Objectively Assessing Treadmill Walking During the Second and Third Pregnancy Trimesters

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Background: To effectively promote physical activity (PA) and quantify the effects of PA interventions for pregnant women, PA measurement during pregnancy needs improvement. The purpose of this study was to assess PA monitor output during a controlled, treadmill walking protocol among pregnant women at 20- and 32-weeks gestation. Methods: Women (N = 43) wore an Actigraph accelerometer, NL1000, and Yamax pedometer during a 20-minute treadmill walking test [5-minute periods at 4 different speeds (54, 67, 80, and 94 m·min⁻¹)] at 20- and 32-weeks gestation. Results: Repeated-measures ANOVAs indicated that Actigraph total counts/minute and minutes of moderate-vigorous PA (MVPA), NL1000 steps and minutes MVPA, and Yamax steps decreased from 20- to 32-weeks gestation (P ≤ .05), while body girth circumference and activity monitor tilt increased (P ≤ .05). Repeated measures ANCOVAs, controlling for changes in body girth and monitor tilt, yielded no significant differences in any outcome measures from 20- to 32-weeks gestation. Conclusions: Preliminary results suggest physical changes during pregnancy impact activity monitor output in controlled settings. Accurately measuring and statistically controlling for changes in body girth at monitor placement site and monitor tilt may improve the accuracy of activity monitors for use with pregnant populations.

Keywords: women, measurement, Actigraph, Yamax, NL1000

Daily moderate-intensity physical activity (PA) is safe and recommended for healthy pregnant women.¹ Despite the benefits of PA, self-reported data illustrates that PA declines from the second to the third trimester,²-⁵ with nearly 70% of women not meeting the PA recommendations during pregnancy.² Thus, there is a need for interventions designed to successfully promote PA during pregnancy.

However, to effectively promote PA and quantify the effects of PA interventions for pregnant women, PA measurement during pregnancy needs improvement.⁶ Accelerometers and pedometers may offer a solution to the methodological issues associated with self-reported PA data, such as under- and over-reporting PA time and intensity. That is, while self-reported PA measures are useful in describing the types of activities women participate in during pregnancy, the use of accelerometers and pedometers may present a clearer picture of the duration and intensity of PA behavior during pregnancy.

Although pregnancy is a temporary period of time, significant physical changes take place that likely influence PA measurement and behaviors. For example, body mass index (BMI) and waist circumference increase across the trimesters⁶ and potentially influence the type, intensity, and duration of PA. It is also possible that factors such as monitor placement, tilt of the monitor, BMI, and deviations in gait may alter the performance of PA monitors among women across the trimesters. However, only a few studies have examined PA using accelerometers and pedometers in pregnant populations,³,⁵,⁷-⁹ and no published studies were located assessing potential differences in PA monitor output [ie, steps, activity counts, minutes of moderate-vigorous PA (MVPA)] across the trimesters.

Findings from existing studies¹⁰-¹⁵ examining the accuracy of pedometers and accelerometers in overweight and obese nonpregnant adults raise important issues for researchers assessing pregnancy-related PA because significant body changes take place at the anatomic site where monitors are worn. However, the findings from these studies are equivocal in that some have found BMI category to have no effect on pedometer accuracy,¹⁰ while others found pedometer accuracy to be compromised in overweight and obese adults.¹⁵-¹⁷ Unfortunately, no research examining the influence of the physical changes that occur as pregnancy progresses (eg, increasing waist circumference, gestational weight gain, and variability in weight status) on the PA monitor output have been examined. That is, to test if there are differences in PA behavior across the trimesters it is important to first understand if PA monitors record the same data at different time points in pregnancy (ie, 2nd trimester vs. 3rd trimester) when the treadmill protocol is kept identical. The most significant physical changes occur during the
last 20 weeks of pregnancy, thus, this is the ideal time to examine any changes in PA monitor data output. Once this is confirmed, researchers can be confident that PA monitor output is accurately assessing movement as pregnancy progresses toward delivery.

