Accuracy of Physical Activity Monitors in Pregnant Women

CHRISTOPHER P. CONNOLLY, DAWN P. COE, JO M. KENDRICK, DAVID R. BASSETT JR., and DIXIE L. THOMPSON

The University of Tennessee, Knoxville, TN

ABSTRACT

CONNOLLY, C. P., D. P. COE, J. M. KENDRICK, D. R. BASSETT JR., and D. L. THOMPSON. Accuracy of Physical Activity Monitors in Pregnant Women. *Med. Sci. Sports Exerc.*, Vol. 43, No. 6, pp. 1100–1105, 2011. **Purpose**: To determine the step count accuracy of three pedometers and one accelerometer in pregnant women during treadmill walking. **Methods**: Participants were 30 women in the second or third trimester (20–34 wk) who were screened for pregnancy-related risk factors. Each participant 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-720ITC (HJ) was placed in the pants' front pocket. Participants walked at 54, 67, 80, and 94 $m \cdot min^{-1}$ for 2 min each. Actual steps were determined by an investigator using a hand-tally counter. The mean percent of steps recorded was calculated for each device at each speed and compared. Pearson correlations were used to determine the effect of body mass index and tilt angle on pedometer accuracy. **Results**: There was a significant interaction between speed and device ($F_{9,20} = 7.574$, $P < 0.001$). Across all speeds, the NL and HJ had the lowest error. The ACT and DW underestimated the actual steps taken, particularly at the slower walking speeds. At 54 $m \cdot min^{-1}$, the ACT averaged 77.5% of steps and the DW averaged 56.9% of steps. Significant differences in the mean percent of steps recorded were found between devices at all speeds. Body mass index was only significantly correlated with percent of steps recorded by the NL, and there were no significant correlations between steps recorded and tilt angle. **Conclusions**: In pregnant women, the ACT and DW had more error than the NL and HJ. On the basis of these results, the NL and HJ should be considered for use in further research studies and physical activity programs that focus on walking during pregnancy. **Key Words:** TREADMILL WALKING, PEDOMETER, ACCELEROMETER, PREGNANCY

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The recently released 2008 Physical Activity Guidelines for Americans (34) recommend at least 150 min of moderate-intensity aerobic activity per week for pregnant women. Walking is the most common choice for recreational physical activity among pregnant women (10,18,20,36). In addition, regular walking has been shown to reduce the risk of pregnancy-related conditions such as gestational diabetes (19,27,35), preeclampsia (16,23,28), and excessive gestational weight gain (31). Objective monitoring of walking activity provides distinct advantages in monitoring interventions (11). If researchers are to objectively quantify walking activity in pregnant women, valid and accurate devices must be identified.

Address for correspondence: Dawn P. Coe, Ph.D., Department of Kinesiology, Recreation, and Sport Studies, 338 HPER, 1914 Andy Holt Ave., Knoxville, TN 37996; E-mail: dcoe@utk.edu.
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The validity and accuracy of these commercially available pedometers and accelerometers are crucial in the objective tracking of walking levels and have been assessed under controlled and free-living conditions in several studies (3,5,13,14,17,24,25,33). Although pedometers and accelerometers have been used to determine physical activity trends during pregnancy (6,8,15,21,22,29), the accuracy of these devices has never been examined in pregnant women.

Several studies have demonstrated the validity and accuracy of the spring-levered Yamax Digiwalker SW-200 (DW) and the piezoelectric New Lifestyles NL 2000 (NL) (5,24,25) pedometers. However, slow walking speeds (13,14,17) and high body mass index (BMI) (17,26) have been shown to increase step count error, particularly in spring-levered pedometers. Crouter et al. (4) assessed the effect of overweight and obesity on pedometer accuracy and found the DW to be less accurate than the NL in the obese population, with the pedometer tilt angle (angle away from the vertical axis) being the primary factor responsible for the inaccuracy. In addition, Dock et al. (7) found that the combination of greater pedometer tilt and slow walking speed greatly decreased pedometer accuracy. It is unknown if walking speeds and pedometer tilt yield similar inaccuracies among pregnant women.

