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Accuracy of Physical Activity Monitors in Pregnant Women

Christopher P. Connolly
The University of Tennessee, Knoxville, cconnoll@utk.edu

To the Graduate Council:

I am submitting herewith a thesis written by Christopher P. Connolly entitled "Accuracy of Physical Activity Monitors in Pregnant Women." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Exercise Science.

Dawn P. Coe, Major Professor

We have read this thesis and recommend its acceptance:

David R. Bassett, Jr, Dixie L. Thompson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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ACCURACY OF PHYSICAL ACTIVITY MONITORS IN PREGNANT WOMEN

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Christopher Patrick Connolly

May 2010

Dedication

This thesis is dedicated to my beautiful wife, Erin and beautiful daughter, Carly. You are my source of constant support, hope, love, happiness, direction, and peace. I love you both more than I can say.

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Abstract

Purpose: To determine the step count accuracy of three pedometers and one accelerometer in pregnant women during treadmill walking. **Methods:** Subjects were 30 women in the second or third trimester (20-36 weeks) who were screened for pregnancy-related risk factors. Each subject was fitted with a belt containing three physical activity monitors: Yamax Digiwalker SW-200 (DW), New Lifestyles NL 2000 (NL), and GT3X Actigraph accelerometer (ACT). The Omron HJ-720 (HJ) was placed in the pants pocket. Subjects walked at 54, 67, 80, and 94 $m \cdot min^{-1}$ for two minutes each. Actual steps were determined by an investigator using a hand-tally counter. Percentage of actual steps was calculated for each device at each speed and compared. **Results:** There was a significant interaction between speed and device ($F_{9,20}=7.574, P<0.001$). At all speeds, the NL and HJ were most accurate. At 54 $m \cdot min^{-1}$, the DW was significantly less accurate ($P<0.001$) than all other devices and the ACT was significantly less accurate ($P<0.001$) than the NL and HJ. At 67 $m \cdot min^{-1}$, the ACT and DW were significantly less accurate ($P<0.001$) than the NL and HJ. At 80 $m \cdot min^{-1}$, the DW was significantly less accurate ($P=0.024$) than the NL and HJ. At 94 $m \cdot min^{-1}$, the ACT was significantly less accurate ($P=0.001$) than the NL and HJ. No significant differences were found at any speed for the NL ($P=0.996$) and HJ ($P=0.298$). Trimester did not significantly affect device accuracy. **Conclusion:** In pregnant women, the ACT and DW are less accurate than the NL and HJ. The HJ appeared to be the most accurate. These results can be useful in developing further research studies and physical activity programs that focus on walking during pregnancy.

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CHAPTER 1

INTRODUCTION

The recently released 2008 Physical Activity Guidelines for Americans (104) provides thorough information on the benefits of physical activity specific to many populations, including pregnant women. Although these guidelines give specific exercise recommendations that may result in increases in physical activity among pregnant women, research is extremely limited investigating the effects of exercise programs on reducing pregnancy-related conditions. Low levels of physical activity before and during pregnancy are associated with excessive pregnancy-related weight gain (44), preeclampsia (25), and gestational diabetes (26). These conditions pose a dangerous health risk to the maternal-fetal unit. Increasing physical activity levels among pregnant women may be crucially important in preventing and reducing the complications associated with pregnancy-related conditions.

Walking is the most common choice of physical activity for both pregnant and non-pregnant women, most likely due to its low intensity and availability to virtually all at any time (76). In addition to improving overall health, studies have shown that walking is associated with a reduced prevalence of pregnancy-related conditions (67, 73, 86, 92, 93, 107). However, further research is needed to examine the health benefits that walking intervention programs may provide for both mother and child during pregnancy and at delivery.

Accurately quantifying physical activity is vital in determining the impact of an intervention (102). Pedometers and accelerometers are useful tools that can allow individuals to objectively track walking and other ambulatory activity. These devices, which typically are used

to record steps, have been assessed for accuracy and validity in various populations. However, the accuracy of pedometers and accelerometers has never been investigated in pregnant women.

Previous research has shown that the accuracy of some pedometers can be adversely affected when used by overweight and obese adults (22, 68, 89). The inaccuracies are partly a result of excess abdominal mass, which causes the pedometer to tilt away from the necessary vertical plane. Additionally, Shepherd et al. (89) suggest that large amounts of abdominal adipose tissue may cushion the vertical accelerations of the pedometer, necessary for registering step counts. It is possible increased abdominal mass as a result of the fetus and amniotic fluid may have similar effects on physical activity monitor accuracy in pregnant women.

The validation of physical activity monitors among pregnant women would enable researchers to accurately examine the effects of walking intervention programs on pregnancy-related conditions. Therefore, the primary purpose of this study is to determine the step count accuracy of physical activity monitors in pregnant women during treadmill walking. A secondary purpose of this study is to determine the effect of gestational age on physical activity monitor accuracy.

Research Question 1: Is there an effect of pregnancy on the step count accuracy of commonly used physical activity monitors?

Research Question 2: Is there an effect of gestational age, as defined by trimester, on the step count accuracy of commonly used physical activity monitors?

Hypothesis: Physical activity monitor accuracy will be negatively affected when used by pregnant women. Additionally, physical activity monitors used by pregnant women in their third trimester will be less accurate than women in their second trimester.

CHAPTER 2

REVIEW OF LITERATURE

INTRODUCTION

One of the first physical activity recommendations for pregnant women was published in 1912 and states that "walking is the best kind of exercise (91)." In 2003, the American College of Obstetricians and Gynecologists recommended walking as a total body workout that is easy on the joints and muscles during pregnancy as well as being an excellent workout postpartum (2). The most current 2008 Physical Activity Guidelines for Americans give similar but more detailed recommendations for pregnant women including at least 150 minutes of moderate-intensity aerobic activity (such as brisk walking) per week (104). In contrast to the initial recommendations given at the beginning of the 20th century, today's physical activity recommendations for pregnant women are supported by various research studies. Further research is needed to assess the effects that specific walking programs may have to both mother and child.

This purpose of this literature review is to provide a detailed description of the physical activity trends during pregnancy and how walking, as a means of leisure-time physical activity (LTPA), protects against a number of pregnancy-related disorders and adverse outcomes. Because objective monitoring of walking is imperative in potential interventions, this literature review also examines previous research on step-count accuracy of physical activity monitors in non-pregnant populations as well as the factors that lead to step-count inaccuracies.

BENEFITS AND PREVALENCE OF WALKING IN ADULTS

Walking is the most common choice of LTPA among U.S. adults and the health benefits have been thoroughly investigated in various populations. Walking at a brisk pace has been shown to reduce blood pressure (30, 70) increase high-density lipoprotein cholesterol (7, 39), assist in healthy weight maintenance (39), improve mental health (5, 41), lower the risk of type 2 diabetes (52), reduce the risk of coronary heart disease (58, 62, 66, 94) and stroke (53), and decrease all-cause mortality (45, 61, 83). Chan et al. (17) found that fewer steps per day were associated with increased BMI, waist circumference, diastolic blood pressure, and all components of the metabolic syndrome. In another study, Thompson et al. (100) showed that middle-aged women who walked more steps per day had a lower percent body fat, body mass index, waist circumference, and waist-to-hip ratio than did women who walked fewer steps per day.

Despite the known health benefits, Rafferty et al. (82) found that many walkers need to be more active, with only 39% of walkers achieving the minimum recommendation of 150 min/week. Even more startling, Eyler et al. (36) has shown that over 20% of Americans do not walk for more than 10 minutes at a time during the week. Kruger et al. (57) used data from the 2005 National Health Interview Survey to discover that only 41.5% of U.S. adults walked for leisure during the week for at least 10 minutes. Additionally, they found that 28.2% of adults used walking as a means of transportation (57). Although walking is the most common LTPA among United States adults, many individuals should be walking for physical activity more frequently and for longer durations.

PHYSICAL ACTIVITY TRENDS OF PREGNANT WOMEN

Physical activity levels among pregnant women, including walking, have been investigated. Ning et al. (72) reported that approximately 61% of women participated in some physical activity during pregnancy, greater than the 48% reported by Zhang and Savitz (108). In addition to being the most common form of LTPA among non-pregnant women, Petersen et al. (76) have shown walking to be the most popular physical activity choice during pregnancy. The preference of walking during pregnancy is supported by similar findings (34, 72, 108).

Most recently, Evenson and Wen (35) have analyzed national physical activity levels during pregnancy using National Health and Nutrition Examination Survey (NHANES) data from 1999 to 2006. Questions asked focused on usual daily activities, frequency, intensity, and type of physical activity, physical activity levels compared to a year earlier, television and computer time outside of work, and past month transportation. Participants were classified as meeting recommendations if they reported 150 min/week of moderate-intensity aerobic activity or 75 min/week of vigorous-intensity aerobic activity. Consistent with earlier studies, walking was the most commonly reported physical activity (41%). However, the authors found that only 14% of pregnant women met the recommendations through moderate-intensity activity, and when including vigorous-intensity activity, only 23% met recommendations. Analysis of sedentary behaviors reveals that from 2003 to 2006, over 15% of pregnant women reported watching at least 5 hours of television per day.

A recent longitudinal study examined physical activity levels among pregnant women through Project Viva, a large cohort of pregnant women at a multi-site medical practice. The investigators used self-report questionnaires pre-pregnancy, mid-pregnancy (26-28 weeks gestation), and at 6 months postpartum to assess LTPA change. Results showed a substantial

decline in physical activity during pregnancy and only a partial return to pre-pregnancy physical activity levels during the postpartum period. Even though walking as a specific LTPA also decreased during pregnancy, pregnant women who walked returned to pre-pregnancy levels at 6 months postpartum (75).

Activity levels have also been investigated across pregnancy trimesters. Dinallo et al. (27) and Downs et al. (29) both determined that physical activity decreased from the second trimester to the third. DiNallo et al. (27, 29) determined that self-selected walking pace, accelerometer activity counts and activity energy expenditure all decreased from 20 to 32 weeks gestation. Downs et al. (29) determined through the Leisure-Time Exercise Questionnaire and pedometer step count that physical activity decreased from 20 to 32 weeks gestation. The authors suggest that the physical activity reduction in the third trimester may be a result of physiological changes, such as increased body weight, respiratory, and blood volume (27, 29). Downs et al. (29) infers that psychological changes, such as anxiety, may also contribute to decreasing physical activity levels as delivery nears. However, one major limitation of both of these studies is that the objective physical activity monitors used have never been validated in pregnant women.

PREGNANCY-RELATED DISORDERS

Prevalence

Gestational diabetes and preeclampsia are two of the most common disorders related to pregnancy that can result in serious adverse health consequences if ignored or left untreated. Getahun et al. (43) reported that the prevalence of gestational diabetes in the United States has increased from 1.9% in 1990 to 4.2% in 2004 and continues to increase. Certain high-risk

populations such as the Native American Cree, Northern California Hispanics, and Northern California Asians have prevalence rates anywhere from 4.9-12.8% (54). Preeclampsia incidence in the United States has been found to be 3-7% (3, 13). Wallis et al. (106) found the rates of preeclampsia in the United States to have increased by 25% from 1987-2004, with a 184% increase in gestational hypertension. These pregnancy-related disorders and the related pregnancy-related outcomes are directly associated with pre-pregnancy obesity and excess gestational weight gain.