No located studies have reported body girth circumference at the site where the PA monitor is worn according to standard procedures (ie, at the hip, over midline of right thigh).18,19 This is important to examine in pregnant women because no data exist on whether body girth at the site of monitor placement changes across the trimesters, potentially altering monitor placement and tilt. In addition, previous research examining pedometer accuracy in normal and overweight children assessed pedometer tilt angle as a possible confounder of accurate step count readings and found tilt angle to have a significant effect on SW-200 pedometer error.14 No published studies, however, have examined activity monitor tilt angle in pregnancy to detect if changes in tilt influence the output of the activity monitors.

Therefore, the purpose of this study was two-fold. The first purpose was to evaluate changes in monitor performance (ie, Actigraph counts, minutes of MVPA calculated with 2 established cut-points20,21 from Actigraph counts, Yamax steps, NL1000 steps, and NL1000 minutes of MVPA) and in body size measurements (ie, body girth circumference and monitor tilt) during a controlled treadmill walking protocol among pregnant women at 20- and 32-weeks gestation. Based on previous research in overweight and obese nonpregnant populations11,22 it was hypothesized that there would be no differences across the time points in (1) Actigraph accelerometer activity counts/minute and minutes of MVPA based on either cut-point, (2) NL1000 pedometer steps and minutes of MVPA, or (3) Yamax pedometer steps. In addition, due to the natural physical changes women experience during pregnancy and the standard site of monitor placement, it was hypothesized that significant increases in body girth circumference at monitor placement site, as well as in activity monitor tilt would be observed. The second study purpose was dependent on the findings of the first purpose. Specifically, if significant changes in body girth circumference and activity monitor tilt were observed, the second purpose was to assess changes in the outputs of the 3 activity monitors while controlling for these variables. Conversely, if no changes in body girth circumference or activity monitor tilt were observed, these variables would not be entered as covariates.

Methods

Instruments

The Actigraph accelerometer (model 7164; Manufacturing Technology, Inc) is a small (2.0 × 1.6 × 0.6 in.) and lightweight (42.5 g) uniaxial, piezoelectric accelerometer that measures accelerations (range of 0.05–2 G; band-limited frequency of 0.25–2.5 Hz). These values correspond to the range in which most human activities are performed. The Actigraph has been used to validate self-report PA surveys for pregnant women.22 Also, in nonpregnant women the Actigraph has been found to be the best estimate for energy expenditure at a range of speeds (ie, 80–188 m·min⁻¹)24 and has shown acceptable interinstrument reliability at MVPA levels in nonpregnant populations.25 To assess minutes of MVPA at 20- and 32-weeks gestation in this study, the cut-points previously established from treadmill walking in nonpregnant populations by Freedson, Melanson, and Sirard20 (>1951 counts/min) and Hendelman, Miller, Bagget, Debod, and Freedson21 (>2191 counts/min) were used. While no Actigraph accelerometer cut-points have been determined to categorize MVPA among pregnant women, these cut-points were chosen because they were developed from walking conditions.

The NL1000 (New Lifestyles, Inc., Lee’s Summit, MO, USA) is a small, piezoelectric pedometer that measures vertical accelerations to count steps and accumulate total activity time spent at or above moderate intensity (>2.9 METs) using a medical-grade accelerometer. The NL1000 user guide indicates that an activity level of 3.0 is equivalent to 2.9 METs, whereas an activity level of 4.0 is equivalent to 3.6 METs. By setting the NL1000 to an activity level of 3.0 (ie, 2.9 METs), no minutes of MVPA would be excluded. This is also in accordance with the American College of Sports Medicine’s (ACSM) guidelines26 stating that walking at 3.0 to 6.0 METs indicates moderate-intensity PA. The accuracy and interinstrument reliability of the NL1000 for recording steps taken and minutes of MVPA has been confirmed in nonpregnant populations.11,27

