Benefits of the SenseWear™ Armband Over Other Physical Activity and Energy Expenditure Measurement Techniques

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Abstract -- The ability to accurately and reliably monitor physical activity and energy expenditure has emerged as a critical component to weight management and the prevention of lifestyle related health problems. Current methods and tools used by researchers, clinical practitioners, and individuals to assess physical activity and energy expenditure were reviewed and found to have practicality and accuracy limitations. Similarly, a competitive analysis of activity and energy expenditure detection devices found that accuracy varied considerably when used in the free-living environment because of their inability to detect energy expenditure during certain non-ambulatory activities. It was found that BodyMedia's SenseWear Armband, which employs an array of physiologic sensors, overcame these limitations. In a structured energy expenditure study, the SenseWear Armband was found to be significantly more accurate and more reliable than the BioTrainer Pro and Sport-Tech Pedometer in determining Resting Energy Expenditure, Active Energy Expenditure and Total Energy Expenditure.

Index of Terms -- Accuracy, Active Energy Expenditure, Ambulatory, Caloric Tracking, Competitive Analysis, Context Detection, , Free-Living Environment, Physiologic Data Sensors, Multiple Sensor Array, Ambulatory, Non-ambulatory, Resting Energy Expenditure, Total Energy Expenditure

INTRODUCTION

The increased prevalence of lifestyle-related diseases and disabilities has made developing a convenient, accurate, and reliable method for tracking physical activity and measuring energy expenditure a crucial goal for healthcare and healthcare research. The ability to monitor physical activity and accurately track calories is proving to be an important component in the management of numerous lifestyle related health problems such as obesity, type II diabetes, coronary artery disease and hypertension. Strong epidemiological data exists that support the claim that a sedentary lifestyle and an overweight status contribute to increased rates of such illnesses, many of which lead to premature death. Conversely, increased physical activity and weight control has been shown to lower mortality rates and result in a number of overall health benefits including improved glucose tolerance, reduced blood pressure and lower rates of chronic back pain and arthritis.

Helping researchers, clinicians as well as individuals see the exact level of physical activity and amount of energy expenditure the body experiences, empowers them to gain a greater understanding of the clinical effects and benefits of physical activity. This notion is supported by literature on behavior change and weight management. (Schnoll, 2001 and Wong, 1995). When it comes to weight management, it is clear that there is a need for tools that can accurately and reliably monitor physical activity level and energy expenditure in order to promote awareness of exactly how many calories the body burns. Currently, there is not a convenient, reliable and cost effective way for professionals or individuals interested in weight management to assess their degree of physical activity and energy expenditure accurately.

I. DELINEATION OF THE NEED

Health professionals as well as individual consumers recognize the importance of establishing and maintaining a healthy lifestyle and maintaining an appropriate balance between food intake and energy expenditure. This is known as energy balance. To achieve energy balance, consumers as well as health professionals monitoring their clients and patients, require tools that gather accurate and reliable energy expenditure information for a range of daily activities The daily schedule in Appendix I illustrates the typical day of Louise, an average working mother age 45, by activity. Note how her daily activities range in level of intensity, position and environment over the course of her day.

See Appendix I – Typical Daily Activity Categories of a Working Mother

Tools that claim to monitor and quantify physical activity and energy expenditure must be accurate and reliable enough to account for activities that naturally shift in intensity and environment over the course of the day, such as those illustrated in Appendix I. To provide accurate feedback, such a device must also be able to sense both ambulatory and non-ambulatory activity. As we will illustrate, devices that sense only motion are inadequate for accurately quantifying energy expenditure since they cannot reliably measure changes in load, grade or effort during many daily activities. For example, load can be high while motion is near zero when lifting a heavy object. In this situation, a pedometer would be unable to effectively monitor calories burned because it only measures steps.

BodyMedia feels that the only way to address such issues of accuracy and reliability is by creating a body-monitoring device that utilizes an array of physiological data sensors that can assess all forms of activity.

II. METHODS AVAILABLE TO ASSESS PHYSICAL ACTIVITY AND ENERGY EXPENDITURE

There are a number of methods for the measurement and quantitative analysis of physical activity and energy expenditure. Methods of assessing physical activity include the use of structured observations; physical activity records or logs, retrospective questionnaires and various motion detectors. Measures of energy expenditure include the use of doubly labeled water, calorimetry, oxygen uptake and ventilation, heart rate monitoring, body temperature measurements and motion sensors. The following discussions will look at the pro and cons of each of the methods.

See Appendix II – Comparison of Methods to Assess Physical Activity and Energy Expenditure

METHODS TO ASSESS PHYSICAL ACTIVITY

A. Motion Detectors

Motion detectors, such as pedometers and accelerometers, are worn on the body in order to quantify ambulation or motion during various activities. The most positive aspect of motion detectors is their ability to provide useful, relatively objective estimates of activity levels.

However, pedometers are limited in their ability to differentiate type, frequency and intensity of physical activity. Accelerometers share this limitation with respect to their ability to measure and discern different types of activities. Furthermore, pedometers and accelerometers are not well suited to estimating energy expenditure during non-ambulatory activities involving resistance, lifting, biking, walking a graded surface, or carrying a heavy load.