Associations with Pre-Pregnancy Obesity

Using the most recent NHANES data, Flegal et al. (38) found that 35.5% of adult women in the United States were obese in 2007-2008. The increasing obesity prevalence over time among American women yields a number of associated pregnancy-related disorders that endanger the maternal fetal unit. Baeten et al. (6) examined potential associations between pre-pregnancy weight and pregnancy-related disorders among nulliparous women. A total of 96,801 Washington State birth certificates were reviewed for maternal pre-pregnancy weight, demographic characteristics, and pregnancy complications. Height for each individual was obtained through the Washington State drivers' license records. Pre-pregnancy BMI was calculated and women were categorized as lean (<20.0), normal (20.0-24.9), overweight (25.0-29.9), or obese (≥30.0). Results showed that women who were overweight and obese prior to pregnancy had a significantly higher risk for developing gestational diabetes and preeclampsia compared to lean women. The risk for both pregnancy-related disorders was strongest for women in the obese pre-pregnancy BMI category.

Associations with Weight Gain

Beazley and Swinhoe (10) showed the relationship between parity and weight gain across subsequent pregnancies. This indicates that managing overweight and obesity may be more challenging for parous women as compared to nulliparous women. Pole and Dodds (79) examined weight change between subsequent pregnancies and associated pregnancy-related disorders. A cohort of 19,932 women was identified from the Nova Scotia Atlee Perinatal Database (NSAPD) from 1988 to 1996. Gestational diabetes and pregnancy-induced hypertension were specifically looked at as outcomes of interest. With the exception of gestational diabetes, weight change between pregnancies showed no association with adverse outcomes. However, women who gained 10% or more of their initial pre-pregnancy weight between pregnancies were 60% more likely to develop gestational diabetes in their last pregnancy. In general, weight gain between pregnancies was an independent risk factor for developing gestational diabetes.

Villamor and Cnattignius (105) used the Swedish Birth Registry to examine weight change and pregnancy-related disorders between first and second pregnancies among 151,025 women between 1992 and 2001. As seen in other studies, pre-pregnancy BMI was calculated and used to observe the changes in maternal weight between pregnancies. The minimal weight gain to see increases in risk for pregnancy-related disorders was one BMI unit (kg/m^2). Consistent with Pole and Dodds (79), the risk of gestational diabetes increased with weight gain between pregnancies. Additionally, the risk of preeclampsia and gestational hypertension increased.

The relationship between gestational weight gain and pregnancy-related disorders has also been investigated. Cedergren (16) investigated the effects of low and high gestational

weight gains on pregnant women of different BMI classes and their birth outcomes. The investigators used the Swedish Medical Birth Registry to identify 245,526 pregnancies from 1994 through 2002 and obtain maternal and gestational information. Pre-pregnancy BMI was calculated and women were categorized accordingly: underweight (<20.0), average (20.0-24.9), overweight (25.0-29.9), obese (≥30.0), or morbidly obese (≥35.0). Additionally, women were categorized into gestational weight gain groups: low weight gain (<8 kg), reference group (8-16 kg), or high weight gain (>16 kg). Results from this study indicate a number of negative health consequences associated with gestational weight gain. Underweight, normal weight, and obese women with high weight gains all had an increased risk for preeclampsia, with the risk for underweight and normal weight women especially high.

PREGNANCY-RELATED OUTCOMES

Pregnancy-related disorders may also affect a number of pregnancy-related outcomes at delivery. Common pregnancy-related outcomes that may endanger the health of the child include: fetal distress, labor and delivery duration, early delivery, method of delivery (instrumental, natural, or cesarean section), late fetal death, and delivery of small or large-for-gestational age infant (birth weight 2 standard deviations below or above the mean birth weight).

Associations with Pre-Pregnancy Obesity

As previously mentioned, Baeten et al. (6) examined the associations between pre-pregnancy weight and pregnancy-related disorders. The association between pregnancy-related outcomes and pre-pregnancy weight was also assessed. In addition to the findings on pregnancy-related disorders, the investigators found that pregnant women who were overweight and obese prior to pregnancy had a significantly higher risk for cesarean deliveries, early deliveries, and

delivery of a macrosomic infant. Additionally, this study indicated that infants have nearly twice the risk of death within the first year of life if born to obese women. The rate of fetal death could not be investigated in this study as a result of birth certificate databases including only live births.

However, the association between high pre-pregnancy weights and the risk of fetal death has been assessed in another study. Cnattingius et al. (21) categorized a cohort of 167,750 Swedish women by their pre-pregnancy BMI as lean (<20.0), normal (20.0-24.9), overweight (25.0-29.9), or obese (≥30.0). Maternal information including age, parity, and complications during delivery was obtained from hospital discharge records. Information regarding late fetal death, duration of gestation, and birth weight was obtained from standardized pediatric records. Results showed an increased risk of late fetal death with increased pre-pregnancy BMI among pregnant women.

Associations with Weight Gain

In addition to assessing the effect of weight gain on the risk of pregnancy-related disorders, the studies conducted by Villamor and Cnattignius (105) and Cedergren (16) also examined the risk association of weight gain and pregnancy-related outcomes. Villamor and Cnattignius (105) found that weight gain between the first and second pregnancy was associated with the delivery of large-for-gestational age births. Cedergren (16) found that high gestational weight gain (>16 kg) among all pre-pregnancy BMI classes significantly increased the risk for delivery of a large-for-gestational age infant, particularly in underweight and normal weight women. Specifically, obese women with high weight gains had an increased the risk for cesarean section deliveries and morbidly obese women with high weight gains had an increased

risk for fetal distress. Overweight women with high gestational weight gains had an increased risk for fetal distress as well as instrumental delivery.

IMPACT OF WALKING ON GESTATIONAL DIABETES

A number of studies have been conducted to examine the associations between walking as a means of LTPA and gestational diabetes mellitus. One of the initial studies found that obese women who engaged in some physical activity were less likely to have gestational diabetes compared to obese women who did not exercise (31). Another early study, found that pregnant women who engaged in vigorous-intensity physical activity or brisk walking before pregnancy had lower risks of developing gestational diabetes, although these associations were not statistically significant (92).

Dempsey et al. (26) investigated the risk of developing gestational diabetes in relation to physical activity both before and during pregnancy. From 1996-2000, a cohort of 909 pregnant women (≥16 weeks gestation) in the State of Washington were interviewed about their lifestyle, medical, and reproductive history. Following labor and delivery, pregnancy outcome information was retrieved through hospital medical records. Results showed that pregnant women who engaged in physical activity either before or during pregnancy had a 48-51% reduced risk for developing gestational diabetes. That same investigator also found in another study that daily stair climbing before and during pregnancy reduced the risk of gestational diabetes up to 78% (25)

More recently Zhang et al. (107) continued the assessment of previous studies through mailed physical activity questionnaires to 21,765 women who gave birth from 1990-1998. Self-reported brisk walking paces resulted in substantially reduced gestational diabetes risk. Before

pregnancy, women who walked 4 or more hours per week at a brisk pace had the lowest risk of developing gestational diabetes, compared to women who walked less than 4 hours per week at a slower pace. Also showing the protective effect walking may have, Oken et al. (73) found that walking more than one hour per week before and during pregnancy was associated with 33% reduced risk for gestational diabetes and abnormal glucose tolerance.

Walking intervention studies have also been conducted to observe the impact on gestational diabetes. Davenport et al. (24) recently investigated the impact of a structured low-intensity walking program on blood glucose levels in gestational diabetic women. Thirty pregnant women (BMI>25.0) with gestational diabetes were recruited to participate in this study and followed conventional management of bi-weekly counseling with a dietician and insulin therapy, if necessary. Ten of these subjects also participated in walking 3-4 times per week for 25-40 minutes at 30% heart rate reserve. All subjects walked for at least six weeks up until delivery. Subjects recorded weekly weight gains and insulin needs. Pre and post walking program capillary glucose concentrations were also recorded. Results showed that the 10 subjects who participated in the structured walking program had significantly lower capillary glucose concentrations in the fasted state and one hour after meals than did the subjects who followed just the conventional management. The investigators also found that capillary glucose concentrations dropped from the start to the end of each walking session, thereby showing an acute effect of walking and confirming the findings of Garcia-Patterson et al. (42).

IMPACT OF WALKING ON PREECLAMPSIA

As with gestational diabetes, understanding the impact that walking and other physical activites have on reducing the risk of preeclampsia, or pregnancy-induced hypertension, is vital. Marcoux

et al. (67) were the first to examine this association and found that LTPA in the first 20 weeks of pregnancy may reduce the risk of preeclampsia and gestational hypertension. Additionally, they showed that frequent walking at work and home was associated with a reduced risk of preeclampsia. Saftlas et al. (86) confirmed that walking during work for pregnant women was associated with lower preeclampsia risk, even after controlling for LTPA. Rudra et al. (85) conducted a cohort study examining recreational physical activity levels one year before pregnancy and during the first trimester. The investigators found that pre-pregnancy recreational activity, including walking, also lowers the risk of preeclampsia.

Sorensen et al. (93) also explored this relationship. The researchers interviewed 587 women using a structured questionnaire during the postpartum hospital stay. Questions pertained to medical and lifestyle information including the frequency, duration, and type of recreational activities engaged in one year before and during the first 20 weeks of gestation. In general, results showed that physical activity before and at the beginning of pregnancy reduced the risk of preeclampsia. Women who were physically active in the first 20 weeks of pregnancy had a 35% reduced risk of developing preeclampsia, compared with inactive women. Specifically, brisk walking was associated with a 30-33% decrease in preeclampsia risk among pregnant women. Stair climbing also showed an inverse association.

IMPACT OF WALKING ON GESTATIONAL WEIGHT GAIN

As previously mentioned, pre-pregnancy obesity rates continue to increase and therefore so does the threat of associated pregnancy-related disorders and adverse outcomes. It is crucially important for pregnant women to ensure that weight gains during pregnancy remain in the recommended ranges recently released by the Institute of Medicine: underweight (28-40 lbs), normal weight (25-35 lbs), overweight (15-25 lbs), and obese (11-20 lbs) (90). Investigations as

to whether or not walking can help pregnant women in the prevention of excessive weight gain have been conducted.

A randomized control trial was conducted by Polley et al. (80) to assess the impact that a combined intervention including progressive walking, weight-gain information, and standard nutritional counseling has on weight gain in pregnant women. Results showed that the intervention produced a reduction in excessive weight gain among normal weight pregnant women. Mottola et al. (71) similarly used a combined nutrition and walking program to examine the prevention of excess weight gain in overweight pregnant women. Seventy-five overweight women (BMI 25.0-29.9) began the intervention at 16-20 weeks gestation up until delivery, walking for at least 25 minutes, 3-4 times per week. Results showed that a mild walking program, in conjunction with an individualized nutrition plan, reduces the risk of excessive pregnancy weight gain among pregnant women. Also recently, Stuebe et al. (98) found through a prospective cohort study that walking and vigorous physical activity were associated with lower gestational weight gains.

IMPACT OF PHYSICAL ACTIVITY ON PREGNANCY-RELATED OUTCOMES

Although research on the association between walking and pregnancy-related outcomes is limited, regular physical activity during pregnancy has been shown to be associated with and provide various health benefits to mother and child at or near birth. Several studies have shown an inverse association between physical activity (including walking) and pregnancy-related discomforts in the last few months before delivery (51, 96). Juhl et al. (56) investigated the risk of preterm birth using the Danish National Birth Cohort. Results showed a reduced risk for preterm labor among those women who participated in some kind of exercise during pregnancy. Hegaard et al. (48) confirmed these findings, specifying that pregnant women participating in

light LTPA had a 24% reduced risk of preterm delivery, while those who engaged in moderate-to-heavy LTPA had a 66% reduced risk. Additionally, the investigators found an association between sedentary lifestyle and higher risk for preterm delivery.