The Yamax Digiwalker SW-701 Pedometer (Yamax Corporation, Tokyo, Japan) is a small, spring-levered pedometer. It has acceptable accuracy, reliability (including interinstrument reliability), and validity for recording steps taken with nonpregnant populations under controlled28,29 and free-living conditions.30–33 The interinstrument reliability of the Actigraph,29 NL1000,11 and Yamax pedometer,16,31–33 when worn concurrently on right and left hips, has been confirmed in adult populations.27,31,33

Minute-by-minute mean oxygen consumption (VO₂) was measured directly (Vmax 229 v.602, SensorMedics, CA) as participants performed the 20-minute walking protocol on a treadmill (Marquette 2000, General Electric, CT). Immediately before every metabolic test, the flowmeter was calibrated using a 3-L calibration syringe (SensorMedics, CA), and the gas analyzers were calibrated using a 2-pint calibration method against certified gases of known concentration (26%, O₂, with nitrogen balance; 4% CO₂, 16% O₂, with nitrogen balance). Expired gases, in 30-second intervals, were collected and analyzed continuously using the previously described metabolic system. A Polar heart rate monitor (Polar S725X, Polar, NY) was used to measure HR in beats per min.

Body Mass Index (kg/m²) was calculated using objectively measured height and weight assessed at 20- and 32-weeks gestation (Seca Mechanical Beam Medical
was consistently placed from the first to the second test belly). This procedure was used to ensure that the belt site of monitor belt placement (eg, at the hip, below the protocol. Body girth circumference was measured at the steps women accumulated during the 20-minute treadmill Yamax pedometer was used to collect the number of MET levels for walking, the NL1000 was programmed to accumulate minutes of activity above 2.9 METs. The NL1000, Yamax pedometer, standardized VO2 breathing the study. In the absence of contraindications, an on-site exercising during pregnancy, they were excluded from consistent with the ACOG (2002) contraindications to preeclampsia), showed evidence of 1+ protein in a BMI was calculated from a retrospective self-report of pregnancies at 20- and 32-week gestation visits. In addition, prepregnancy BMI was calculated from a retrospective self-report of prepregnancy weight at the 20-week visit. If women had unusually high blood pressure (140/90 guidelines for preeclampsia), showed evidence of 1+ protein in a urine screen, and/or demonstrated any other symptoms consistent with the ACOG (2002) contraindications to exercising during pregnancy, they were excluded from the study. In the absence of contraindications, an on-site physician’s assistant cleared the women for participation. Participants were verbally informed about study procedures and then completed the informed consent form. Measures of height, weight, blood pressure, and urine were obtained by a nurse at both the 20- and 32-week gestation visits. In addition, prepregnancy BMI was calculated from a retrospective self-report of prepregnancy weight at the 20-week visit. If women had unusually high blood pressure (140/90 guidelines for preeclampsia), showed evidence of 1+ protein in a urine screen, and/or demonstrated any other symptoms consistent with the ACOG (2002) contraindications to exercising during pregnancy, they were excluded from the study. In the absence of contraindications, an on-site physician’s assistant cleared the women for participation. Participants were then fit with the Actigraph, NL1000, Yamax pedometer, standardized VO2 breathing apparatus, and a Polar HR monitor. The Actigraph and Yamax were placed on a belt on the right hip, under the belly, in line with the right knee; and the NL1000 was worn likewise on the left hip. The Actigraph was initialized on a laptop computer to record activity counts in 30-second epochs and was synced with an external watch. Following the treadmill walking test, data were downloaded via the Actigraph software into an Excel data file, at which time the data were cleaned and the mean activity counts/minute were calculated. The NL1000 was used in this study to assess the number of steps and the number of minutes of MVPA accumulated during the 20-minute treadmill protocol at 20- and 32-weeks gestation. In accordance with ACSM guidelines regarding MVPA MET levels for walking, the NL1000 was programmed to accumulate minutes of activity above 2.9 METs. The Yamax pedometer was used to collect the number of steps women accumulated during the 20-minute treadmill protocol. Body girth circumference was measured at the site of monitor belt placement (eg, at the hip, below the belly). This procedure was used to ensure that the belt was consistently placed from the first to the second test (20- to 32-weeks gestation), and to assess any changes in circumference at the site where the monitor belt was worn. It is important to note here that by definition this was not a waist circumference measurement (ie, “one inch above the umbilicus or at the smallest circumference between the ribcage and umbilicus”) and therefore did not reflect the probable increase in the size of women’s waists at the umbilicus. Activity monitor tilt was assessed using a protractor according to previously-used methods in overweight populations, and the degrees were recorded before the start of the treadmill protocol. A positive tilt (>0°) indicated the degree to which the top of the activity monitor was tilted away from the body.