In addition, numerous reports site discrepancies between accelerometers measuring energy expenditure in the laboratory and free-living environment. (Freedson, 2000, Eston 1998, Chen 1997, Hendelmen 2000). While the cost of simple off the shelf pedometers can be as low as $15 to $30, the most sophisticated, and therefore more accurate, motion detectors can range as high as $1,000.

With regard to weight management efforts, motion detectors can offer valuable assistance if the goal is simply to monitor the degree of physical activity during an intervention effort such as a walking program. However, their value in helping people manage energy balance and weight loss is highly limited and would be dependent upon additional costly support from a health or fitness professional. Therefore, motion detectors cannot be viewed as viable tools to provide the kind of accurate information about energy expenditure over the course of a 24-hour period which, is critical to achieving the balance between food intake and physical activity that is necessary for weight loss.

B. Physical Activity Records

Physical activity records, logs and recalls are all variants of methods which have been developed to enable individuals to record the amount of physical activity in their daily life. These types of measurement tools can provide a great deal of detail on the types of physical activities engaged in along with the individual's pattern of participation (Leenders, 2001, Weston 1997). While these measurement tools are quite inexpensive, there is a significant cost disadvantage in that many are manpower intensive requiring personnel to gather and analyze the data generated. In the case of computer logs, participants must have a computer and be computer literate. Most importantly, the quality of data gathered by use of these tools can be impacted by response bias, poor recall or poor compliance (Salmon, 2001). When used over long periods of time, participants may tire of the need for constant recording and this may adversely affect the accuracy of the data gathered. Finally, these tools obviously cannot automatically sample physiologic information directly from the body nor accurately calculate energy expenditure or context. The primary value of physical activity records lies in their ability to gather information about a wide range of activities over lengthy periods of time.

When used as one component of energy expenditure calculations, physical activity logs can provide valuable information about activity patterns and contexts. However, this data is of limited utility when it comes to guiding the daily decision-making that is a part of effective weight management.

METHODS TO ASSESS ENERGY EXPENDITURE

A. Doubly Labeled Water

Doubly labeled water is considered the "gold standard" for the assessment of energy expenditure in field or free-living conditions. The estimation of energy expenditure utilizing this technique is based on the rate of carbon dioxide production and urinary excretion during various physical activities. Doubly labeled water utilizes stable water isotopes and is administered as a liquid dosed according to body size. A given dose generally lasts for about 14 days and costs approximately $800-$1000. Doubly labeled water provides a very precise estimate of total energy expenditure over a specific period of time, generally one to two weeks.

Doubly labeled water cannot be used to differentiate the duration, frequency or intensity of any single episode of physical activity within the larger time frame. Its clinical utility and applicability is highly restricted by its prohibitive cost, the need for specialized personnel and lab facilities, and the fact that it can only provide a long-term view of energy expenditure. Its primary application is in small research studies.

B. Room Calorimetry

Room calorimetry or the use of a metabolic chamber provides a determination of energy expenditure by assessing body heat production in an enclosed environment. It is considered to be the "gold standard" for energy expenditure assessment in the lab or controlled environment. Though an excellent method to assess energy expenditure, like doubly labeled water, it is an extremely expensive technique. The cost of a metabolic chamber is approximately $350,000 and requires specialized personnel. Calibrating and maintaining such a metabolic chamber can be difficult. By definition, it has no role in assessing free-living activities or activities that extend over a prolonged period of time. Again, its primary use is in small research studies.

C. Oxygen Uptake

Oxygen uptake provides an indirect assessment of calories burned during specific activities. Energy expenditure is estimated based on the assumed relationship between oxygen uptake and the caloric cost of substrate oxidation. Cost is again a major prohibitive factor in the use of oxygen uptake assessment devices for individual health monitoring. The cost of a metabolic cart can range from $20,000-$100,000. Additionally, these devices are quite cumbersome and can alter patterns of physical activity particularly in free-living environments because of the limitations they place on the individual's movement (Salmon, 2001). The use of the system requires a mask and/or mouthpiece and nose clip for the entire sampling period.

There are some mobile oxygen uptake devices available, however they are intrusive, cumbersome, costly, and less accurate than stationary versions. While validity is well established in laboratory settings where they are frequently used as a "gold standard", there are no well-documented studies utilizing oxygen uptake assessment devices in free-living situations.

D. Heart Rate Monitoring

Heart rate monitoring has been used to estimate energy expenditure based upon a direct relationship between heart rate and oxygen uptake during most typical activities. However, there is insufficient evidence that this relationship is as strong during periods of low or very high levels of activity (Rowlands et al, 1997). There are multiple factors unique to the individual that can impact the relationship between heart rate and energy expenditure. Such factors need to be accounted for on a case-by-case basis in order to accurately estimate energy expenditure utilizing this technique. This obviously limits its applicability to large populations with their inherent individual differences. Though heart rate monitoring can be a valuable tool in the measurement of energy expenditure, it is not effective as a stand alone measurement. When used in conjunction with other methods of gathering data, it can provide important, useful information.

E. Core Body Temperature

Core body temperature has been used under laboratory conditions to estimate energy expenditure. Under highly controlled conditions, there is a close relationship between core body temperature and energy expenditure (Gass 1998). However, it is not seen as an effective, single measure of energy expenditure under other conditions (van Marken 2001). When combined with other energy expenditure tools, core body temperature can add a valuable dimension. This approach has not been utilized extensively in free-living conditions. Due to its invasive nature, core body temperature is impractical and inconvenient for wide scale use by individuals in free-living situations.