In 1990, Clapp (18) monitored the labor of 131 active pregnant women for duration of labor and delivery outcome. Results showed that women who engaged in physical activity during pregnancy at or above 50% of their preconception level had a lower incidence of cesarean section and vaginal operative delivery as well as lower levels of acute fetal distress during labor. Recently, Melzer et al. (69) also showed the impact of physical activity during late pregnancy on cesarean section and vaginal operative delivery in 44 healthy pregnant women. Pregnant women who were inactive had 3.6 times the risk of operative delivery than did the active women (≥30 minutes of moderate-intensity physical activity per day). This study also showed that the duration of the second stage of labor (defined as time from full dilation to delivery) was shorter in the active pregnant women compared to the inactive (on average 88 minutes vs. 146 minutes). As a result, the investigators hypothesized that regular physical activity among pregnant women was especially beneficial during this "pushing" phase of labor.

There are mixed results concerning the impact of physical activity during pregnancy on birth weight (19, 77). Some studies have shown that physical activity during pregnancy decreases birth weight (11, 20). In contrast, other investigators have found that physical activity during pregnancy increases birth weight (47). The general consensus of birth weight research indicates that physical activity during pregnancy yields healthy decreases in birth weight (78).

OBJECTIVE PHYSICAL ACTIVITY MONITORING

The President's Council on Physical Fitness and Sports recently published a review by Pivarnik and Mudd (78), which concluded that future pregnancy research should focus on the assessment of physical activity through more objective measures. Although several studies have been conducted assessing activity trends during pregnancy with the use of objective physical activity monitors, the validity of these devices has never been investigated in this population. Only by examining the accuracy of these commonly used devices in pregnant women, will it be possible to observe the impact certain walking programs have on reducing pregnancy-related disorders and adverse outcomes.

Self-report questionnaires have been shown to underestimate daily walking distance compared with objective monitor values (9). For this reason, pedometers and accelerometers are useful tools in that they objectively quantify ambulatory physical activity. Pedometers are relatively small monitors worn on the midline of the thigh, hip, or in the pocket, usually costing from $10-$200 (87). They are particularly advantageous because of their design to count and display steps during walking or running, giving the user immediate feedback. A recently conducted meta-analysis showed that pedometer use is associated with significant increases in physical activity levels as well as decreases in body mass index and blood pressure (15). Researching a similar topic, Pal et al. (74) found that pedometer use among overweight and obese women increased physical activity levels and decreased systolic blood pressure.

In general, pedometers use one of two types of counting mechanisms: spring-levered or piezoelectric accelerometer. The spring-levered pedometer uses a spring-suspended arm, which moves up and down with the vertical accelerations during ambulatory activity. Each vertical movement opens an electrical circuit allowing the arm to make an electrical contact, thereby

registering a step (12, 22, 87). One limitation with this type of pedometer is the need for it to be placed vertically, or perpendicular to the ground. The piezoelectric pedometer uses a horizontal beam with a weight on the end. When an accelerated movement occurs, the weight on the end of the beam compresses a piezoelectric crystal, recording a step and generating voltage proportional to the acceleration (22).

Accelerometers are devices that measure accelerations of movement in certain time increments and record activity counts congruent with the intensity of activity. Thus, a unique advantage to using an accelerometer is the ability to observe the intensity, frequency, and duration of physical activity (12). The sensitivity of different accelerometer models is dependent on the number of planes in which it measures movement: uniaxial, biaxial, or triaxial. Many accelerometers also have a step count function. Depending on the specific model, accelerometers are commonly attached by a belt, clip or band to the waist or ankle. However, one limitation of accelerometer use is the substantially higher price compared to pedometers, ranging from $300-$1200 (4, 12). Also unlike a pedometer, activity data is not usually shown on the actual accelerometer device, but rather must be downloaded onto a computer in order to view.

VALIDATION OF PHYSICAL ACTIVITY MONITORS

This study will incorporate the use of three pedometers (Yamax Digiwalker SW-200, New Lifestyles NL 2000, Omron Healthcare HJ-720ITC) and one accelerometer (Actigraph GT3X). The SW-200 and NL-2000 pedometers are among the most commonly used devices in pedometer and accelerometer research. The HJ-720 pedometer and the Actigraph GT3X accelerometer are newer devices that are currently being used in various studies.

The SW-200 uses the spring-levered system to provide step counts during ambulatory activity. While its Yamax predecessors, the DW-500 and the SW-701 have been validated and used in previous studies (8, 23, 88), the SW-200 is the most common spring-levered pedometer used in current research. Because of the established validity of the Yamax series, one of the initial pedometer accuracy studies used the SW-200 as the criterion against which 12 other pedometers were compared over a 24-hour period (87).

In 2003, a study was undertaken to assess the accuracy of the SW-200 and CSA accelerometer (predecessor of the GT3X) at various speeds on a treadmill. Le Masurier and Tudor-Locke (60) recruited 13 males and 7 females to walk 5-minute bouts at the speeds of 2, 2.5, 3, 3.5, and 4 mph wearing the SW-200 and the CSA accelerometer. The results showed that the difference between the actual steps taken and the number of steps recorded by the SW-200 was minimal at the speeds of 2.5 mph and above. However, at 2 mph the SW-200 detected only 75% of the actual steps. Another study from the same laboratory group compared the SW-200 and two other pedometers to the criterion CSA accelerometer in both a controlled and free-living condition. Results showed that the SW-200 was closest in accuracy to the criterion over a 24-hour period. However, the controlled part of the study once again suggested that at the slowest treadmill walking speeds, the inaccuracy of the SW-200 increased (59).

The NL 2000 uses the piezoelectric accelerometer mechanism and has been a widely used physical activity monitor for some time. Crouter et al. (23) examined the accuracy of 10 pedometers, including the NL 2000, during 5-minute bouts of walking at the speeds of 2, 2.5, 3, 3.5, and 4 mph. To record actual steps, an investigator used a hand-tally counter. Results showed the NL 2000 was one of the most accurate at measuring steps at every speed. Using the

same 10 pedometers, Schneider et al. (88) assessed the step count accuracy over a 400-meter track walk. Once again, an investigator determined actual steps with a hand-tally counter. They found that the NL-2000 was within 3% of actual recorded steps 95% of the time, demonstrating excellent reliability during self-paced walking.

The HJ-720 is a recently developed pedometer that features two internal piezoelectric sensors capable of detecting vertical and horizontal accelerations. This allows for steps to be counted when the device is placed in either a vertical or horizontal position. Additionally, the HJ-720 features 41-day memory storage for activity information, including step count, with a 7-day recall display. This particular model can also be used with the Omron Health Management Software, allowing for the tracking of personal physical activity on a personal computer.

Holbrook et al. (50) have validated the accuracy of the HJ-720 in both prescribed and self-paced walking conditions. An initial part to this study tested whether or not the pedometers would record steps for 8 participants during two minutes of heel tapping, leg swinging, and driving. The investigators also recruited 34 adults to walk three 100-meter trials at different speeds for each model. Pedometers were placed the on the right hip, left hip, midback, right pocket, left pocket, and in a backpack. Additionally, a third part of this study required the participants to walk two separate 1-mile trials at a self-selected pace. Placements for the HJ-720 remained the same. For both parts of this study, an investigator used a hand-tally counter to determine actual steps walked. This study showed the HJ-720 pedometer to be exceptionally accurate at measuring ambulatory activity while having a low sensitivity to non-ambulatory movement at all placements.

Containing the exact internal mechanism as the HJ-720, the Omron HJ-112 differs only in its inability to be used with the Omron Health Management Software. Recently, Hasson et al. (46) also validated this device through bouts of treadmill walking at speeds of 2.5, 3, and 3.5 mph among 92 participants. Results showed this pedometer to accurately record steps taken among both non-obese (BMI<30 kg/m^2) and obese (BMI≥30 kg/m^2) groups.

The Actigraph GT3X is a new triaxial activity monitor that is sensitive to accelerations of the body on three planes. Previous uniaxial Actigraph models (CSA, Actigraph 7164, Actigraph GT1M) have been shown to be accurate during ambulatory activity (4, 14, 33, 49, 60). The GT1M uses a Micro-Electro-Mechanical System (MEMS) internal accelerometer and filter like the GT3X, while the older CSA and 7164 models use a cantilever beam system. The GT3X has the ability to collect data on three axes compared to the one or two axes of previous models and therefore, is beginning to be used in current research. However, the GT3X has yet to be validated during ambulatory activity.

John et al. (55) found the Actigraph 7164 and three versions of the Actigraph GT1M to have no statistically significant differences in activity counts. However, they did not assess step count accuracy. Abel et al. (4) examined the validity of the GT1M during walking and running. Ten males and ten females walked three 10-minute trials at speeds of 2, 3, and 4 mph on a treadmill. They also ran three 10-minute trials at speeds of 5, 6, and 7 mph. During the walking and running, two investigators used hand tally counters to record actual steps taken. Results showed that at speeds of 3 mph and higher, the GT1M yielded step counts within 3% of the actual steps taken. However at 2 mph, the GT1M recorded only 64% of the actual steps taken.

FACTORS AFFECTING ACCURACY IN PHYSICAL ACTIVITY MONITORS

With the various anatomical changes during pregnancy, it is commonly assumed that various alterations to walking gait occur, especially during the third trimester. In reality, research shows mixed results (40, 64). However, pregnant women may slow their walking pace as they approach delivery. Because slow walking speeds have been shown to yield step count inaccuracies in other populations, pedometer and accelerometer accuracy should be investigated in pregnant women.

Walking Speed

Bassett et al. (8) conducted the first known accuracy study of electronic pedometers. The investigators recruited ten participants to walk on a treadmill at the speeds of 2, 2.5, 3, 3.5, and 4 mph while wearing the 5 devices: Freestyle Pacer 798, Eddie Bauer Compustep II, L.L. Bean Pedometer, Acusplit Fitness Walker, and the Digiwalker DW-500. While the devices (all of which are now no longer being manufactured) showed satisfactory accuracy at the highest speeds, step count error showed the lower speeds to be potentially problematic. Tudor-Locke et al. (101) compared step counts from a common spring-levered pedometer (SW-200) to a CSA accelerometer after 52 participants wore both devices for 7 straight days. Results showed the SW-200 to undercount steps compared to the CSA accelerometer. The investigators noted that the SW-200 required a force of at least 0.35 x g to register a step whereas the CSA required a lesser force of 0.30 x g. Therefore, it was suggested that slow speeds might not generate enough vertical acceleration to register a step in certain pedometers, suggesting that device sensitivity combined with speed may be a primary contributor to step count inaccuracy.