Treadmill Protocol
Participants straddled the treadmill belt for 1 minute before the start of the protocol, which consisted of a 5-minute warm-up at 40 m·min⁻¹, followed by 4, 5-minute periods of treadmill walking at 4 different speeds (54, 67, 80, and 94 m·min⁻¹), and a 5-minute cool-down at 54 m·min⁻¹, all at 0 percent grade. The NL1000 and Yamax pedometers were cleared to 0 promptly following the 5-minute warm-up and removed from the participant’s belt at the end of the 20-minute protocol, before the cool-down period. Yamax steps and NL1000 steps and minutes of MVPA were recorded. Because the Actigraph has an internal timer, there was no need to remove it before the end of the cool-down period. Every 5 minutes during the treadmill protocol, women were prompted to self-report perceived exertion and any negative pregnancy symptoms. None of the participants reported negative symptoms during the treadmill walking condition.

Data Treatment
Data screening, manipulation, and analyses were conducted using SPSS Data Analysis Version 17.0 (SPSS Inc, Chicago, IL). All comparisons were considered significant at an alpha level of 0.05. All data were normally distributed and no outliers were identified. Analyses were only performed if treadmill data at both 20- and 32-weeks gestation were available, and this resulted in some data of the original 87 participants being deleted. Specifically, at 20-weeks gestation, 20% (N = 17) of the women did not participate in the treadmill walking test due to schedule conflicts (n = 14), medical complications (n = 2), and accelerometer failure (n = 1). At 32-weeks gestation, 32% (N = 28) of the women did not participate in the treadmill walking test due to schedule conflicts (n = 9), medical complications (n = 12), moving out of the local area (n = 6), and accelerometer failure (n = 1). Thus, 43 women with valid treadmill data at both 20- and 32-weeks gestation were included in the final study sample. It is important to mention that not all of the women included in the final sample (N = 43) were able to walk at the fastest speed (94 m·min⁻¹) of the treadmill walking protocol at 20-weeks [n = 3; 1 participant from each BMI category (ie, normal, overweight, obese)] and 32-weeks (n = 5; 1
from normal weight BMI category, 1 from the overweight category, and 3 from obese BMI category) gestation, so we were not able to use their data for the analyses at that speed (see N in Tables 1, 2, 3).

To examine differences in the output of the Actigraph accelerometer and NL1000 and Yamax pedometers, as well as in body girth circumference and monitor tilt, from 20- to 32-weeks gestation, repeated measures analyses of variance (ANOVA) were conducted. Next, to control for factors that changed significantly from 20- to 32-weeks gestation, repeated measures analyses of covariance (ANCOVA) were conducted, with changes in body girth circumference (cm) at monitor placement site and monitor tilt (°) entered as covariates.

**Results**

The final participant sample included second trimester pregnant women (N = 43, mean age = 30.8 ± 4.4 years). Most women were Caucasian (73%), had a college education or higher (95%), had a family income > $40,000 (68%), and were working part-time (73%). Prepregnancy BMI was 24.2 kg/m² (SD = 4.8; range = 15.5–42.21 kg/m²). Approximately 40% (n = 17) of the participants were in the overweight category (BMI \(\geq 25\) kg/m²), and of those women, 17.6% (n = 3) were obese (BMI \(\geq 30\) kg/m²).

