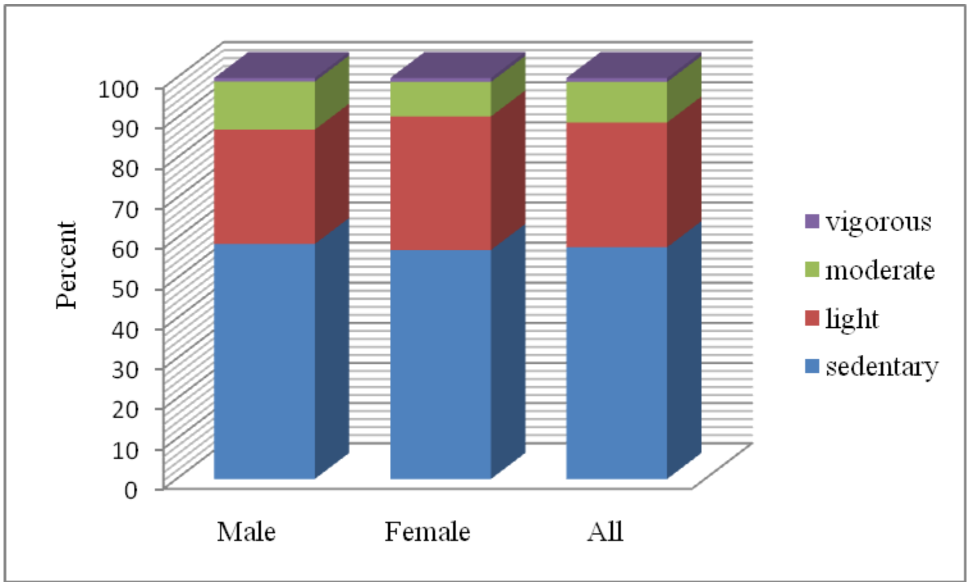


Figure 2. Difference in Observed Weight Loss by Dietary Record Rating

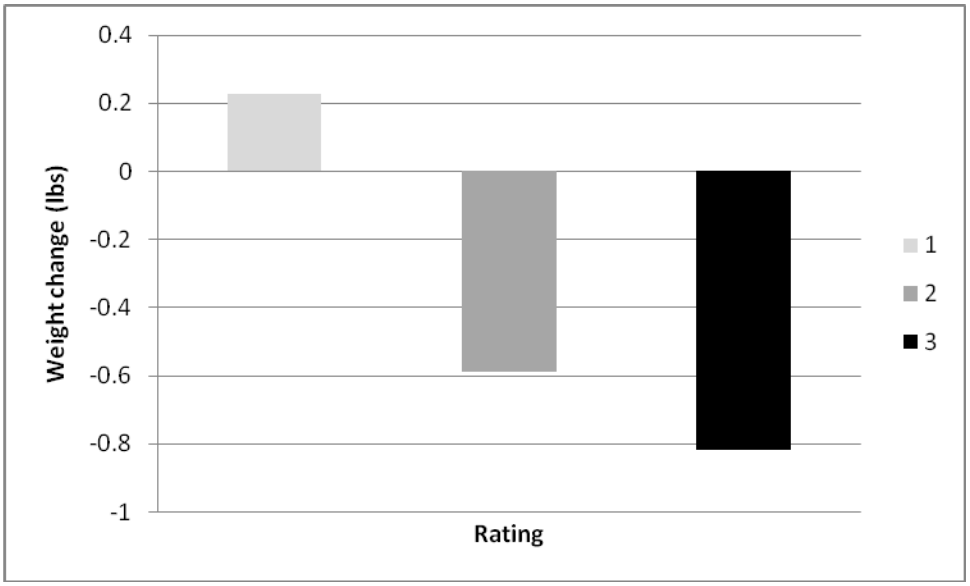
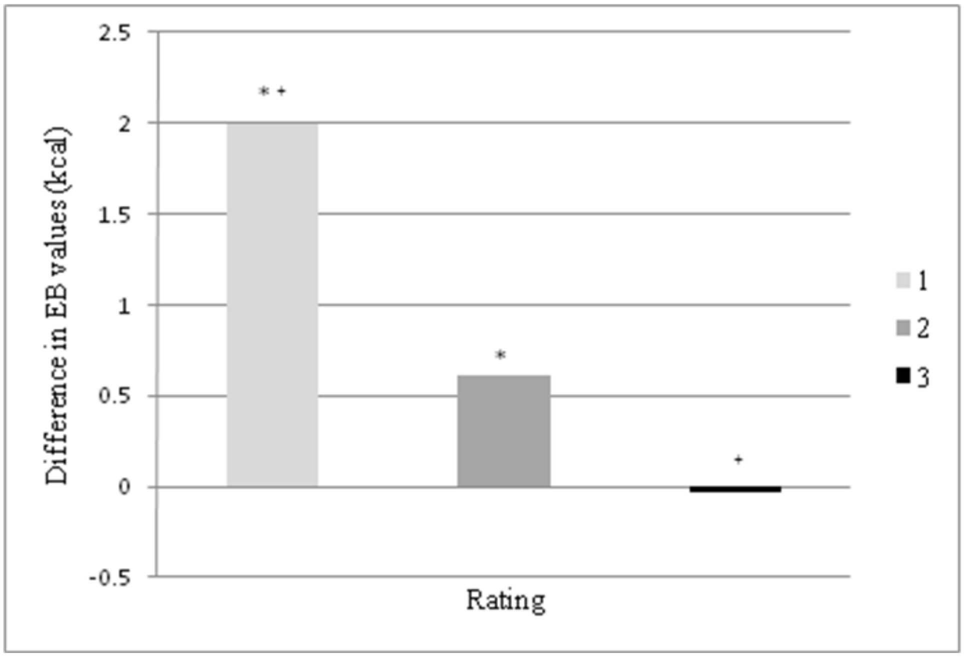