As mentioned previously, additional research studies also found the accuracy of the SW-200 pedometer to decrease at slower walking speeds (59, 60). Research has also been conducted

to investigate gait and step count accuracy in populations assumed to walk at slower speeds. Manns et al. (65) looked at step length, variability, and gait speed in conjunction with SW-200 step counts in 45 adults with neurological disabilities. They found that gait speed, not length variability yielded the greatest step count inaccuracies in this population. Storti et al. (97) examined gait speed and step count accuracy in 34 men and women living in community homes using a Yamax Digiwalker pedometer, an Actigraph accelerometer, and a StepWatch activity monitor. The digiwalker was the most inaccurate of the three devices at all speeds, but particularly at speeds below one meter/second (2.24 mph). Additionally, the Actigraph was also less accurate at less than one meter/second. These studies all indicated that spring-levered pedometers may be the more susceptible to step count error at slow walking speeds, due to a lower sensitivity.

Melanson et al. (68) conducted a two-part study regarding accurate step counting in commercially available pedometers. The first part examined the effect of age, obesity, and self-selected walking speed on SW-200 pedometer accuracy during treadmill walking for 259 participants. Step count accuracy was 71% at walking speeds less than 2 mph. The second part compared a piezoelectric pedometer (Omron HF-100) to two spring-levered pedometers (Walk-4-Life LS-2500 and Step Keeper HSB-SKM) when worn on 32 subjects as they walked at speeds of 1, 1.8, and 2.6 mph. Once again, results showed that piezoelectric pedometers demonstrated considerably better accuracy at slower walking speeds than spring-levered pedometers. Additionally, these investigators also found that the accuracy of SW-200 pedometer decreased in individuals with greater weights and a higher BMI, as a result of average slower walking speeds.

Body Mass Index

A study conducted by Shepherd et al. (89) was the first to examine the effects of BMI on step count accuracy of pedometers. Twenty nine subjects were recruited and participated in walking 400 meters, walking 10 meters slowly, and ascended and descended a flight of stairs while wearing a Step Activity Monitor and a Sportline pedometer. Obese individuals were defined as having a BMI greater than 30.0 units. Results showed that step count error was substantially greater in obese individuals than in non-obese individuals, particularly the with Sportline device. The investigators also proposed that in overweight and obese individuals, the vertical accelerations necessary to record steps might be dampened by a larger amount of abdominal mass and adipose tissue, resulting in decreased accuracy.

Swartz et al. (99) found contrasting results. Twenty-five normal weight (BMI<25.0), 24 overweight (BMI 25.0-29.9), and 17 obese adults (BMI>30.0) were recruited from the University of Tennessee campus and Knoxville community to participate in this study. Participants walked on a treadmill at speeds of 2, 2.5, 3, 3.5, and 4 mph for 3 minutes each while investigators recorded actual steps with a hand-tally counter. Although the primary purpose was to test the effect that BMI category has on SW-200 step count accuracy, a secondary purpose was to investigate the impact of alternate position placement of pedometer on accuracy in overweight and obese individuals. Therefore, pedometers were placed on the recommended anterior mid-line of thigh, mid-axillary line, and posterior mid-line of thigh. Contrary to Shepherd et al.(89), the investigators found that BMI had no effect on pedometer accuracy. Similarly, Elsenbaumer and Tudor-Locke (32) found BMI category to have little effect on pedometer accuracy at a self-selected walking pace.

Furthermore, Swartz et al. (99) determined that although the accuracy of the pedometer placed on mid-axillary line had greater step count inaccuracies than the other two positions, no significant differences in accuracy were found between the three placements. Pregnant women undergo a number of physiological changes, including an increasing abdominal mass. Like the individuals who are overweight and obese, pregnant women may also benefit from alternate pedometer placements during ambulatory activity.

Recent studies have been undertaken to further the investigation on the effect of BMI on step count accuracy. Feito et al. (37) recruited 25 normal weight, 15 overweight, and 10 obese adults (as defined by BMI category) to walk on a treadmill at 1.5, 2.5, and 3.5 mph, while wearing the NL 2000 pedometer, the Actical accelerometer, the GT1M accelerometer, and the StepWatch accelerometer. Results showed all devices to not be affected by BMI at the two faster speeds with some inaccuracies at the slowest speed.

Tyo et al. (103) investigated the effect of BMI on activity monitor accuracy in a free-living environment. Fifty-six normal weight, overweight, and obese adults (as defined by BMI category) wore the SW-200 and the NL 2000 pedometers for seven days. Steps counts were compared to those measured by a StepWatch activity monitor that was also worn for seven days. Although both pedometers undercounted steps compared to the StepWatch, those in the higher BMI category had increased step count error for the SW-200 only.

Tilt Angle

Crouter et al. (22) specifically examined the effect of adiposity on the accuracy of a spring-levered (SW-200) and piezoelectric (NL 2000) pedometer. Forty participants were recruited to walk at speeds of 2, 2.5, 3, 3.5, and 4 mph for 3 minutes each while wearing both

pedometers. Waist, hip, and abdomen circumferences were taken, as was height and weight to calculate BMI. Once pedometers were placed correctly, the investigators measured pedometer tilt angle using a protractor. Following the walking trials, 36 participants wore the devices for a 24-hour period. The primary finding of this study was that the piezoelectric pedometer (NL 2000) was more accurate than the spring-levered pedometer (SW-200) in overweight and obese individuals during treadmill walking. However, another vital finding of this study was that SW-200 error substantially increased with greater absolute tilt angle, particularly when greater than 15˚.

Dock et al. (28) further investigated pedometer tilt angle. They recruited 20 participants to walk two sets of 21 trials wearing a custom-built gimbal with attached SW-200 and NL 2000 pedometers. The gimbal device was used to alter pedometer tilt angle so that the investigators could see its effect on pedometer accuracy. Participants walked a combination of speeds (2.5, 3, and 3.5 mph) and tilt angles (-30, -20, -10, 0, +10, +20, +30°). Results from this study confirmed the findings of Crouter et al. (22), namely that increased absolute tilt angle decreases pedometer accuracy. Although the SW-200 was most affected by pedometer tilt angle, the NL 2000 was also affected. The combination of greater tilt angle and slower speeds appeared to have the greatest impact on pedometer inaccuracy.

SUMMARY

Numerous health benefits have been associated with walking in pregnant women. To truly know the effects of walking programs on reducing pregnancy-related disorders, objective monitoring of walking must be validated specific to this population. Although the accuracy of pedometers and accelerometers has never been examined among pregnant women, a number of

studies have assessed the accuracy of physical activity monitors among other populations. The factors that decrease pedometer accuracy among these groups may be similar to those found in pregnant women.

CHAPTER 3

MANUSCRIPT

ABSTRACT

Purpose: To determine the step count accuracy of three pedometers and one accelerometer in pregnant women during treadmill walking. **Methods:** Subjects were 30 women in the second or third trimester (20-36 weeks) who were screened for pregnancy-related risk factors. Each subject was fitted with a belt containing three physical activity monitors: Yamax Digiwalker SW-200 (DW), New Lifestyles NL 2000 (NL), and GT3X Actigraph accelerometer (ACT). The Omron HJ-720 (HJ) was placed in the pants pocket. Subjects walked at 54, 67, 80, and 94 $m \cdot min^{-1}$ for two minutes each. Actual steps were determined by an investigator using a hand-tally counter. Percentage of actual steps was calculated for each device at each speed and compared. **Results:** There was a significant interaction between speed and device ($F_{9,20}=7.574, P<0.001$). At all speeds, the NL and HJ were most accurate. At 54 $m \cdot min^{-1}$, the DW was significantly less accurate ($P<0.001$) than all other devices and the ACT was significantly less accurate ($P<0.001$) than the NL and HJ. At 67 $m \cdot min^{-1}$, the ACT and DW were significantly less accurate ($P<0.001$) than the NL and HJ. At 80 $m \cdot min^{-1}$, the DW was significantly less accurate ($P=0.024$) than the NL and HJ. At 94 $m \cdot min^{-1}$, the ACT was significantly less accurate ($P=0.001$) than the NL and HJ. No significant differences were found at any speed for the NL ($P=0.996$) and HJ ($P=0.298$). Trimester did not significantly affect device accuracy. **Conclusion:** In pregnant women, the ACT and DW are less accurate than the NL and HJ. The HJ appeared to be the most accurate. These results can be useful in developing further research studies and physical activity programs that focus on walking during pregnancy.

INTRODUCTION

The recently released 2008 Physical Activity Guidelines for Americans (104) recommend at least 150 minutes of moderate-intensity aerobic activity per week for pregnant women. Regular walking is the most common choice for recreational physical activity among pregnant women (34, 72, 76, 108) and has been shown to reduce the risk of pregnancy-related conditions such as gestational diabetes (73, 92, 107) and preeclampsia (67, 86, 93). Additionally, walking has been shown to reduce the risk of excessive gestational weight gain (98). Intervention studies are needed to examine the degree of effect that walking may have on decreasing pregnancy-related conditions and negative health outcomes to both mother and baby.

Ambulatory activity, such as walking, is often quantified by step counts with the use of physical activity monitors such as pedometers and accelerometers. The accuracy of these commercially available devices is crucial in the objective tracking of walking levels and has been assessed under controlled and free-living conditions in several studies (8, 23, 59, 60, 68, 87, 88, 101). Although pedometers and accelerometers have been used to determine physical activity trends during pregnancy (27, 29, 63, 81, 84, 95), the accuracy of these devices has never been examined in pregnant women.

Several studies have presented acceptable accuracy for the spring-levered Yamax Digiwalker SW-200 (DW) and the piezoelectric New Lifestyles NL 2000 (NL) (23, 87, 88) pedometers. However, slow walking speeds (59, 60, 68) and high body mass index (68, 89) have been shown to increase step count error, particularly in spring-levered pedometers. Crouter et al. (22) further assessed the impact of overweight and obesity on pedometer accuracy and found the DW to be less accurate than the NL in this population, the pedometer tilt angle (angle away from

the vertical axis) being the primary factor for inaccuracy. Additionally, Dock et al. (28) found the combination of greater pedometer tilt and slow walking speed to be especially preventative of pedometer accuracy. Walking speeds and pedometer tilt may yield similar inaccuracies among pregnant women.

Due to the limitations of the older spring-levered and piezoelectric pedometers, which must be placed on the vertical plane for optimal accuracy, manufacturers have recently developed more sensitive devices with multiple internal sensors. The Omron HJ-720ITC (HJ) pedometer features two internal piezoelectric accelerometers capable of detecting both vertical and horizontal accelerations. Holbrook et al. (50) found the HJ to be accurate in both normal and overweight adults at various speeds. Similarly, Actigraph (Pensacola, FL) has recently released the GT3X (ACT), a triaxial accelerometer capable of detecting and measuring motion in three planes. However, step count accuracy of the Actigraph GT3X has not yet been examined.

In order to objectively monitor walking interventions in pregnant women and investigate the degree of effect they may have on reducing negative outcomes to the maternal-fetal unit, the accuracy of physical activity monitors in pregnant women must first be determined. Therefore, the primary purpose of this study is to examine the step count accuracy of three commonly used pedometers and one accelerometer in pregnant women during treadmill walking. A secondary purpose is to determine the effect of gestational age (as defined by trimester) on pedometer and accelerometer accuracy.

METHODS

Subjects. Thirty pregnant women (15 second trimester, 15 third trimester) from a high risk OB/GYN office at the University of Tennessee Medical Center participated in the current study.