F. MET Tables

Established by reviews of scientific studies, MET tables specify energy expenditure for various activities and classify activity level into light, moderate, hard, and very hard categories. The most sophisticated of these tables provide coding schemes to categorize activities, (Ainsworth 1993). Once an activity is classified, energy expenditure can be reasonably estimated for specific activities or types of activities particularly if the individual's weight is taken into account. While approaches using MET tables can be useful for activity recall, their accuracy is dependent upon the reliability of self-reporting. The most significant limitation in using MET tables is their inability to account for individual differences in movement patterns. It can also be problematic to use MET tables to estimate energy expenditure during non-continuous tasks that might be interrupted by breaks or rest periods. Not only is it difficult to account for the absolute intensity of an activity using the MET tables, but individuals also vary significantly with regards to their perceived intensity of effort during an activity. In summary, MET table estimates may or may not be accurate once individual differences are taken into account.

E. Harris-Benedict Equation

Reports in the literature indicate that the frequency of error in energy expenditure estimation using the Harris-Benedict equation is high. Studies by van der Ploeg (2001), et. al, De Lorenzo (2000), et. al, Tverskaya, (1998), et. al, Osborne (1994), et. al, and Van Way (1992), all show significant variability in the energy expenditure estimations (ranging from - 12% to + 15% error) made by the Harris-Benedict equation. Van Way also notes that there are significant variations in the published versions of the equation, which can result in errors in calculations of energy expenditure. In his review of medical texts, he found errors in the constants used in the equation in approximately 30% of the texts.

III. SELECTIVE COMPETITIVE ANALYSIS OF PHYSICAL ACTIVITYAND ENERGY EXPENDITURE DEVICES

In addition to conducting a survey of the common physical activity and energy expenditure assessment tools that are available, we have also conducted a selective analysis of products considered competitors to the SenseWear Armband. The following is a summary of the results of this analysis.

A. Pedometers (off the shelf)

In general, studies have demonstrated that pedometers do not provide reliable energy expenditure estimates in free-living environments (Eston 1998, Leender 2001, Hendelman 2000). They tend to be inaccurate at detecting variation in walking speeds and cannot accurately detect and measure activities that do not involve ambulatory locomotion, such as weightlifting or biking. Furthermore, the pedometer tends to underestimate the degree of movement during highly intense physical activities. They are also subject to errors due to auto-motion such as traveling in a car.

B. CSA Monitor

The CSA monitor is a uni-axial accelerometer. Its accuracy is highly dependent upon where it is placed on the body and the characteristics of the activity being recorded. Studies have shown that it is accurate in laboratory settings (Bassett, 2000) but less accurate in the field where it tends to underestimate energy expenditure by as much as 59% when compared to oxygen uptake or room calorimetry (Welk 2000, Leender, 2000).

C. Bio-trainer

The Bio-trainer is a uni-axial accelerometer that calculates energy expenditure utilizing a body weight formula coupled with data gathered from the accelerometer. It is more accurate than either a pedometer or body weight formula used in isolation. However, the Bio-trainer has been shown to overestimate energy expenditure in laboratory studies (101-136% of measured values) and to underestimate energy expenditure in field studies (42-67% of measured values) (Welk 2000). A significant limitation of the Bio-trainer is its inability to accurately detect and measure all forms of activity such as load carrying or grade change during ambulation. The measurement of auto-motion (e.g., motion that occurs while traveling in a car) can also cause inaccuracies.

D. Cal-trac (now CTI from Stay Healthy)

Like the Bio-trainer, the Cal-trac uses data gathered by a uni-axial accelerometer in combination with a body weight formula to calculate energy expenditure. It is worn at the hip and, therefore, measures primarily trunk acceleration. Due to the nature of its accelerometer, the Cal-trac is limited to recording vertical movements and has significant problems measuring inactive states. Its output is expressed in terms of total counts accumulated for an entire sampling period so that variations in patterns of activity cannot be discerned and accurately assessed. Furthermore, Pambianco et al (1990) and Haymes and Byrnes (1993) demonstrated that the Caltrac significantly overestimated energy expenditure during treadmill walking.

E. Tri-trac (Stay Healthy)

The Tri-trac is a tri-axial accelerometer. It calculates energy expenditure based on a prediction equation using body weight, age and gender, coupled with accelerometer data. It is worn at the waist and is sensitive to changes in speed but not grade. Nichols et al (1999) found that the Tri-trac consistently overestimated energy expenditure during horizontal treadmill walking. Chen (1997) found the Tri-trac significantly underestimated total energy expenditure and energy expenditure during sedentary and light-intensity activities, as well as, during physical activities such as stepping exercises. Jakicic et al (1999) reported similar underestimations when using the Tri-trac in their studies.

Summary Statement Regarding Accelerometers

In general, multiple studies have reported that the accuracy of accelerometers is highly dependent on the type of activity performed. This appears to be a consequence of their inability to detect energy expenditure resulting from upper body movement, non-ambulatory locomotion (e.g., biking), load carriage, or changes in surface or terrain. The tendency to respond to false motion (e.g. driving a car) contributes to their inaccuracies.