Because spring-levered and uniaxial piezoelectric pedometers must remain in the upright (vertical) position for optimal accuracy, manufacturers have recently developed

more sensitive devices with multiple internal sensors. The Omron HJ-720ITC (HJ) pedometer features two piezoelectric accelerometers capable of detecting both vertical and horizontal accelerations. Holbrook et al. (12) found the HJ to be accurate in 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, there are currently no studies that have examined the step count accuracy of the ActiGraph GT3X.

Therefore, the purpose of this study was to examine the step count accuracy of three commonly used pedometers (DW, NL, and HJ) and one accelerometer-based activity monitor (ACT) in pregnant women during treadmill walking. We hypothesized that there are differences in accuracy between models and that BMI, tilt angle, and speed will affect the pedometer's accuracy in pregnant women.

METHODS

Participants. Thirty pregnant women from a high-risk obstetric 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 yr with a gestational age of 20–34 wk. The most common reason for visiting the high-risk obstetric clinic was gestational diabetes. 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 (2). Demographic data for each participant, including age, gestational age, height, weight, and BMI were provided by the nursing staff. BMI was calculated from measurements completed at the time of assessment. Each participant provided informed consent before participating in the study. The University of Tennessee's Institutional Review Board and the University of Tennessee Graduate School of Medicine's Institutional Review Board approved the protocol.

Treadmill walking. The four physical activity monitors were properly positioned on each participant by the researcher. Because pedometer tilt angle in populations with excess abdominal mass has been shown to affect step count accuracy in some devices (4), special care was taken in physical activity monitor placement (see figure, Supplemental Digital Content 1, which illustrates physical activity monitor placement, http://links.lww.com/MSS/A69). The DW and the NL were placed just anterior to the right and left iliac crests of the hips on an elastic belt around the waist. The ACT was also placed on the elastic belt at the midaxillary line of the left thigh, and the HJ was placed in the pants' front right pocket.

Participants walked on a treadmill (TF 9200; Vision Fitness, Cottage Grove, WI) for a total period of 8–13 min. Before testing, an optional 5-min walking period was given at the speed of 54 $m \cdot min^{-1}$ to ensure familiarity with the treadmill. Participants completed four walking stages at the speeds of 54, 67, 80, and 94 $m \cdot min^{-1}$ for 2 min at each stage. Individuals unable to complete any of the stages due to discomfort or inability to maintain walking pace were excluded from this study. Although participants who completed the current study were recruited from a high-risk obstetric office, their conditions did not affect walking ability. During each walking stage, the primary investigator tallied steps with a hand-tally counter. At the end of each stage, 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 stage. The HJ does not allow step counts to be reset; thus, pedometer-recorded steps were calculated by taking the step count difference between the beginning and the end of each stage. The step count data from the ACT was downloaded and recorded at the end of all four walking stages. Before physical activity monitors were removed from the participant, a protractor (Craftsman Magnetic Professional, Sears, IL) was used to measure the pedometer tilt angle.

Statistical analysis. Descriptive statistics are reported as mean ± SD. A two-way repeated-measures ANOVA (speed × device) was used to compare percentage of actual steps [100 × (actual steps taken − device recorded steps)/(actual steps taken)]. 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. In addition, Pearson correlations were calculated to explore 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. An α of 0.05 was used to indicate statistical significance for all analyses. All data were analyzed using SPSS version 17.0 (SPSS, Inc., Chicago, IL).

RESULTS

Participant characteristics are shown in Table 1. Figure 1 illustrates the group comparison between each device with the criterion measure. The NL and HJ seem to be more valid compared with ACT and DW. Both the ACT and DW seem to undercount the number of steps taken, whereas the NL and HJ showed very good agreement when compared with

TABLE 1. Participants' characteristics (mean ± SD).