Participants were recruited during one of their regularly scheduled appointments by a certified nurse practitioner. All participants were at least 18 years of age with a gestational age of 20 to 36 weeks. Participants were excluded from the study if these criteria were not met or if they had one or more contraindications for exercise, as outlined by the American College of Obstetrics and Gynecology (1). Demographic data for each participant, including age, gestational age, height, weight, BMI, parity, and gravidity, were provided by the nursing staff. Each participant provided informed consent prior to participating in the study. The protocol was approved by the University of Tennessee Institutional Review Board and the University of Tennessee Graduate School of Medicine.

Treadmill Walking. The four physical activity monitors were introduced to the participant and properly positioned. Because pedometer tilt angle in populations with excess abdominal mass has been shown to effect step count accuracy in some devices (22), caution was taken in physical activity monitor placement (Figure 1). The DW and the NL were placed just anterior to the right and left iliac crest of the hips on an elastic belt around the waist. The ACT was also placed on the elastic belt at the mid-axillary line of the left thigh and the HJ was placed in the front right pants pocket.

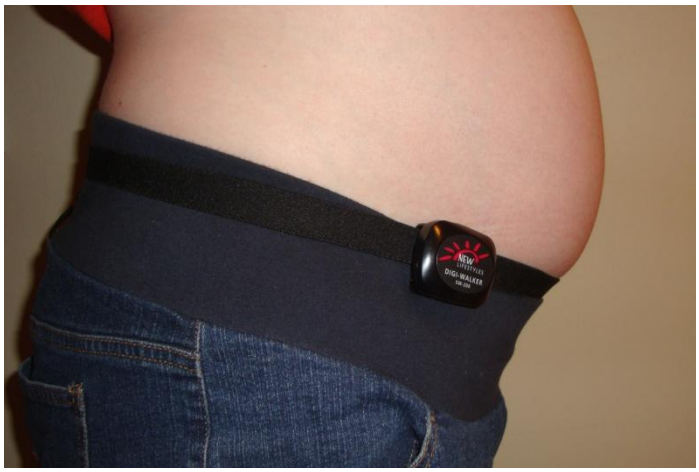
Participants walked on a treadmill (Vision Fitness TF 9200 model) for a total period of 8-13 minutes. Prior to testing, an optional 5-minute walking period was given at the speed of 54 $m \cdot min^{-1}$ to ensure familiarity with the treadmill. Participants walked four trials at the speeds of 54, 67, 80, and 94 $m \cdot min^{-1}$ for 2 minutes at each speed. During each walking trial, an investigator tallied steps with a hand-tally counter. At the end of each trial, the participant straddled the treadmill belt in order for the investigator to record actual tallied steps as well as

steps recorded from the physical activity monitors. During this time, the DW and NL were reset to 0 in preparation for the next trial. The HJ does not allow step counts to be reset, and therefore, pedometer-recorded steps were calculated by taking the step count difference between the beginning and end of each trial. The step count data from the ACT was downloaded and recorded at the end of all four walking trials. Before physical activity monitors were removed from the participant, a protractor (Sears Craftsman magnetic professional) was used to measure the pedometer tilt angle.

Statistical Analysis. All data were analyzed using SPSS version 17.0 (SPSS, Inc., Chicago IL). An alpha of 0.05 was used to indicate statistical significance for all analyses. Descriptive statistics are reported as mean ± standard deviation. A two-way repeated measures ANOVA (speed x device) with trimester as a between subjects factor was used to compare percentage of actual steps (100 x (actual steps taken – device recorded steps)). Pairwise comparisons with Bonferroni adjustments were performed to explore the significant interactions by comparing the four speeds within each device as well as the four devices at each speed. Additionally, Pearson correlations were calculated to observe potential relationships between percentage of actual steps recorded and gestational age, pedometer tilt angle, and BMI for each device at each speed. Bland-Altman plots were used to examine variability in device error scores. Mean error score and the 95% prediction interval are displayed. Prediction intervals that are tightly spaced around zero signify greater device accuracy. Devices that underestimate actual steps taken are plotted above zero and devices that overestimate actual steps taken are plotted below zero.

A

B



C

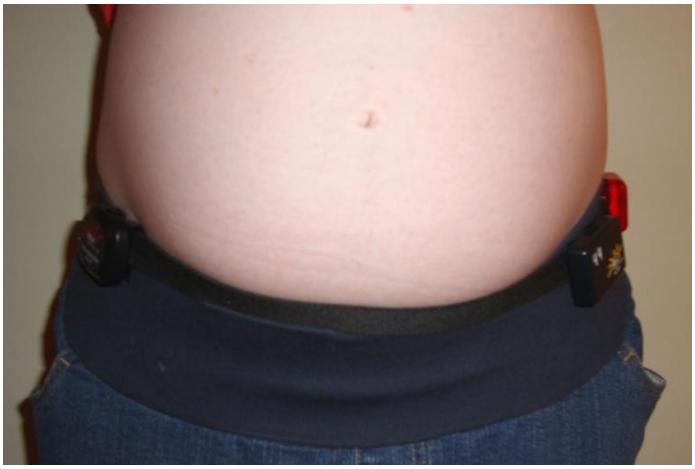


FIGURE 1—Placement of physical activity monitors on participant (28 week gestational age). (*A*) Left side – NL just anterior to illiac crest of left hip, ACT at mid-axillary line of left thigh. (*B*) Right side – DW just anterior to illiac crest of right hip, HJ front right pants pocket. (*C*) Front – shows placement of all physical activity monitors.

RESULTS

Participant characteristics are shown in Table 1. Pregnant women in the third trimester had increased mean age, gestational age, body mass, and BMI compared to pregnant women in the second trimester. However, only gestational age was significantly greater for 3rd trimester pregnant women than 2nd trimester pregnant women (P<0.001).

The percentage of actual steps recorded by each physical activity monitor at all speeds combined was as follows: ACT (86.9 ± 16.2%), DW (78.6 ± 29.6%), NL (103.3 ± 11.9%), and HJ (97.7 ± 7.4%). The percentage of actual steps recorded at each speed by all physical activity monitors combined was as follows: 54 m·min^{-1} (83.1 ± 27.8%), 67 m·min^{-1} (93.2 ± 18.6%), 80 m·min^{-1} (95.6 ± 15.9%), and 94 m·min^{-1} (94.7 ± 15.3%). The results of the repeated measures ANOVA indicated that trimester did not significantly affect device accuracy. There was a significant interaction between speed and device ($F_{9,20}$=7.574,P<0.001).

To examine this interaction, individual devices were compared at each speed (Table 2). At the speed of 54 m·min^{-1}, all devices significantly differed (P<0.001) from one another with the exception of the NL and HJ, which had the highest accuracy. At the speed of 67 m·min^{-1}, the ACT and DW were found to not be significantly different from each other and the NL and HJ were found to not be significantly different from each other. However, the NL and HJ were significantly more accurate (P<0.001) than the ACT and DW. At the speed of 80 m·min^{-1}, significant differences were found (P=0.024), with the DW being less accurate than the NL or HJ. At the speed of 94 m·min^{-1}, devices again differed significantly (P=0.001), with the ACT significantly less accurate than the NL and HJ.

TABLE 1. Participant characteristics (mean ± SD).

Variable	2nd Trimester (*N* = 15)	3rd Trimester (*N* = 15)	All Participants (*N* = 30)
Age (yr)	29.8 ± 5.2	31.4 ± 6.0	30.6 ± 5.6
Gestational Age (wk)*	23.3 ± 2.4	30.7 ± 1.9	27.0 ± 4.3
Body Mass (lbs)	181.5 ± 43.3	186.1 ± 30.6	183.8 ± 36.9
Height (in)	64.7 ± 3.2	63.9 ± 2.9	64.3 ± 3.0
BMI ($kg \cdot m^{-2}$)	30.3 ± 6.1	32.2 ± 5.8	31.3 ± 5.9

BMI, body mass index, * significant difference between 2nd and 3rd trimester pregnant women, $P < 0.05$

TABLE 2. Percent of actual steps recorded by each device at each treadmill walking speed (mean ± SD)

Speed	ACT	DW	NL	HJ	Overall
54 ($m \cdot min^{-1}$)	77.5 ± 19.2	56.9 ± 32.8	103.2 ± 15.8	94.6 ± 13.1	83.1 ± 27.8
67 ($m \cdot min^{-1}$)	90.4 ±13.4	80.2 ± 28.7	103.1 ± 9.3	99.0 ± 2.4	93.2 ± 18.6
80 ($m \cdot min^{-1}$)	93.2 ± 10.9	86.5 ± 23.9	103.5 ± 13.2	99.0 ± 2.0	95.6 ± 15.9
94 ($m \cdot min^{-1}$)	86.3 ± 16.3	90.8 ± 20.3	103.3 ± 8.4	98.4 ± 5.7	94.7 ± 15.3
Overall	86.9 ± 16.2	78.6 ± 29.6	103.3 ± 11.9	97.7 ± 7.4	

ACT, Actigraph GT3X; DW, Yamax Digiwalker SW-200; NL, New Lifestyles NL 2000; HJ, Omron HJ-720ITC

Additionally, individual speeds were compared for each device. The ACT was most inconsistent ($P<0.001$), showing significantly less accuracy at 54 $m \cdot min^{-1}$ than 67 $m \cdot min^{-1}$ and 80 $m \cdot min^{-1}$, but not significantly different from 94 $m \cdot min^{-1}$. The DW was significantly more accurate ($P<0.001$) at the speeds of 67 $m \cdot min^{-1}$, 80 $m \cdot min^{-1}$, and 94 $m \cdot min^{-1}$ than it was at the speed of 54 $m \cdot min^{-1}$. No significant speed differences were found for the NL ($P=0.996$) and the HJ ($P=0.298$). Figure 2 illustrates the average percentage of actual steps recorded by each device at each speed.

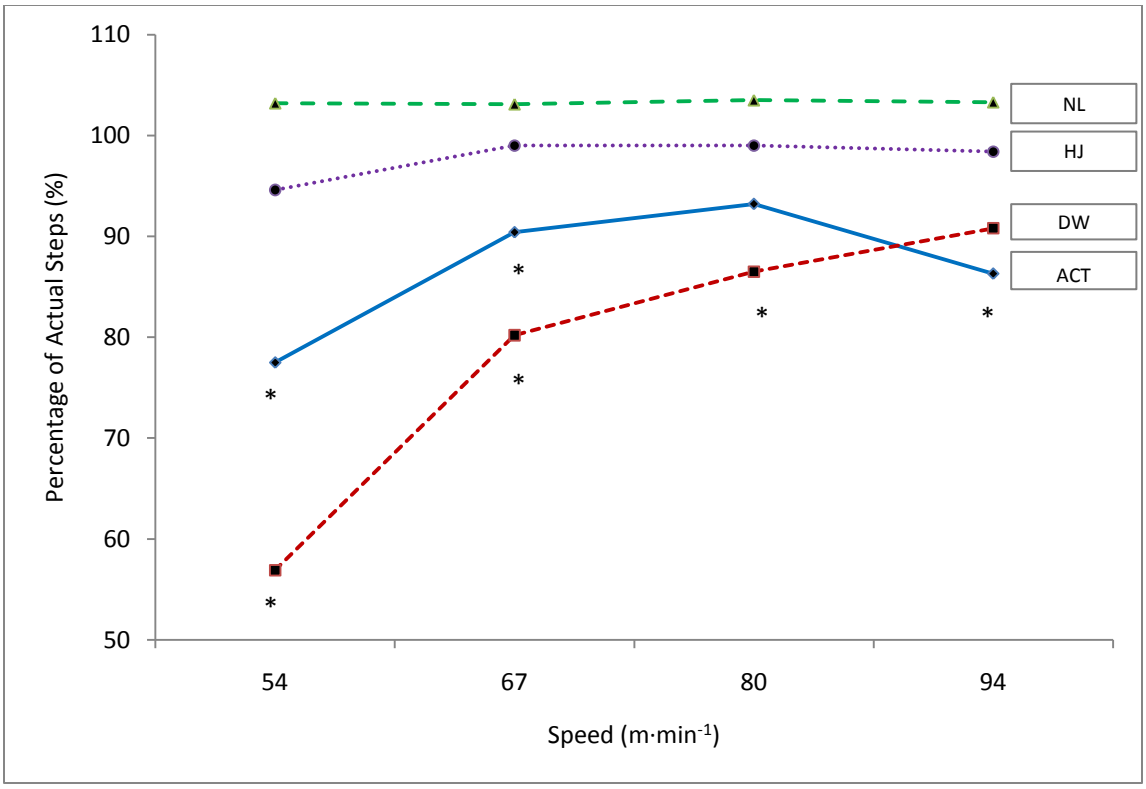


FIGURE 2—Effect of treadmill walking speed on the percent of actual steps recorded by the Actigraph GT3X (ACT), Yamax Digiwalker SW-200 (DW), New Lifestyles NL-2000 (NL), and Omron HJ-720 (HJ) when worn by pregnant women. * Significantly less accurate than the NL and HJ at the given speed (*P*<0.05).