IV. THE SENSEWEAR ARMBAND: THE BODYMEDIA ALTERNATIVE to PHYSICAL ACTIVITY AND ENERGY EXPENDITURE ASSESSMENT

One of the primary goals behind the design and development of the SenseWear Armband was to create a wearable device that could quantitatively assess physical activity and energy expenditure in free-living environments more efficiently and effectively than current alternatives discussed above. More specifically, we sought to create a device that was more accurate and reliable than competitive products and that, ultimately, could be produced at a cost that made large scale, consumer adoption possible. To that end, we have created a device utilizing multiple sensors that not only meet the standards set by other available devices, but exceed their capabilities.

Description of the SenseWearÔ Armband

The SenseWear Armband includes a 2-axis accelerometer, heat flux sensor, galvanic skin response sensor, skin temperature sensor and a near-body ambient temperature sensor. The SenseWear Armband also offers the addition of heart rate detection through the use of a Polar™ Chest Strap. The following is a brief description of each sensor and its function in the device. More detailed specifications can be found in the paper “Characterization and Implications of the Sensors Incorporated into the SenseWear Armband.”

1) The accelerometer in the SenseWear Armband is a 2-axis micro-electro-mechanical sensor (MEMS) device that measures motion. The motion can be mapped to forces exerted on the body and hence energy expenditure. By taking into account gravity, our algorithms can also assess the context in which the armband was being worn.

2) The proprietary heat flux sensor in the armband is a robust and reliable device that measures the amount of heat being dissipated by the body. The sensor is comprised of materials with very low thermal resistance and extremely sensitive thermocouple arrays. It is placed in a thermally conductive path between the skin and the side of the armband exposed to the environment. A high gain internal amplifier is used to bring the signal to a level that can be sampled by the microprocessor located in the SenseWear Armband.

3) Skin temperature is measured using a highly accurate thermistor-based sensor located on the backside of the armband near its edges and in contact with the skin. Continuously measured skin temperature is linearly reflective of the body's core temperature activities.

4) The near-body ambient temperature sensor measures the air temperature immediately around the wearer's armband. This sensor also uses a highly accurate thermistor-based sensor and directly reflects changes in environmental conditions around the armband; for example, walking out of an air-conditioned building on a hot day.

5) Galvanic skin response (GSR) represents electrical conductivity between two points on the wearer's arm. The SenseWear Armband GSR sensor includes two hypoallergenic stainless steel electrodes integrated into the underside of the armband connected to a circuit that measures the skin's conductivity between these two electrodes. Skin conductivity is affected by the sweat from physical activity and by emotional stimuli. GSR can be used as an indicator of evaporative heat loss by identifying the onset, peak, and recovery of maximal sweat rates.

6) The SenseWear Armband houses a custom receiver board to receive the pulses transmitted by a heart beat detection chest strap. The receiver board includes a free-running 8kHz timer derived from the crystal controlled microprocessor clock that is accurate to 50 beats per minute. Heart rate and energy expenditure exhibit a linear relationship, particularly between a heart rate of 110 and 150 beats per minute. Heart rate can also be used as an aid in distinguishing frequency, intensity, and duration of activity.

Advantages of the SenseWear Armband

As can be seen from the description above, the SenseWear Armband has been designed to collect and analyze a broad range of data from the body and its movement allowing us to more accurately quantify physical activity and energy expenditure. In contrast to available pedometers and accelerometers, the SenseWear Armband gathers information about much more than just body motion. With the addition of the heat flux and temperature sensors, the armband can measure heat produced by the body as a result of basic metabolism and, as well as, all forms of physical activity. This combination of multiple sensors enables the SenseWear Armband to overcome many of the limitations of assessment devices reviewed earlier. Unlike pedometers and accelerometers, the armband can detect and measure physical activity of the upper and lower body, it can detect the increased effort and energy expenditure associated with load carrying, change of grade and non-ambulatory physical activity. Additionally, the multiple sensor array and related software is able to accurately determine context and, therefore, eliminate the difficulties pedometers and accelerometers have with detection of false motion. Furthermore, the SenseWear Armband is small, unobtrusive, and comfortable to wear. It is not invasive and does not alter normal patterns of motion or activity. It can be worn throughout the day, in virtually all environments (except in water) and for all types of activities thus overcoming the limitations of the highly accurate energy expenditure devices described earlier (doubly labeled water, room calorimetry and oxygen uptake). The SenseWear Armband also serves as an auto journal, gathering information directly from the body and requires minimal effort from the user other than putting it on. In all respects, the SenseWear Armband represents a superior alternative for activity and energy expenditure assessment.

V. COMPARISON OF THE SENSEWEAR ARMBAND, THE BIO-TRAINER PRO AND THE SPORT-TECH PEDOMETER IN AN ENERGY EXPENDITURE STUDY

In order to further define the advantages of the SenseWear Armband, we conducted a head-to-head study comparing the SenseWear Armband to the Bio-trainer Pro and the Sport-Tech Pedometer during an energy expenditure study. Forty-nine subjects were studied during a physical activity protocol which is described in detail elsewhere (see the paper entitled “Accuracy and Reliability of the SenseWear Armband as an Energy Expenditure Assessment Device”). In summary, subjects 18-60 years of age, male and female, with body mass indices ranging from 24 to 33, were recruited from the general population. Subjects were screened for health conditions or medications that could alter their energy expenditure or otherwise preclude their participation in the study. A number of physical parameters were collected (including height, weight, body fat percentage, leg length, handedness, blood pressure, heart rate, skin fold thickness and skin temperature). Subjects participated in two sessions of treadmill and one session of cycling activities. Each session also included rest periods before and after the physical activity. For each activity, subjects wore the SenseWear Armband, a Sport-Tech Fitness Pedometer and a Bio-Trainer Pro digital calorimeter/accelerometer. The CPX Express VO2 cart was also used for all sessions. Detailed results of the energy expenditure study can be found in the aforementioned document.