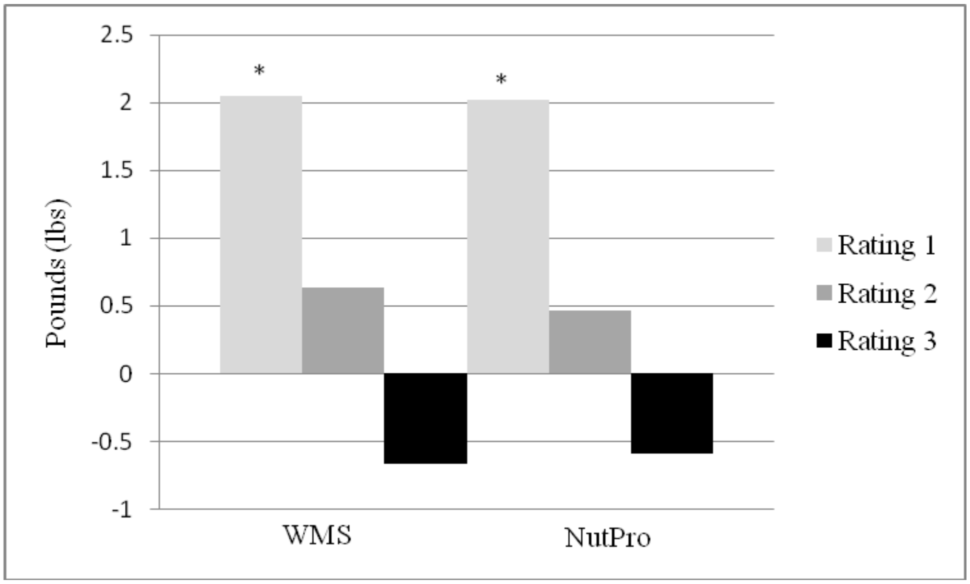
Figure 3. Difference in Energy Balance Values (Actual – Theoretical) by Dietary Record Rating