Variable	n = 30
Age (yr)	30.6 ± 5.6
Gestational age (wk)	27.0 ± 4.3
Body mass (kg)	83.5 ± 16.8
Height (m)	1.63 ± 0.02
BMI ($kg \cdot m^{-2}$)	31.3 ± 5.9

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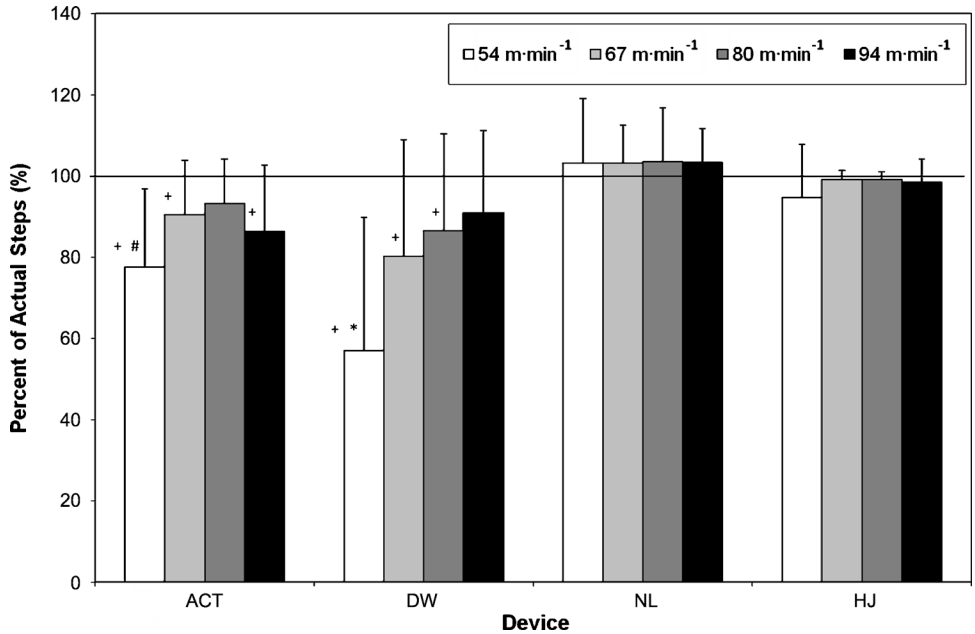

FIGURE 1—Influence of treadmill walking speed on the percent of actual steps recorded (mean ± SD) by the ActiGraph GT3X (ACT), Yamax Digiwalker SW-200 (DW), New Lifestyles NL 2000 (NL), and Omron HJ-720 (HJ) when worn by pregnant women. Data are presented as means with SD. *Significantly less accurate than all other speeds for that device ($P < 0.05$). #Significantly less accurate than 67 and 80 m·min^{-1} for that device ($P < 0.05$). +Significantly less accurate than the NL and HJ at that same speed ($P < 0.05$).

the criterion. 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 for 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%). There was a significant interaction between speed and device ($F_{9,20} = 7.574$, $P < 0.001$).

To examine this interaction, the percentage of actual steps recorded by individual devices was compared at each speed (Fig. 1). At the speed of 54 m·min^{-1}, all devices differed from one another ($P < 0.001$), 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 did not significantly differ, and the NL and HJ did not significantly differ. 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.

In addition, the percentage of actual steps recorded at individual speeds was compared for each device (Fig. 1). The ACT was most inconsistent ($P < 0.001$), showing significantly less accuracy at 54 m·min^{-1} than at 67 and 80 m·min^{-1}, but no significant differences between 54 and 94 m·min^{-1}. The DW was significantly more accurate ($P < 0.001$) at the speeds of 67, 80, and 94 m·min^{-1} than it was at the speed of 54 m·min^{-1}. No significant speed effects were found for the NL and the HJ.

Pearson correlation coefficients were moderately significant only between BMI and the NL percentage of actual steps at all speeds ($r = 0.36$–0.57). There were no significant correlations between tilt angle and percentage of actual steps for any device at any speed. The overall accuracy of each device is represented in Figure 2 using Bland–Altman plots, which assessed the agreement between actual steps and device recorded steps. The NL and HJ were far more accurate than the DW or ACT. The DW increased in accuracy, with increasing walking speed as represented in Figure 2B.