Results of the head to head comparison between the SenseWear Armband, accelerometer and pedometer are summarized in Tables III and IV.

The data in Table III clearly demonstrates the superior accuracy of the SenseWear Armband. Of the three devices, only the SenseWear Armband could be expected to detect Resting Energy Expenditure (REE). It did so with an accuracy equivalent to the Harris-Benedict equation. The SenseWear Armband was significantly more accurate than the other devices in detecting energy expenditure during the treadmill activity. Neither the Bio-Trainer Pro accelerometer nor the Sport-Tech pedometer were able to detect energy expenditure during the stationary bike activity while the SenseWear Armband did so with only 1/8th the error relative to utilizing the Harris-Benedict equation in combination with the ACSM Mets Tables.

Table III – Absolute error results (inter-person)

Device	REE - *Lying down*	AEE - *Treadmill*	AEE - *Bike*	TEE
SenseWear Armband (multiple sensors)	8.0%	9.7%	7.5%	7.9%
Biotrainer PRO ($200 +)	N/A	32.6%	FAILED	17.5%
Sport-Tech ($20)	N/A	41.5%	FAILED	16.5%
ACSM Look-up tables (Harris-Benedict METS factor/24 hour recall)	8.10%	28.0%	57.0%	22.0%

Table IV – Repeatability variation results (inter-person)

Device	REE - *Lying down*	AEE - *Treadmill*	AEE- *Bike*	TEE
SenseWear Armband (multiple sensors)	6.5%	8.0%	2.0%	5.8%
Biotrainer PRO ($200 +)	N/A	17.2%	FAILED	15.6%
Sport-Tech ($20)	N/A	21.8%	FAILED	16.2%
ACSM Look-up tables (Harris-Benedict METS factor/24 hour recall)	5.7%	13.4%	22.0%	35.0%

As can be seen in Table IV, the accuracy of SenseWear Armband is highly repeatable for resting, active and total energy expenditure. Repeatability for REE was essentially equivalent to the Harris-Benedict equation. The SenseWear Armband demonstrated significantly better repeatability for the detection of treadmill energy expenditure compared to the Sport-Tech pedometer and Bio-Trainer Pro accelerometer. The SenseWear Armband showed a very high repeatability for detection of energy expenditure during the stationary bike activity, which again significantly exceeded that of the Harris-Benedict equation used in combination with the ACSM Mets Tables.

Taken as a whole, these results support the clear superiority of the SenseWear Armband compared to the Sport-Tech Fitness Pedometer and the Bio-Trainer Pro digital Calorimeter/ Accelerometer in terms of accuracy and repeatability of energy expenditure detection.

VIII. COMPARISON OF CALORIES BURNED DURING DAILY ACTIVITIES AS DETECTED BY SENSEWEAR VS. PEDOMETER/ACCELEROMETER

The following chart details the calories burned for each of the activities that are a part of the typical daily schedule of Louise which was presented earlier:

CHART I – Calories Burned During Typical Daily Activities

Activity Type	Calories	Time	Total
Cooking/meal preparation	40c/10 min.	80 min.	320c
Jogging	90c/10 min.	30 min.	270c
Walk (post office)	40c/10 min.	20 min.	80c
Walk (incidental)	30c/10 min.	30 min.	90c
Shower (not detectable by either)	30c/10 min.	10 min.	30c
Dress	30c/10 min.	25 min.	75c
Cleaning/light work (kitchen, stock, wait on customers)	30c/10 min.	200 min.	600c
Driving	18c/10 min.	70 min.	Not included
*Office type activities	18c/10 min.	110 min.	198c
Grocery shop	40c/10 min.	30 min.	120c
Unload/put away groceries	30c/10 min.	10 min.	30c
*Watch TV	12c/10 min.	45 min.	54c
*Eat	18c/10 min.	65 min.	117c
*Meditate	18c/10 min.	15 min.	27c
		Total Day	2011

***not detectable by pedometer/accelerometer**

Based upon the previous competitive review of pedometers/ accelerometers and an analysis of the capabilities of the SenseWear Armband, the following comparisons regarding calorie detection during Louise's typical daily activities can be made:

Daily Calories Detectable by SenseWear	1981
Daily Calories Detectable by Pedometer/Accelerometer	1564
Difference in calories per day	417
Difference in calories per week	2919
Difference in calories per month	12,510 (or 3.57 lbs)
Difference in calories per 3 months	37,530 (or 10.71 lbs.)