*****Mean EBdiff significantly different between rating 1 and 2 ($p < 0.05$)

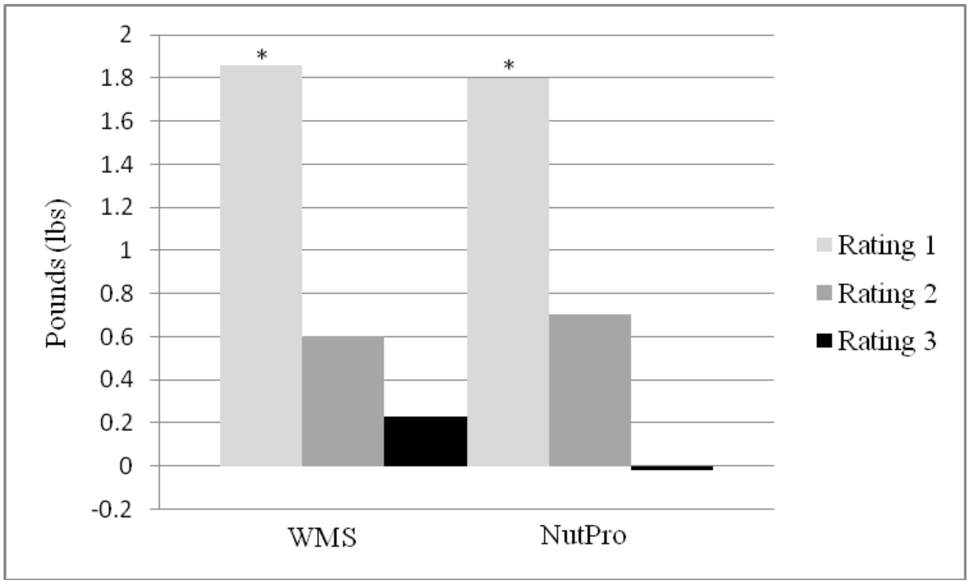
[+] Mean EBdiff significanly different between rating 1 and 3 ($p < 0.05$)

Figure 4. Differences in Energy Balance Values (EBdiff) by Dietary Record Quality in Males for both the WMS and Nutritionist Pro



*Difference between actual and theoretical weight gain is significant (P < 0.05)

Figure 5. Differences in Energy Balance Values (EBdiff) by Dietary Record Quality in Females for Both the WMS and NutPro



*Difference between actual and theoretical weight gain is significant ($P < 0.05$)