DISCUSSION

Pedometers and accelerometers are useful tools in the quantification of ambulatory activity. It is important that these devices be examined for step count accuracy in pregnant women to ensure that the most accurate objective devices are used in current research studies and physical activity programs. 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 possible that pregnant women slow their walking pace as pregnancy progresses. Therefore, the slowest speed used in this study (54 m·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 walking speed is inversely related to pedometer accuracy in nonpregnant populations, particularly for spring-levered

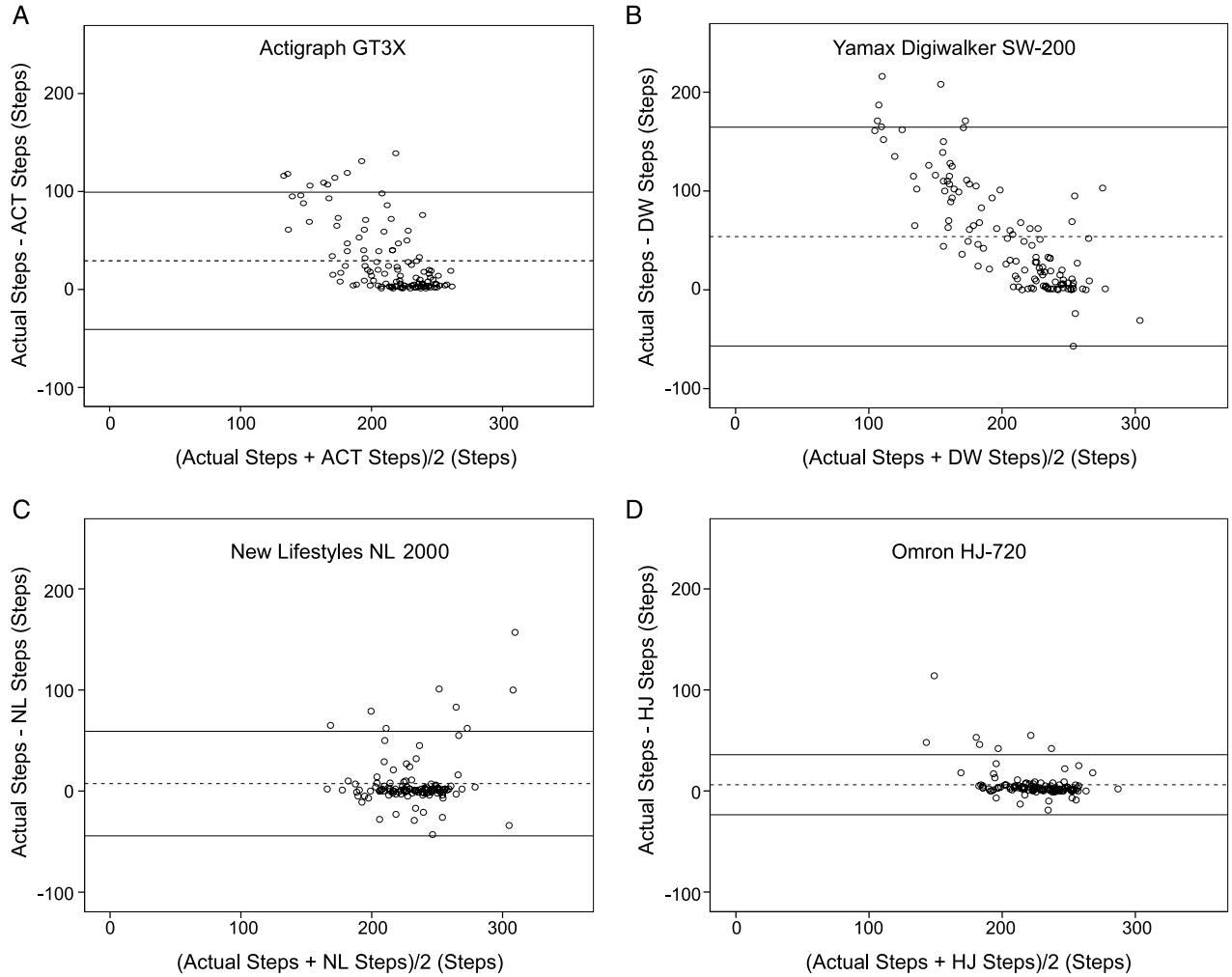

FIGURE 2—Bland–Altman plots depicting error scores (actual steps − pedometer steps) for the (A) ActiGraph GT3X (ACT), (B) Yamax Digiwalker SW-200 (DW), (C) New Lifestyles NL 2000 (NL), and the (D) Omron HJ-720 (HJ). *Dashed line* represents mean difference; *solid lines* represent 95% prediction interval.