The overall accuracy of each device is represented in Figure 3 using Bland-Altman plots, which assessed the agreement between actual steps and device recorded steps. The NL and HJ showed to be far more accurate than the DW or ACT, with the HJ having minimal variability compared to the DW, ACT, and NL. Although recording the lowest overall percentage of actual steps of the physical activity monitors, the DW increased in accuracy with increased walking speed as represented in Figure 3(*B*).

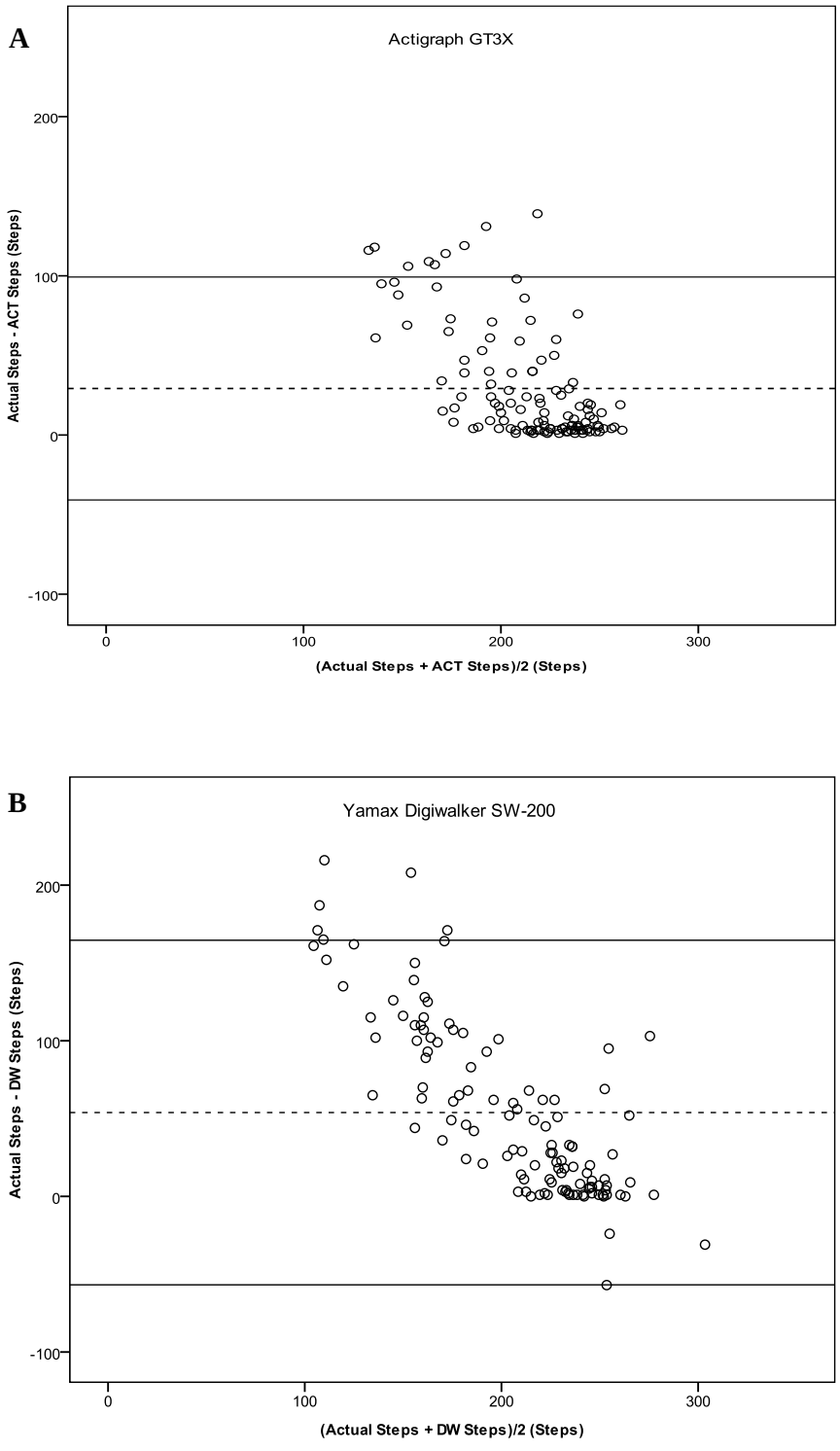
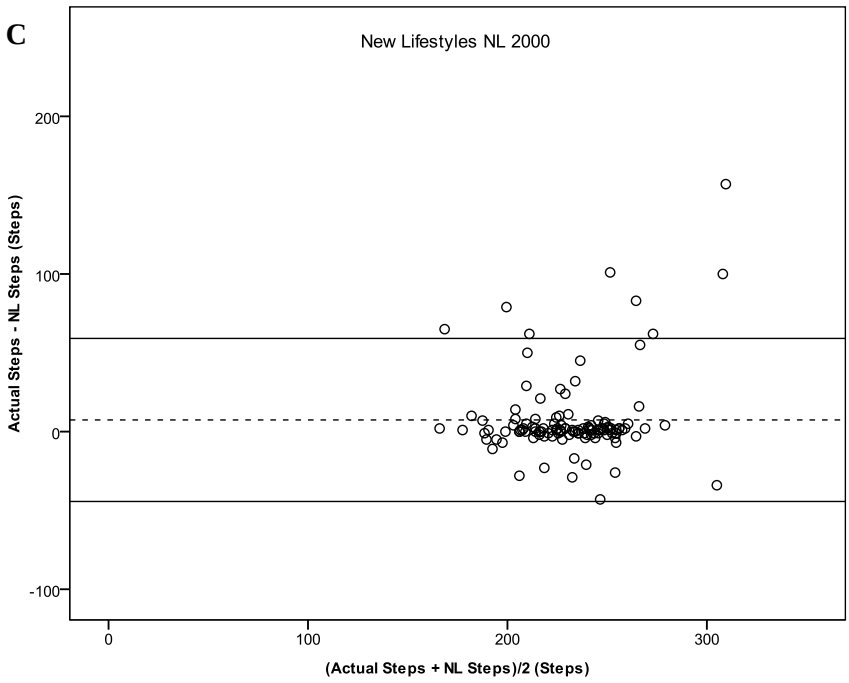


Figure 3-Bland-Altman plots depicting error scores (actual steps minus pedometer steps) for the (*A*) Actigraph GT3X, (*B*) Yamax Digiwalker SW-200, (*C*) New Lifestyles NL 2000, and the (*D*) Omron HJ-720. *Dashed line* represents mean difference; *solid lines* represent 95% prediction interval.



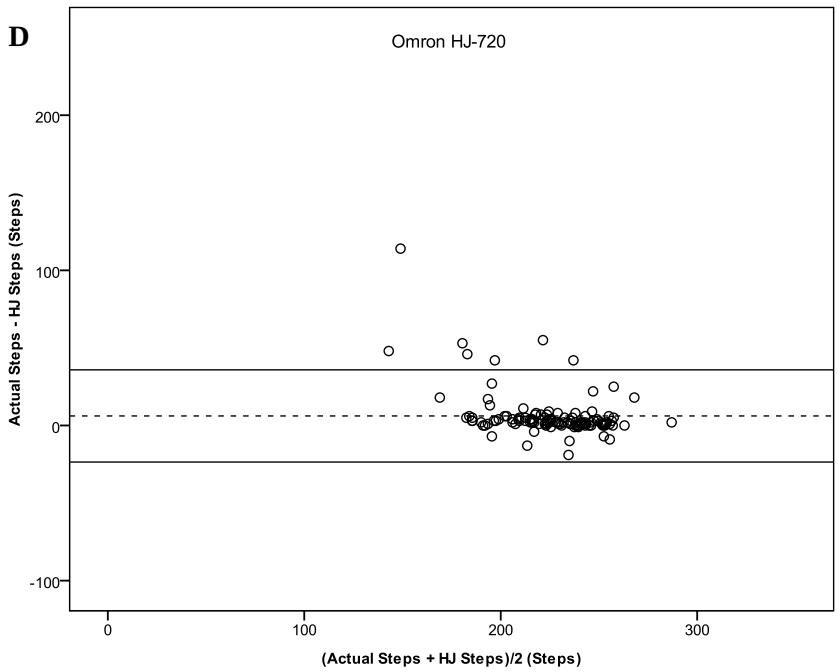


Figure 3-Continued.

Pearson correlations were run to investigate the relationship between percentage of actual steps recorded and gestational age, pedometer tilt angle, and BMI for all devices at all speeds. Significant correlations were found between BMI and NL percentage of actual steps recorded at speeds of 54 $m \cdot min^{-1}$ (r=0.537,*P*=0.002), 67 $m \cdot min^{-1}$ (r=0.571,*P*=0.001), 80 $m \cdot min^{-1}$ (r=0.362,*P*=0.049), and 94 $m \cdot min^{-1}$ (r=0.465,*P*=0.010). All other devices were not correlated with BMI. These significant relationships should be interpreted carefully due to the small sample size and the unique nature of BMI during pregnancy. Additionally, significant correlations were found between gestational age and HJ percentage of actual steps recorded at the speed of 94 $m \cdot min^{-1}$ (r=0.413,*P*=0.023) and between pedometer tilt angle and ACT percentage of actual steps recorded at the speed of 67 $m \cdot min^{-1}$ (r=-0.443,*P*=0.014).

DISCUSSION

Pedometers and accelerometers are useful tools in the quantification of ambulatory activity. It is important that these devices are validated in pregnant women, in order to see possible effects of walking on reducing the negative health outcomes of pregnancy-related conditions such as gestational diabetes, preeclampsia, and excess gestational weight gain. The current study was the first to examine the step count accuracy of physical activity monitors in this population. The primary finding of this study is that the NL and HJ pedometers are more accurate than the DW pedometer and ACT accelerometer in pregnant women during treadmill walking.