Figure 6. Mixed Model Analysis for EI: Method by Gender Interaction

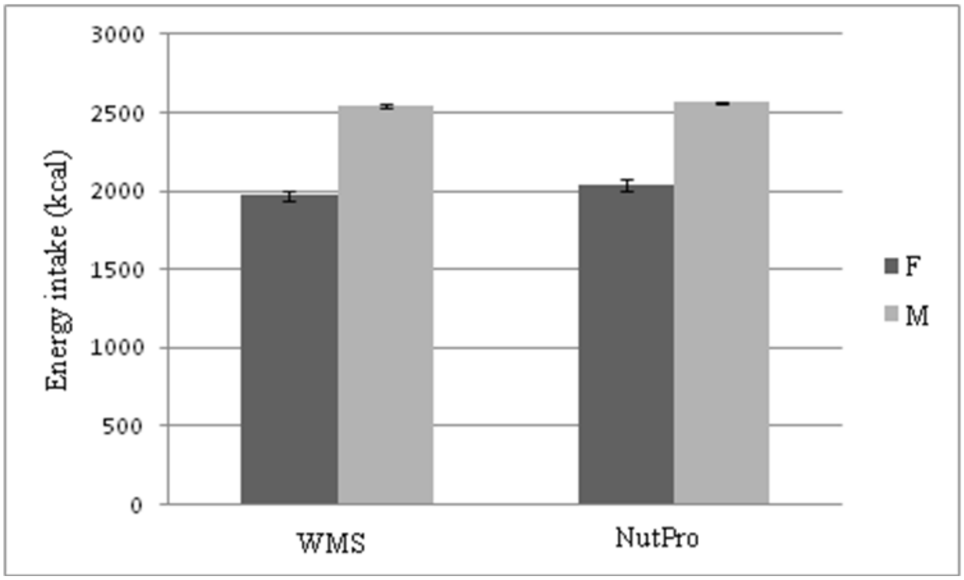
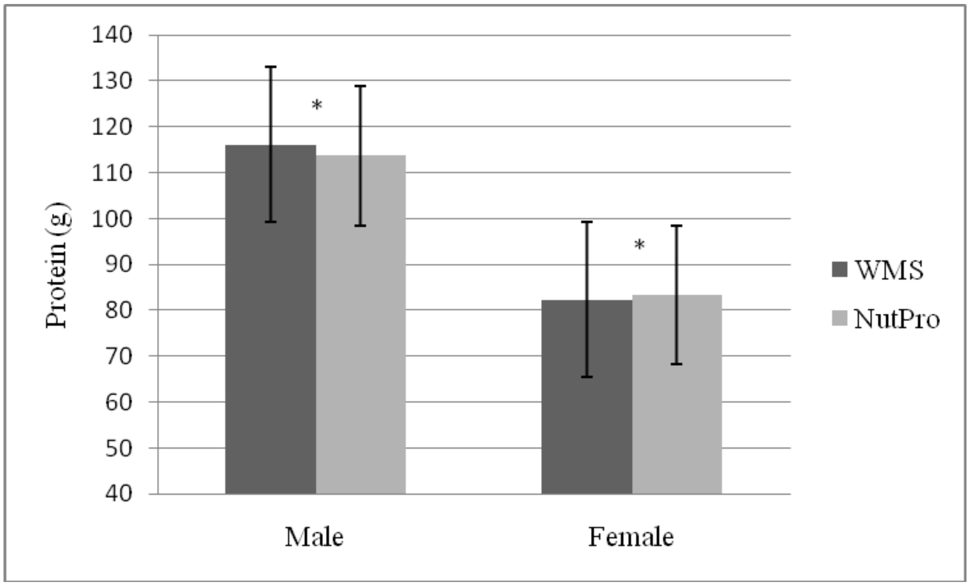


Figure 7. Mixed Model Analysis for Protein: Method by gender interaction



*Significant gender by method interaction ($p < 0.05$)

CHAPTER 4. GENERAL CONCLUSION

The obesity epidemic has become one of the leading health challenges facing the nation. This progression stems directly from the inability of individuals to balance energy expenditure (EE) and energy intake (EI) on a daily basis. Instruments that can facilitate monitoring of energy balance (EB) under free-living conditions may enhance research on obesity prevention.

There are a variety of methods available to assess EE and EI individually; however, very few of these have an integrated system to assess EE and EI simultaneously. The SenseWear Pro 3 armband (SWA) monitor and associated weight management system (WMS) offer promise as a method suitable for EB assessment. This devise has the ability to assess EE from the SWA monitor and EI from dietary records inputted into the WMS. In our study, higher quality dietary records inputted into the WMS had a small (non-significant) difference in the observed weight loss (pre-weight – post-weight) and estimated weight loss from the SWA and WMS. Thus, this method allowed the ability to assess EB and provide detailed information of EE, EI, and EB to the individual on a daily basis.

Many studies have demonstrated the vital role self-monitoring of EE and EI plays in weight loss and weight maintenance; however, few indicate the role of self-monitoring of EB. Our study was consistent with these finding that self-monitoring aids in weight loss. More importantly, self-monitoring of EB through the SWA and WMS also resulted in weight loss during the course of one week. Future research related to the effect the SWA and WMS have on weight maintenance could provide evidence for the importance of this method in weight loss and maintenance programs.

In conclusion, the SWA and associated WMS offers promise as a method to assess EB and provide self-monitoring, which is a vital component of weight loss and maintenance. Therefore, this method can potentially be a useful device for obese individuals.