As can be seen in the table above, there is a significant difference in the number of calories detected by the SenseWear Armband compared to the pedometer/accelerometer particularly when projected out over 30 and 90 days. This could potentially represent a difference to the consumer of 3 ½ pounds in a month and almost 11 pounds in 3 months! This difference becomes even more dramatic when one considers that we have credited pedometers/accelerometers as being able to detect the full number of calories in certain "mixed" activities (i.e., activities such as cooking, cleaning and grocery shopping, which combine ambulatory and non-ambulatory activities). Two major activities have not been included in calculating the difference in calorie detection: sleeping and driving. We know that the SenseWear Armband can detect calories expended during sleep while the other devices cannot. Driving activity has not been included because it represents a unique activity. Our contextual studies support the fact that the SenseWear Armband can accurately detect calories burned during driving. On the other hand, accelerometers may falsely interpret the movement of the motor vehicle as the movement of the person and, thereby, record that more calories were burned than was actually the case. This inaccurate information could lead people to assume they are burning more calories than they truly are. For example, an accelerometer could record 70 minutes of driving as walking at 30 to 40 calories burned per 10 minute rate as opposed to 18 calories, which is a considerably more accurate measurement for such a sedentary activity. This error could result in an error of approximately 119 calories burned for that day. In charts II and III we have assumed that the pedometers/ accelerometers would only detect 50% of the calories expended in mixed activities. Additionally, in chart III, we have assumed that the pedometers/ accelerometers would interpret car travel as walking motion.

CHART II – Comparison of Calories Burned Detection by the SenseWear Armband vs. Pedometer/Accelerometer for Daily Activities

Activity Type	Calories	Time	Total	SenseWear	Pedometer/ Accelerometer
Cooking/meal preparation	40c/10 min.	80 min.	320c	320c	260c*
Jogging	90c/10 min.	30 min.	270c	270c	270c
Walk (post office)	40c/10 min.	20 min.	80c	80c	80c
Walk (incidental)	30c/10 min.	30 min.	90c	90c	90c
Shower (not detectable by either)	30c/10 min.	10 min.	30c	------	------
Dress	30c/10 min.	25 min.	75c	75c	38c*
Cleaning/light work	30c/10 min.	200 min.	600c	600c	300c*
Driving	18c/10 min.	70 min.	N/A	+	
Office type activities	18c/10 min.	110 min.	198c	198c	------
Grocery shop	40c/10 min.	30 min.	120c	120c	60c
Unload/put away groceries	30c/10 min.	10 min.	30c	30c	15c
Watch TV	12c/10 min.	45 min.	54c	54c	------
Eat	18c/10 min.	65 min.	117c	117c	------
Meditate	18c/10 min.	15 min.	27c	27c	------
		Total	2011	1981	1113
				(98.5 % of total)	(55% of total)

*** These activities consists of a mixture of ambulatory, non-ambulatory and sit/stand states. We have assumed the pedometers/accelerometers would detect approximately 50% of these states.**

+ Due to pedometers/accelerometers tendency to record false motion, driving calories were not included above. For 70 minutes of driving, SenseWear would record 126calories. Pedometers/accelerometers could interpret this movement as walking and record approximately 245 calories.

Utilizing the revised guidelines for interpretation of "mixed" activities and driving, the difference between the SenseWear Armband's and the pedometer/accelerometer's ability to detect calories can be summarized as follows:

Daily Calories Detectable by SenseWear	1981
Daily Calories Detectable by Pedometer/Accelerometer	1131
Difference in calories per day	868
Difference in calories per week	6076
Difference in calories per month	26,040
Difference in calories per 3 months	78,120

This means that under these conditions of accuracy, the consumer could face errors equivalent to 7.4 pounds per month and approximately 90 pounds per year.

See Appendix III - Comparison of Running Totals of Calories Burned Detected by the SenseWear Armband vs. Pedometer/ Accelerometer

Appendix III illustrates the potential impact of the difference in detection accuracy on the consumers seeking to control energy balance. If a consumer was carefully tracking calories burned with a pedometer/accelerometer and using this information to make behavioral decisions (i.e., what and how much to eat or exercise), she would already be operating with greater than a 200-calorie error by 9:00 AM. This would increase to a 400-calorie error by noon and would reach 700 calories by dinnertime. Inaccuracies of this magnitude would clearly compromise healthy decision-making.
As can be seen in all three calories burned comparison charts, there is a significant difference in the detection of calories burned in favor of the SenseWear Armband, even when one assumes that the pedometers/accelerometers would detect all of the calories involved in "mixed category activities."

Using the most accommodating method for the pedometer/ accelerometer, this difference is equivalent to 3 ½ pounds per month or almost 11 pounds over three months. This level of inaccuracy in a weight management program is simply not acceptable. For the woman in this example, maintenance of an energy balance based on the calories detected by the pedometer/accelerometer vs. the SenseWear would require eating 1600 calories per day vs. 2000 calories per day respectively. This translates to eating a more restrictive diet when relying on the pedometer/accelerometer as opposed to a more normal, balanced diet when utilizing the SenseWear Armband. Over time, this inaccurate feedback could contribute to increasing frustration, feelings of deprivation and a tendency to give up the weight loss effort. It is well understood that the vast majority of people who begin weight management programs fail or quit for these very reasons. More accurate information contributes to better self-awareness, improved self-monitoring, and better decision-making, which leads to weight management success. We are currently extending these comparison studies to targeted consumers in free-living environments in order to further validate our assumptions.