It is common assumption that pregnant women slow their walking pace as pregnancy progresses. Therefore, the slowest speed used in this study (54 $m \cdot min^{-1}$) may be representative of a pregnant woman's typical walking pace. The current study showed that walking speed

directly affects the accuracy of the DW pedometer and ACT accelerometer in pregnant women. Previous research has consistently shown that slower walking speeds in non-pregnant populations yield greater pedometer inaccuracies, particularly in the spring-levered devices (8, 23, 59, 60, 68, 99). Tudor-Locke et al. (101) suggested slow walking speeds might not generate the necessary vertical acceleration (0.35 *g*) for the DW to register a step. This appears to be the case in the current study with the DW recording 56.9% of actual steps at 54 $m \cdot min^{-1}$ but greater than 80.2% at all other speeds. The ACT requires less vertical acceleration to record a step than does the DW, a possible explanation as to why the ACT was significantly more accurate at the slowest speed of 54 $m \cdot min^{-1}$. However, the ACT was also affected by slow walking speeds, similar to the results of older Actigraph models in non-pregnant populations (4, 97).

The current study also revealed that the piezoelectric NL and HJ pedometers recorded 103.2% and 94.6% of actual steps at the slowest speed of 54 $m \cdot min^{-1}$ in pregnant women. This extends the findings of the superior accuracy of piezoelectric pedometers at slow speeds in non-pregnant populations (22, 23, 50) and confirms the suggestion of Melanson et al. (68) that the use of a piezoelectric pedometer would be more accurate in those populations who naturally walk at slower speeds. The HJ appears (Figure 3*D*) to be more accurate than the NL (Figure 3*C*) at the faster speeds, possibly as a result of its dual piezoelectric sensor system.

Although the accuracy of physical activity monitors in pregnant women has not been examined prior to the current study, the impact of tilt angle and BMI on device accuracy has been investigated in overweight and obese individuals. Crouter et al. (22) examined the accuracy of a spring-levered (SW-200) and piezoelectric (NL 2000) pedometer in 40 overweight and obese individuals during treadmill walking at speeds of 2, 2.5, 3, 3.5, and 4 mph for 3 minutes

each. Following the walking trials, 36 participants wore the devices for a 24-hour period. As previously mentioned, the primary finding of this study was that the piezoelectric NL 2000 was more accurate than the spring-levered SW-200. Additionally, pedometer tilt angle (angle away from the vertical axis) was the primary reason for step count inaccuracy, particularly when greater than 15° and combined with slower walking speeds. In order to negate pedometer inaccuracies that result from large tilt angles in the current study, the DW and NL were placed just anterior to the iliac crest of the right and left hips. This resulted in only one participant having a pedometer tilt angle greater than 15°. The placement of these pedometers in a different location other than the recommended midline of the thigh is supported by Swartz et al. (99) who found no significant differences in DW accuracy when placed at the recommended midline of the thigh and mid-axillary line of the hip.

High BMI levels have been found to affect pedometer accuracy in several studies (68, 89), while other research has showed BMI to have no effect (32, 99). In the current study, increased BMI was positively related to percentage of actual steps recorded by the NL at the speeds of 54 $m \cdot min^{-1}$, 67 $m \cdot min^{-1}$, 80 $m \cdot min^{-1}$, and 94 $m \cdot min^{-1}$. However, at all other speeds and for all other devices, BMI was not related to device accuracy or inaccuracy. Another finding of the current study is that trimester had no significant effect on the accuracy of each device. An explanation to this might be the varying body mass and BMI levels among pregnant women in both trimesters, which resulted in third trimester pregnant women having only slightly higher averages than did second trimester pregnant women.

The current study has several strengths and limitations. A notable strength was that the physical activity monitors examined are among the most commonly used in physical activity

research. Furthermore, each monitor contained a different internal mechanism for step counting. Additionally, actual steps were counted through direct observation with the use of a hand-tally counter as opposed to using another activity monitor as a criterion device. A final strength was that participants in the current study were women at various stages of pregnancy, with gestational ages ranging from 20 to 34 weeks. This gestational range allowed for a large variation in abdominal size and shape. Concerning limitations, the sample size was relatively small and certain anthropometric assessments were not taken, including waist and hip circumferences. Also, participants engaged in treadmill walking only. Free-living walking was not assessed as in previous pedometer and accelerometer research. A final limitation to the current study is that participants were not assessed longitudinally, but rather cross-sectionally.

The main objective of this study was to assess the accuracy of three pedometers and one accelerometer in pregnant women of various gestational ages during treadmill walking. Results show the NL and HJ pedometers to be substantially more accurate than the DW pedometer and the ACT accelerometer. Slower walking speeds greatly affected the accuracy of the DW and ACT and had minimal effect on both the NL and HJ. Overall, both the NL and HJ are effective tools for providing step count accuracy in pregnant women, with the HJ appearing to be most accurate. Future research investigating the impact of walking during pregnancy on pregnancy-related conditions should consider using the NL and HJ for accurate measurements.

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APPENDICES

APPENDIX A

INFORMED CONSENT

Version Date: 6/8/2009

Consent to Take Part in a Research Study

Title: Accuracy of Physical Activity Monitors in Pregnant Women

Principal Investigators: Dawn P. Coe, Ph.D.

Sub Investigators: David R. Bassett, Ph.D.
Christopher Connolly, B.S.
Jo Kendrick, RNC, MSN, WHNP, CDE
Dixie L. Thompson, Ph.D.

You are being asked to take part in a research study. This consent will tell you about the study. Please read this form carefully. You will be given a chance to ask questions. If you decide to be in the study, you will be given a copy of this consent.

Taking part in this research study is voluntary. You may choose not to take part in the study. Saying no will not affect your rights to health care or services. You are also free to withdraw from this study at any time.

Why is this study being done?
The purpose of this study is to see how well physical activity monitors work on pregnant women during treadmill walking. Another goal of this study is to see if gestational age affects the monitors' accuracy. (Gestational age is the number of weeks you have been pregnant.)

How long will the study last?
You will be in this study for one visit lasting about 30 minutes. This 30 minute time frame includes the consent process, time to get comfortable with the treadmill (5 minutes, if needed), and the actual testing (8 minutes). Estimated walking time for this study is 8-13 minutes. Your office visit with your physician will not be delayed by participating in this study.

How many people will be in the study?
About 40 people will be in this study at UT Medical Center (UTMC).

What will happen to me during the study?
You will be shown the physical activity monitors and the treadmill will be explained. Three activity monitors will be placed on a belt around your waist and one activity monitor will be placed in your pocket. The activity monitors are each the size of a pager. We will also look at how much the activity monitors are tilted using a protractor. You will then walk on the treadmill for five minutes at 2.0 miles per hour (mph) (slow walking pace) to become familiar with treadmill walking. Testing will begin with you walking at 2.0 mph for two minutes. We will then ask you to walk at 2.5 mph , 3.0 mph (normal walking pace), and 3.5 mph (fast walking pace) for 2 minutes each. Total walking time will be 8 minutes. Actual steps in all four stages will be counted by a researcher using a hand-tally counter.

What risks can I expect from being in the study?
Risks associated with this study are minimal. There is a slight chance that you may be injured while walking on the treadmill. Injuries may include a muscle sprain or strain, bruising, or a bone fracture from falling off of the treadmill. There is also risk of injury to the unborn child in the event that a fall occurs. You will have time to get used to the treadmill before data collection, which may help to reduce risk of injury. You may hold on to the treadmill railings if you feel that you are losing your balance. A researcher will be standing alongside the treadmill for support and to reduce the risk of falls. Additional risks include: dizziness or lightheadedness, increased shortness of breath, rapid heartbeat, difficulty walking, uterine contractions or chest pain. You should stop walking if you have any of these symptoms. If the walking pace is too fast for you to perform comfortably, you are free to stop. There will be nurses and doctors nearby to care for you if you have any of these symptoms.

Subject's Initials _____

Are there benefits to taking part in the study?
There are no direct benefits to you from this study. However results from this study may help researchers learn which physical activity monitor is most accurate in the measurement of physical activity in pregnant women.

What if I am injured in this study?
You are not waiving any legal rights or releasing the University of Tennessee, the University of Tennessee Medical Center, or its agents from liability for negligence. In the event of physical injury resulting from research procedures the University of Tennessee does not have funds budgeted for compensation either for lost wages or for medical treatment.

You will get medical treatment if you are injured as a result of taking part in this study. You and/or your health plan will be charged for this treatment. The study will not pay for medical treatment.

It is important that you tell your study researcher, Dawn Coe, Ph.D. if you feel that you have been injured because of taking part in this study. You can tell the researcher in person or call her at 865-974-0294.

In the case of injury resulting from this study, you do not lose any of your legal rights to seek payment by signing this form.

Who do I call if I have questions about the study?
Questions about the study: Dawn Coe, Ph.D:

865-974-0294 (Phone #)
dcoe@utk.edu (E-mail)

Questions about your rights as a research subject: You may contact the University of Tennessee Graduate School of Medicine Institutional Review Board (IRB) at 865-305-9781 or the University of Tennessee, Knoxville, Office of Research Compliance Officer at 865-974-3466. The IRB is a group of people that reviews studies for safety and to protect the rights of study subjects.

What will it cost me to be in the study?
There will be no cost to you to be in the study.

Will I be paid for participating?
You will be reimbursed for your parking for participating in this study.

Is the Investigator paid to do this study?
No, the investigator is not being paid to enroll people in this study.

Can I stop being in the study?
You may withdraw from the study at any time. Please see the section on confidentiality for more information on withdrawing from the trial.

Could I be removed from the study?
You may be withdrawn for the study for any of the following reasons:

- You are not able to safely walk on the treadmill.
- You cannot keep up a walking pace with any of the specified treadmill speeds.
- You experience any difficulty or discomfort while walking.

Will my medical information be kept private?
All reasonable efforts will be made to keep your protected health information (PHI) private and confidential. PHI is health information that is, or has been, collected or maintained and can be linked back to you. Using or sharing ("disclosure") of such information must follow federal privacy guidelines. By signing the consent document for this study, you are giving permission ("authorization") for the uses and

Subject's Initials _____

disclosures of your personal health information. A decision to participate in this research means that you agree to let the research team use and share your PHI as described below, for the purpose of this research study.

As part of the study, Dawn Coe, Ph.D. and her study team may share the results of your pregnancy status (gestational age and due date). These may be study or non-study related. They may also share portions of your medical record, with the groups named below:

- The Federal Government Office for Human Research Protections,
- The University of Tennessee Graduate School of Medicine Institutional Review Board,

Federal privacy regulations may not apply to these groups; however, they have their own policies and guidelines to assure that all reasonable efforts will be made to keep your personal health information private and confidential.

The study results will be retained in your research record for at least six years after the study is completed. At that time, the research information not already in your medical record will be destroyed. Any research information entered into your medical record will be kept indefinitely.

Unless otherwise indicated, this permission to use or share your PHI does not have an expiration date. If you decide to withdraw your permission, we ask that you contact Dawn Coe, Ph.D. in writing and let her know that you are withdrawing your permission. The mailing address is 338 HPER, 1914 Andy Holt Avenue Knoxville, TN 37996. At that time, we will stop further collection of any information about you. However, the health information collected prior to this withdrawal may continue to be used for the purposes of reporting and research quality.

Your treatment, payment or enrollment in any health plans or eligibility for benefits will not be affected if you decide not to participate. You will receive a copy of this form after it is signed.