As expected, no significant changes in VO₂ (ml/kg/min) were observed from 20- to 32-weeks gestation during controlled treadmill walking at any of the 4 speeds (\(P > .05\); see Table 1). This finding is consistent with previous research performed in our laboratory.\(^{13}\) In addition, body weight increased significantly (\(P < .05\)) from 20-weeks (156.9 ± 35.2 lbs) to 32-weeks (171.2 ± 34.2 lbs) gestation. Significant increases (\(P < .05\)) were also observed for body girth circumference from 20-weeks (97.4 ± 11.4 cm) to 32-weeks (103.0 ± 11.7 cm) gestation, as well as for monitor tilt from 20-weeks (3.8 ± 3.1°) to 32-weeks (7.1 ± 3.9°) gestation (see Table 1).

Repeated-measures ANOVAs revealed significant differences in Yamax steps (2043 ± 409 steps; 1856 ± 443 steps; respectively), NL1000 steps (2122 ± 223 steps; 2029 ± 330 steps; respectively), and NL1000 minutes of MVPA (16.3 ± 4.4 min; 15.0 ± 5.5 min; respectively) from 20- to 32-weeks gestation (\(P \leq .05\); see Table 2). Likewise, activity counts/minute as assessed by the Actigraph accelerometer changed significantly (\(P < .05\)) from 20-weeks (2732.8 ± 457.1 counts/min) to 32-weeks (2516.3 ± 522.8 counts/min) gestation for the total 20-minute treadmill protocol, as well as for the first treadmill speed (54 m·min\(^{-1}\); 684.8 ± 152.5 counts/min; 751 ± 175 counts/min; respectively), second treadmill speed (67 m·min\(^{-1}\); 1011.5 ± 230.8 counts/min; respectively), third treadmill speed (80 m·min\(^{-1}\); 1505.3 ± 329.2 counts/min; respectively), and fourth treadmill speed (94 m·min\(^{-1}\); 1954.5 ± 587.9 counts/min; respectively; see Table 2).

Repeated-measures ANOVAs were used to examine Actigraph minutes of MVPA (\(P < .05\); see Table 2). Minutes of MVPA, tallied across the 20-minute treadmill protocol based on both of the established cut-points,\(^{20,21}\) decreased significantly from 20- to 32-weeks gestation. Specifically, Freedson’s cut-point\(^{20}\) for MVPA (ie, >1951 counts/min) categorized significantly fewer minutes of MVPA at 32-weeks (2.57 ± 2.84 min), compared with 20-weeks gestation (3.65 ± 2.75 min), despite that fact that the treadmill protocol was kept identical. Similarly, Hendelman’s cut-point\(^{21}\) for MVPA (ie, >2191 counts/min) categorized fewer minutes of MVPA at 32-weeks (1.34 ± 1.94 min), compared with 20-weeks gestation (1.92 ± 2.15 min; see Table 2).

Due to the significant differences found in body girth circumference and monitor tilt from 20- to 32-weeks gestation (Table 1), and the potential impact these variables may have on the

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Means (M), Standard Deviations (SD), and Paired Samples t-tests at 20- and 32-Weeks Gestation</th>
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<tbody>
<tr>
<td>Variables</td>
<td>20-weeks gestation</td>
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<tr>
<td>Body weight (lbs)</td>
<td>156.9</td>
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<tr>
<td>Body girth circumference (cm)</td>
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<td>PA monitor tilt (°)</td>
<td>3.8</td>
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<tr>
<td>VO₂ (ml·kg(^{-1})·min(^{-1}))</td>
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</tr>
<tr>
<td>54 m·min(^{-1})</td>
<td>7.5</td>
</tr>
<tr>
<td>67 m·min(^{-1})</td>
<td>8.6</td>
</tr>
<tr>
<td>80 m·min(^{-1})</td>
<td>10.2</td>
</tr>
<tr>
<td>94 m·min(^{-1})</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Abbreviations: lbs, pounds; cm, centimeters; ml·kg\(^{-1}\)·min\(^{-1}\), milliliters per kilogram of body weight per min; m·min\(^{-1}\), meters per min; bpm, beats per min.