APPENDIX. BLAND ALTMAN PLOTS

Figure 8a. Energy intake (kcal) agreement between WMS and Nutritionist Pro

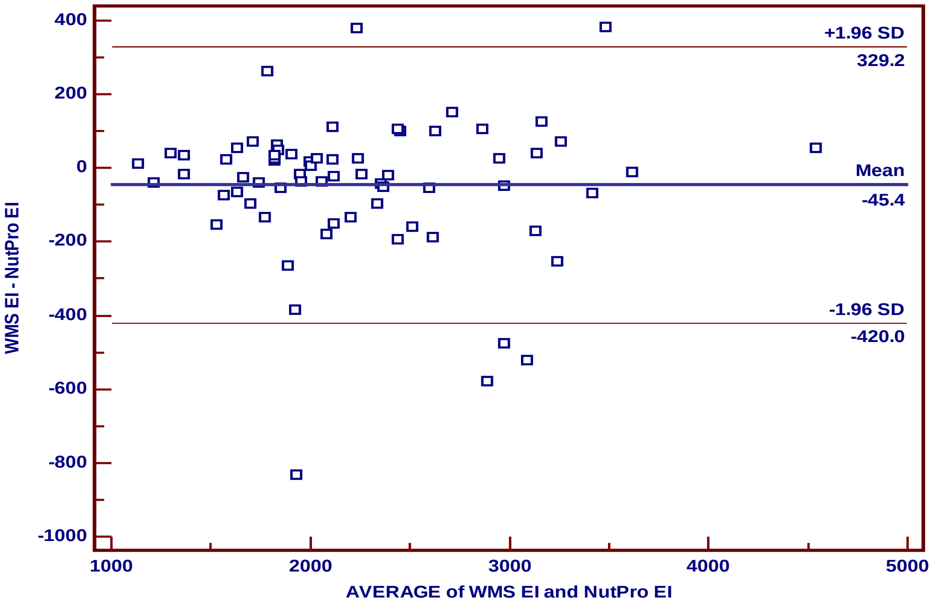


Figure 8b. Protein (g) agreement between WMS and Nutritionist Pro

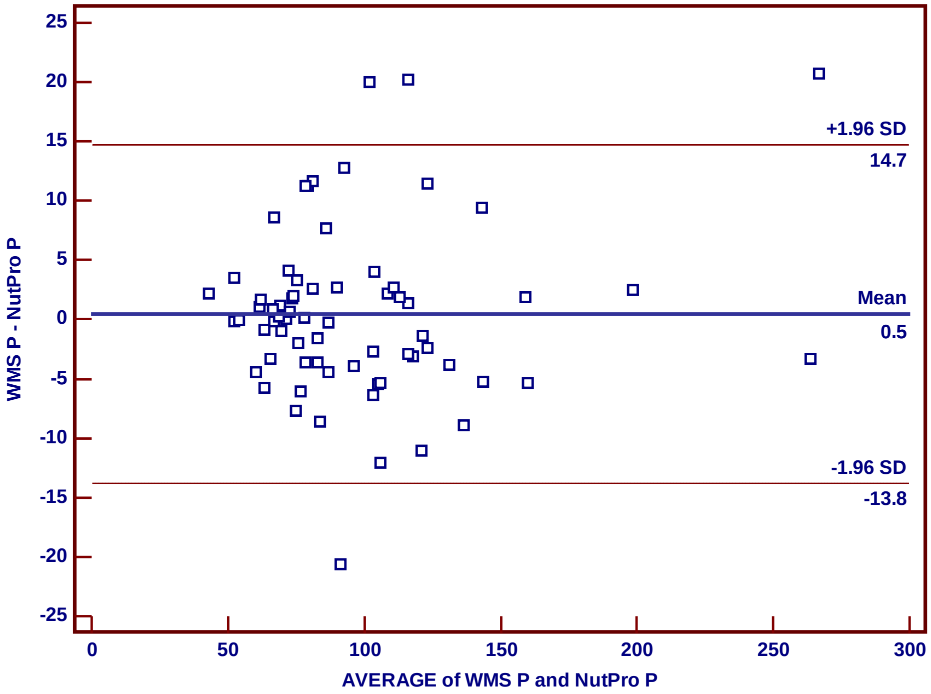