CONSENT OF SUBJECT:
I have read or have had read to me the description of the research study. The investigator or her representative has explained the study to me and has answered all of the questions I have at this time. I have been told of the potential risks, discomforts and side effects as well as the possible benefits (if any) of the study. I freely volunteer to take part in this study.

Printed Name of Subject	Signature of Subject	Date & Time
Printed name of person Obtaining Consent	Signature of person Obtaining Consent	Date
Printed name of Investigator	Signature of Investigator	Date

IRB APPROVED
DATE 8-14-2009
Brenda Lawson
Compliance Officer & IRB Administrator

Subject's Initials _____

APPENDIX B

PARTICIPANT DEMOGRAPHIC SHEET

Data Sheet

Code#_____Medical Record:_____DOB:_____

Name:_____Age:_____ Gravida:_____Parity:_____

Gestation Age:_____ Estimate Date of Conception:_____

Maternal weight:_____Height:_____BMI:_____

RISK FACTORS:

Contraindications for Exercising During Pregnancy*
Relative
- Severe anemia
- Unevaluated maternal cardiac dysrhythmia
- Chronic bronchitis
- Poorly controlled type I diabetes
- Extreme morbid obesity
- Extreme underweight [Body mass index (BMI) <12]
- History of extremely sedentary lifestyle
- Intrauterine growth restriction in current pregnancy
- Poorly controlled hypertension
- Orthopedic limitations
- Poorly controlled seizure disorder
- Poorly controlled hyperthyroidism
- Heavy smoker

Absolute
- Hemodynamically significant heart disease
- Restrictive lung disease
- Incompetent cervix / cerclage
- Multiple gestation at risk for premature labor
- Persistent second or third trimester bleeding
- Placenta previa after 26 wk of gestation
- Premature labor during the current pregnancy
- Ruptured membranes
- Preeclampsia / pregnancy-induced hypertension

*Reprinted with permission from American College of Obstetricians and Gynecologists. Exercise during pregnancy and the postpartum period. ACOG Committee Opinion No. 267. Obstet Gynecol 2002;99:171–173.

APPENDIX C

RECRUITMENT FLYER

Subjects are Needed to Determine the Accuracy of Physical Activity Monitors During Walking in Pregnant Women

The purpose of this study is to see how well physical activity monitors work on pregnant women during treadmill walking. Another goal of this study is to see if gestational age affects the monitors' accuracy. (Gestational age is the number of weeks you have been pregnant.)

If you choose to participate, you will be in this study for one visit lasting about 30 minutes. This 30 minute time frame includes the consent process, time to get comfortable with the treadmill (5 minutes, if needed), and the actual testing (8 minutes). Estimated walking time for this study is 8-13 minutes. Your office visit with your physician will not be delayed by participating in this study.

Please tell your nurse if you are interested in participating in this study.

Study contact information:
Dawn Coe, Ph.D.
865-974-0294
dcoe@utk.edu

Jo Kendrick,WHNP-BC, CDE
865-305-6882
JKendric@utmck.edu

APPENDIX D

CONSENT FROM HIGH-RISK OBSTETRIC CONSULTANTS

Working with
mother and doctor
for a healthy delivery.

REGIONAL
Obstetrical
Consultants

Mark D. Hennessy, M.D.
Maternal-Fetal Medicine
hennessy@rocob.com

Bobby Howard, M.D.
Maternal-Fetal Medicine
howard@rocob.com

C. David Adair, M.D., FACOG
Maternal-Fetal Medicine
adair@rocob.com

Joseph H. Kipikasa, M.D.
Maternal-Fetal Medicine
kipikasa@rocob.com

Carlos Torres, M.D.
Maternal-Fetal Medicine
torres@rocob.com

Christian Briery, M.D.
Maternal-Fetal Medicine
briery@rocob.com

Shawn Stallings, M.D.
Maternal-Fetal Medicine
stallings@rocob.com

Kristin L. Frazer, MS, CGS
Genetic Counselor
kristin@rocob.com

Stephanie Porter, MSN
Research Coordinator
stephanie@rocob.com

Jo Kendrick, MSN, CDE
Diabetes Coordinator
jo@rocob.com

Regional Obstetrical
Consultants of Knoxville
1924 Alcoa Highway
Suite 6 - South
Knoxville, TN 37920
865-305-8888
Fax: 865-305-6180

Web Site
www.rocob.com

TO: Institutional Review Board
University of Tennessee

FROM: Jo M. Kendrick, WHNP, CDE
Coordinator Perinatal Diabetes Center
Regional Obstetrics of Knoxville
1924 Alcoa Hwy., 6 South
Knoxville, TN 37920

SUBJ: Accuracy of Physical Activity Monitors in Pregnancy

DATE: 6/8/09

I am in full support of the above referenced study to determine the accuracy of pedometers during pregnancy and will assist with risk assessment and recruitment of participants from our practice. The study will also be conducted in a private area of our office.

APPENDIX E

INSTITUTIONAL REVIEW BOARD CONSENT

THE UNIVERSITY of TENNESSEE KNOXVILLE

Institutional Review Board
Office of Research
1534 White Avenue
Knoxville, TN 37996-1529
Phone: 865.974.3466
865.974.7400

DATE: August 14, 2009

IRB #: 7926 B
TITLE: Accuracy of Physical Activity Monitors in Pregnant Women

Coe, Dawn P.
Exercise, Sport & Leisure Studies
338 HPER Building
Campus - 2700

Bassett, David, Co-PI
Exercise, Sport & Leisure Studies
325 HPER
Campus - 2700

The points of clarification you submitted to this office regarding the above-captioned project, satisfied the concerns of the reviewers and the IRB, thus your project has been granted approval.

Approval is for a period ending one year from the date of this letter. Please make timely submission of renewal or prompt notification of project termination (see item #3 below).

Responsibilities of the investigator during the conduct of this project include the following:

1. To obtain prior approval from the Committee before instituting any changes in the project.
2. To retain signed consent forms from subjects for at least three years following completion of the project.
3. To submit a Form D to report changes in the project or to report termination at 12-month or less intervals.

The Committee wishes you every success in your research endeavor. This office will send you a renewal notice on the anniversary of your approval date.

Sincerely,

Brenda Lawson
Compliances

Enclosure

APPENDIX F

GRADUATE SCHOOL OF MEDICINE CONSENT

THE UNIVERSITY of TENNESSEE HEALTH SCIENCE CENTER

GRADUATE SCHOOL of MEDICINE

Institutional Review Board - FWA 2301
1924 Alcoa Highway, U-76
Knoxville, TN 37920
Phone: 865-305-9781
865-305-9275
http://gsm.utmck.edu/irb

August 17, 2009

Dawn P. Coe, PhD
Department of Exercise, Sport and Leisure Studies
The University of Tennessee
338 HPER
1914 Andy Holt Ave.
Knoxville, TN 37996

IRB #	2906
Title	Accuracy of Physical Activity Monitors in Pregnant Women
IRB Action	approval by administrative review
Informed Consent:	August 14, 2009
Approval Period	**August 17, 2009 – June 24, 2010**

Dear Dr. Coe,

On August 14, 2009, the University of Tennessee Graduate School of Medicine in Institutional Review Board administratively reviewed the revised informed consent document, in the above referenced protocol. This constitutes full approval of the amended revised informed consent document dated August 14, 2009.

Renewal: By federal regulation, all research approved by the IRB must be reviewed not less than once per year. Your approval period is listed above. Therefore, it is **your responsibility** to submit the appropriate application for continuing review to this office 3-6 weeks prior to the expiration of the approval period if you want to continue your research beyond that date.

Informed Consent Requirement: Informed consent and documentation of that consent from must be obtained from each participant prior to any research involvement. The approved and IRB-stamped informed consent document *(identified as Version date August 14, 2009)* must be used exclusively. Maintain all signed originals with your research records and provide a copy to each participant.

Modifications: This approval authorizes you to conduct the research only as described in your application and protocol. RB review and approval must be granted **before** making any changes, modifications or alterations to this research. Adverse events and protocol deviations must be reported to the IRB in accordance with our policies posted at http://gsm.utmck.edu/irb.

Thank you for informing us of this project.

Sincerely,

Kimberly C. Mason, PharmD
Chairperson
Institutional Review Board

KCM: rl

APPENDIX G

CORRELATIONS

Correlations

		GEST. AGE	TILT ANG.	BMI
2PERA	Pearson Correlation	-.157	-.158	.038
	Sig. (2-tailed)	.408	.406	.843
2PERD	Pearson Correlation	-.349	.047	.136
	Sig. (2-tailed)	.059	.807	.472
2PERN	Pearson Correlation	-.162	-.038	.537**
	Sig. (2-tailed)	.391	.843	.002
2PERO	Pearson Correlation	.008	.266	.191
	Sig. (2-tailed)	.966	.155	.311
2.5PERA	Pearson Correlation	-.056	-.443*	-.092
	Sig. (2-tailed)	.768	.014	.630
2.5PERD	Pearson Correlation	-.130	.128	.140
	Sig. (2-tailed)	.492	.500	.460
2.5PERN	Pearson Correlation	-.161	-.061	.571**
	Sig. (2-tailed)	.397	.748	.001
2.5PERO	Pearson Correlation	.011	.291	.139
	Sig. (2-tailed)	.955	.119	.462
3PERA	Pearson Correlation	-.043	-.029	-.338
	Sig. (2-tailed)	.820	.881	.068
3PERD	Pearson Correlation	-.140	-.029	.076
	Sig. (2-tailed)	.459	.877	.689
3PERN	Pearson Correlation	.014	-.061	.362*
	Sig. (2-tailed)	.941	.747	.049
3PERO	Pearson Correlation	.184	.039	.350
	Sig. (2-tailed)	.331	.839	.058
3.5PERA	Pearson Correlation	-.165	.111	-.242
	Sig. (2-tailed)	.384	.560	.198
3.5PERD	Pearson Correlation	-.048	.004	-.054
	Sig. (2-tailed)	.800	.984	.778
3.5PERN	Pearson Correlation	-.241	-.119	.465**
	Sig. (2-tailed)	.199	.532	.010
3.5PERO	Pearson Correlation	.413*	.152	-.030
	Sig. (2-tailed)	.023	.423	.874

Pearson correlation coefficient (r) between percentage of actual steps recorded and gestational age, pedometer tilt angle, and BMI for each device at each speed; ** significant (P<0.01), * significant (P<0.05)

VITA

Christopher Patrick Connolly was born on May 4th, 1983 to Patrick and Lisa Connolly. In May of 2001, he graduated from William Henry Harrison High School in West Lafayette, Indiana as a member of the National Honors Society and Captain of the high school swim team. He began his undergraduate education at Brigham Young University in Provo, Utah in the fall of 2001. From 2002-2004, he served a L.D.S. church mission in southern Germany and Austria. On June 24th, 2006, Chris was married to his lovely bride, Erin. He graduated from BYU in April of 2008 with a Bachelor of Science degree in Exercise Sciences. Since the fall of 2008, Chris has attended at the University of Tennessee and has worked as a Graduate Teaching Associate in the Physical Education Activity Program and as the Graduate Assistant for the Center for Physical Activity and Health. On August 10th, 2009, Chris and Erin welcomed their beautiful daughter, Carly, to the world. In May of 2010, he will graduate with a Master of Science degree in Exercise Science, with a concentration in exercise physiology. Chris will continue his graduate education in the fall of 2010 as a doctoral candidate at Michigan State University.