pedometers (3,5,13,14,17,32). Tudor-Locke et al. (33) suggested that slow walking speeds might not generate the necessary vertical acceleration (0.35*g*) for the DW to register a step. This seems to be the case in the current study, with the DW recording 56.9% of actual steps at 54 m·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, which may explain why the ACT was significantly more accurate at the slowest speed of 54 m·min^{-1}. However, the ACT was also influenced by slow walking speeds, similar to the results of older ActiGraph models in nonpregnant populations (1,30).

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·min^{-1} in pregnant women. This extends the previous finding of superior accuracy of piezoelectric pedometers at slow speeds in nonpregnant populations (4,5,12) and confirms the suggestion of Melanson et al. (17) that piezoelectric pedometers would be more accurate in those populations who naturally walk at slower speeds. The HJ seems (Fig. 2D) to be more accurate than the NL (Fig. 2C) 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 before the current study, the effect of tilt angle and BMI on device accuracy has been investigated in overweight and obese individuals. Crouter et al. (4) 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 54, 67, 80, 94, and 107 m·min^{-1} for 3 min each. After the walking trials, 36 participants wore the devices for a 24-h period. The primary finding was that the piezoelectric NL 2000 was more accurate than the spring-levered SW-200. In addition, 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. 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 sides of the hips. This resulted in only one participant having a pedometer tilt angle > 15°. The placement of these pedometers in a different location other than the recommended midline of the thigh is supported by Swartz et al. (32), who found no significant differences in DW accuracy when devices were placed on nonpregnant individuals at the recommended midline of the thigh and midaxillary line of the hip.

High BMI levels have been shown to negatively affect pedometer accuracy in several studies (17,26), whereas other research has showed BMI to have no effect (9,32). In the current study, higher BMI was positively related to percentage of actual steps recorded by the NL at all speeds. BMI was not related to device accuracy for any other device at any speed. These significant associations should be interpreted carefully owing to the limited sample size and the unique nature of BMI during pregnancy.

The current study has several strengths and limitations. A strength was that the physical activity monitors examined included several that are the most commonly used in physical activity research. Furthermore, each monitor contained a different internal mechanism for step counting. In addition, 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 wk. This gestational range allowed for a large variation in abdominal size and shape. Limitations of the study include the relatively small sample size and the fact that certain anthropometric assessments were not taken, including waist and hip circumferences. Also, prepregnancy BMI was not available, and therefore, we were unable to assess the possible effect of gestational change in BMI on pedometer accuracy. Because of the cross-sectional nature of the study, it is difficult to determine whether trimester affects pedometer accuracy. Finally, participants engaged in treadmill walking only and free-living activity was not assessed.

The main objective of this study was to assess the step count accuracy of three pedometers and one accelerometer in pregnant women during treadmill walking. Results show the NL and HJ pedometers to be substantially more accurate than the DW pedometer and the ACT accelerometer-based activity monitor. Slower walking speeds greatly decreased the accuracy of the DW and ACT and had minimal influence on both the NL and HJ. It does not seem that BMI and tilt angle have significant effects on the step count accuracy of these activity monitors, with the exception that the NL accuracy is greater in pregnant women with a higher BMI. Overall, both the NL and HJ are effective tools for counting steps in pregnant women, with the HJ appearing to be most accurate. Future research investigating the effect of walking during pregnancy on pregnancy-related conditions should consider using the NL and HJ for accurate measurements.

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The results of the current study do not constitute endorsement of any products by the American College of Sports Medicine.

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