Figure 8c: Carbohydrate (g) agreement between WMS and Nutritionist Pro

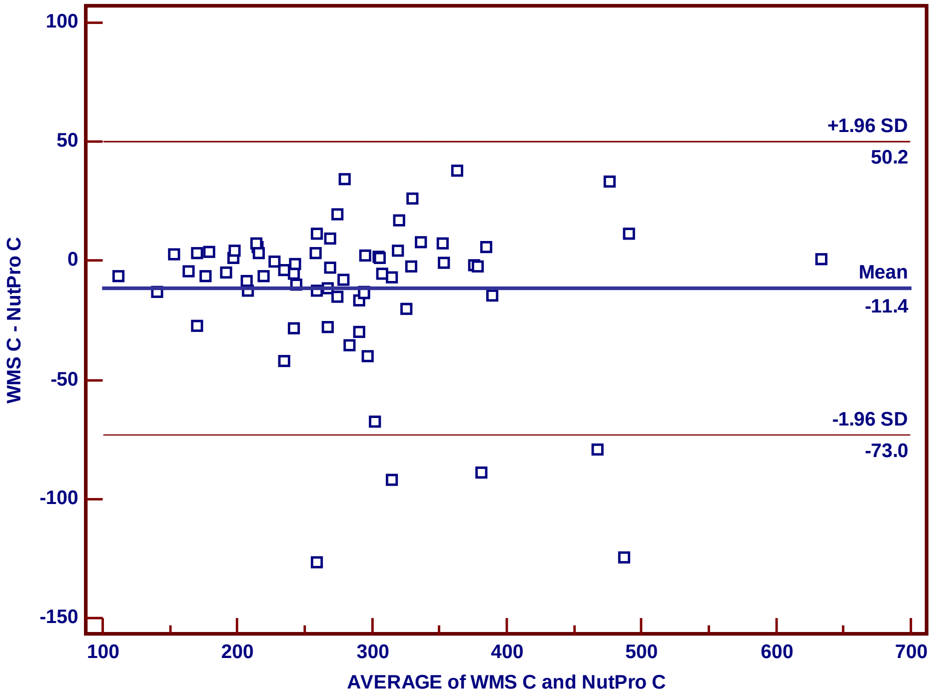
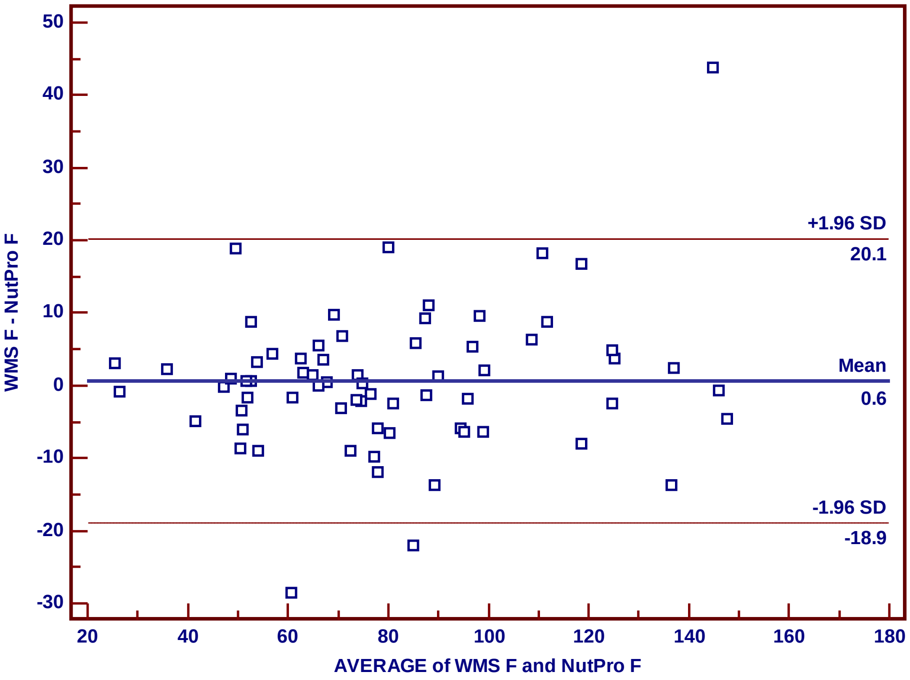


Figure 8d: Fat (g) agreement between WMS and Nutritionist Pro



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