VI. CONCLUSION

The ability to more accurately and reliably measure motion and energy expenditure without the inconveniences and cost constraints of other devices and methods makes the SenseWear Armband the best choice for use in weight management programs. The SenseWear Armband can measure a full range of physical activities and provide the kind of accurate energy expenditure information needed to ensure a clearer picture of energy balance (food intake vs. calories burned) the most critical issue in successful weight management.

ACKNOWLEDGEMENTS

The authors wish to thank: John Jakicic, John Moss, Yoed Raben, Scott Safier, Brian Erinstadt, MD and Maria Sunseri, MD for their invaluable scientific and technical consultation to this project; Bob Gilbert, Leigh Zeh and Gary Cole for the important role they played in conducting many of the studies done to characterize the sensors; as well as Sharon Spiaggi and Chris Pacione for preparing drafts, graphs & tables and proof reading this manuscript.

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Appendix I – Typical Daily Activity Categories of a Working Mother

Time	Activity	Active - ambulatory	Active – non ambulatory	Sit, stand, mostly at rest	In transit	Lying down	Off the arm
6:00 AM	Sleeping					X	
6:30	Wake			X			
	Meditate			X			
	Eat			X			
7:00	Prepare casserole for dinner	X	X				
	Wake kids	X	X				
	Breakfast for kids	X	X				
7:30	Kids leave for school	X					
	Jog 30 minutes	X					
8:00	Shower		X				X
	Dress		X				
	Pack lunch	X	X				
9:00	Light Kitchen Cleaning	X	X				
9:30	Drive to work				X		
10:00	Arrive at work	X		X			
	Quick snack			X			
10:30	Shop opens		X				
11:00	Wait on customers	X	X	X			
	Stock shelves	X	X				
11:30	Eat Lunch			X			
12:30 PM	Work in back office, paperwork.			X			
1:30	Make phone calls			X			
2:00	Walk to post office			X			
3:00	Snack			X			
3:30	Wait on customers	X	X	X			
6:00	Give instructions to staff			X			
	Leave work	X					
6:30	Arrive home				X		
	Prepare Dinner	X	X				
	Dinner with family			X			
7:00	Drive son to soccer practice				X		
	Grocery shop	X	X				
8:00	Drive home				X		
	Unload groceries	X	X				
8:30	Read mail			X			
	Pack lunches	X	X				
	Make phone calls			X			
	Supervise homework			X			
9:00	Snack			X			
10:00	Call shop			X			
	Watch TV			X			
11:00	Go to bed					X	

.

Appendix II – Comparison of Methods to Assess Physical Activity and Energy Expenditure

Type/Cost	Source	Standard of comparision	REE	AEE – treadmill/bike	TEE	Free- living
Harris-Benedict	Clark, 1991	Respirometer	92.4 - 98.1%			
		Ventilated hood	88.5 – 99.1 %			
	Van der Ploeg, 2001	Open circuit - Indirect calorimetry	RMR HB overestimated the mean RMR by 518-600 kj / day (P < 0.001)			
	DeLorenzo, 1999	Indirect calorimetry	RMR by calimetry was 1834 +/- 160 k cal/day – by H-B was 1779 =/- 84 k cal.day			
Activity Questionnaire	Lenders, 2001 7 day recall	Vo2 DLW				Group average was in general agreement. Significant differences between individuals.
	Weston, 1997 previous day recall	Pedometer				Correlation 0.88
		Caltrac				Correlation 0.77 p<0.01
		HR				Correlation 0.53
Motion Sensors	Basset, 2000	Vo2		Mean error scores		
	CSA			.97 MET		
	CSA 2			.47 MET		
	CSA 3			.05 MET		
	Caltrac			.83 MET		
	Kenz			.96 MET		
	Yamax			.1.12 MET		
Pedometer ($20.00)	Eston, 1998	V02 (biokinetics)		Hip 0.782	Hip 0.806	Hip 0.92
	Digiwalker Vamax			Ankle 0.708	Ankle 0.789	Ankle 0.912
				Wrist 0.173 * *(not significant)*	Wrist 0.655	Wrist 0.865
		HR (BH <6000 medical)		Hip 0.622	Hip 0.622	Hip 0.883
				Ankle 0.588	Ankle 0.588	Ankle 0.865
				Wrist 0.534	Wrist 0.534	Wrist 0.792
	Bassett et al, 1996 Vamax	Observation		Steps-accurate for counting on concrete surface 100.6% - 100.7% of actual steps		
	Hendelman et al, 2000 Vamax	Vo2		Walking Correlation r = 0.75		
	Lender, 2001 Vamax	Vo2 DLW				Underestimate by 59%
Uni-axial ($900.00)	Trost, 1998 CSA	Vo2			R = 0.62 – 0.85	
	Janz, 1994	HR				R = 0.69
	Leender, 2001	Vo2 DLW				Underestimate EE by 59%
	Ilitis, 2000 Caltrac	Vo2 (sensor medics vamax 29) Caltrac underestimated actual calorie cost by 4.2, 5.6, and 6.7 k cals/min at 75, 100 and 125 W respectively		95% confidence limits – 5.9 | 2.3 k cal/min below Vo2		
	Easton, 1998 WAM CSA	Vo2 (biokinetic)		Correlation 0.692	Correlation 0.780	Correlation 0.852
		HR (BH <6000 medical)		Correlation 0.614	Correlation 0.684	Correlation 0.734
	Sallis et al, 1990 Cal trac	HR Vo2				Correlations R = 0.42 0.54 R = 0.82
	Maliszewski, 1991 Cal-Trac	Vo2		Correlation R = 0.88 (men)		
	Melanson and Freedson, 1996, CSA	Indirect calorimetry Vo2		R = 0.66 – 0.82 R = 0.77 – 0.89		
Tri-axial	Easton, 1998 Tri-trac R3D model T303 version 6.0	Vo2 (biokinetic)		Correlation 0.883	Correlation 0.908	Correlation 0.926
		HR (BH <6000 medical)		Correlation 0.855	Correlation 0.791	Correlation 0.876

Tri-axial - continued	Chen, 1997 Tri-Trac	Whole room indirect (Vanderbilt) * Despite significant correlations, the Tri-Trac significantly underestimated total EE for the exercise day when compared to the calorimeter (SEE = 0.523 and 0.468 w/kg respectively, P < 0.001)	SEE = 0.112 x/kg P= 0.822	AEE – stepping mean +/- SD Calorimeter – 1.60 +/- 0.51 Range 0.56 – 3.37 Tri-Trac – 1.07 +/- 0.38, Range 0.37 – 2.47 Sig. (P<0.05) AEE – walking Clorimeter – 1.11 +/- 0.39, range 0.36 – 3.05 Tri-trac – 1.02 +/- 0.38, Range 0.27 – 2.89	Estimated vs Measured EE Exercise Day Mean – 0.912 +/- 0.038 Range – 0.665 – 0.969 Normal Day Mean – 0.663 +/- 0.302 Range – 0.252 – 0.970	
	Hendelman et al, 2000 Tri-Trac R3D	Vo2 (METS) Observed a 31.2 – 53.1 % under prediction from Tri-Trac for all activities		Over-ground walking Correlation R=0.89	R=0.62	
	Matthews and Freedson, 1995 Tri-Trac R3D	3 day diary underprediction (mean difference 362.4 k cal/day				
	Lenders, 2001 Tri-trac	DLW Underestimated by 35%				
	Welk, 2000 CSA Bio-Trainer Tri-Trac	Vo2 Mean for all R=0.86 CSA most accurate, Tri-Trac and Bio-Trainer overestimated 101-136% of measured value All monitors underestimated 42-67% of measured value				Lifestyle activity Mean for all R = 0.55
Heat Rate Monitor ($200.00 - $500.00)	Janz et al, 1992	Recall Questionnaire				Total activity R = 0.50
	Strath, 2000	Vo2				Daily activity R = 0.68 With adjustment for age and fitness R = 0.87 SEE = 0.76 METS
Flex HR (HR + Vo2)	Livingstone et al, 1992	Doubly labeled water				Total Daily EE 16.7 – 18.8% of DLW determination

Appendix III – Comparisons of Running Totals of Calories Burned Detected by the SenseWear Armbans vs. a Pedometer/Accoleromter.

Time	Activity	Active - ambulatory	Active – non ambulatory	Sit, stand, mostly at rest	In transit	Lying down	Off the arm	TEE SenseWear armband	TEE Pedometer / Accelerometer
6:00 AM	Sleeping					X			
6:30	Wake			X				27 C	N/A
	Meditate			X				45 C	N/A
	Eat			X					
7:00	Prepare casserole for dinner	X	X	X				125 C	40 C
	Wake kids	X	X					140 C	65 C
	Breakfast for kids	X	X					180 C	85 C
7:30	Kids leave for school	X						195 C	100 C
	Jog 30 minutes	X						465 C	370 C
8:00	Shower		X				X	------	------
	Dress		X					540 C	370 C
	Pack lunch	X	X					580 C	390 C
9:00	Light Kitchen Cleaning	X	X					640 C	420 C
9:30	Drive to work				X			676 C	490 C
10:00	Arrive at work	X		X				691 C	505 C
	Quick snack			X				700 C	505 C
10:30	Shop opens		X					718 C	505 C
11:00	Wait on customers	X	X	X				763 C	533 C
	Stock shelves	X	X					808 C	533 C
11:30	Eat Lunch			X				844 C	533 C
12:30 PM	Work in back office, paperwork.			X				952 C	533 C
1:30	Make phone calls			X				997 C	533 C
2:00	Walk to post office			X				1077 C	633 C
3:00	Snack			X				1086 C	633 C
3:30	Wait on customers	X	X	X				1521 C	851 C
6:00	Give instructions to staff			X				1530 C	851 C
	Leave work	X						1545 C	860 C
6:30	Arrive home				X			1581 C	930 C
	Prepare Dinner	X	X					1621 C	950 C
	Dinner with family			X				1657 C	950 C
7:00	Drive son to soccer practice				X			1675 C	985 C
	Grocery shop	X	X					1835 C	1065 C
8:00	Drive home				X			1853 C	1100 C
	Unload groceries	X	X					1883 C	1115 C
8:30	Read mail			X				1891 C	1115 C
	Pack lunches	X	X					1931 C	1145 C
	Make phone calls			X				1940 C	1145 C
	Supervise homework			X				1967 C	1145 C
9:00	Snack			X				1976 C	1145 C
10:00	Call shop			X				2003 C	1145 C
	Watch TV			X				2084 C	1145 C
11:00	Go to bed					X			