\(^{a}\) Indicates that incomplete VO₂ data exists because some women were not able to walk at the fastest treadmill speed (ie, 94 m·min\(^{-1}\)) at 20-weeks (\(n = 3\)) and 32-weeks (\(n = 5\)) gestation, and therefore ended the treadmill test following the third speed (ie, 80 m·min\(^{-1}\)).
Actigraph output, repeated measures ANCOVAs were performed with changes in these variables entered into the analyses as covariates. After controlling for changes in body girth circumference and monitor tilt no significant differences \((P > .05)\) were observed for Actigraph activity counts/minute or minutes of MVPA, according to the 2 selected cut-points,20,21 across the 20-minute treadmill protocol or at any of the 4 speeds \((54, 67, 80, \text{ and } 94 \text{ m·min}^{-1})\), or for Yamax steps, NL1000 steps, or NL1000 minutes of MVPA (see Table 3).

**Table 2  Repeated Measures ANOVA, Not Controlling for Changes in Body Girth Circumference or Monitor Tilt**

<table>
<thead>
<tr>
<th>Variables</th>
<th>20-weeks gestation</th>
<th>32-weeks gestation</th>
<th>(F)</th>
<th>(df)</th>
<th>(P)-value</th>
</tr>
</thead>
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<tr>
<td>Actigraph activity counts/min</td>
<td>43</td>
<td>2732.8</td>
<td>457.1</td>
<td>2516.3</td>
<td>522.8</td>
</tr>
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<td>54 m·min(^{-1})</td>
<td>43</td>
<td>684.8</td>
<td>152.5</td>
<td>751.0</td>
<td>175.0</td>
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<td>67 m·min(^{-1})</td>
<td>43</td>
<td>1133.4</td>
<td>228.4</td>
<td>1011.5</td>
<td>230.8</td>
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<tr>
<td>80 m·min(^{-1})</td>
<td>43</td>
<td>1604.6</td>
<td>267.9</td>
<td>1505.3</td>
<td>329.2</td>
</tr>
<tr>
<td>94 m·min(^{-1})</td>
<td>38(^a)</td>
<td>2127.6</td>
<td>323.94</td>
<td>1954.5</td>
<td>587.9</td>
</tr>
<tr>
<td>Actigraph min of MVPA Freedson cut-points</td>
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<td>2.8</td>
<td>2.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Hendelman cut-points</td>
<td>43</td>
<td>1.9</td>
<td>2.2</td>
<td>1.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Yamax steps</td>
<td>38(^a)</td>
<td>2042.7</td>
<td>409.4</td>
<td>1856.0</td>
<td>442.7</td>
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<td>NL1000 steps</td>
<td>38(^a)</td>
<td>2121.8</td>
<td>223.4</td>
<td>2029.2</td>
<td>330.1</td>
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<td>NL1000 min of MVPA</td>
<td>38(^a)</td>
<td>16.3</td>
<td>4.4</td>
<td>15.0</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Abbreviations: M, mean; SD, standard deviation; \(df\), degrees of freedom; m·min\(^{-1}\), meters per minute; min, minutes; MVPA, moderate-to-vigorous physical activity.

\(^a\) Indicates that incomplete VO\(_2\), step, and MVPA data exist because some women were not able to walk at the fastest treadmill speed \((94 \text{ m·min}^{-1})\) at 20-weeks \((n = 3)\) and 32-weeks \((n = 5)\) gestation, and therefore ended the treadmill test following the third speed \((80 \text{ m·min}^{-1})\). Freedson cut-point for MVPA > 1951 activity counts/min; Hendelman cut-point for MVPA > 2191 activity counts/min.

**Discussion**

Findings from this study offer preliminary data indicating that physical changes induced by the processes of pregnancy may affect PA measurement. Several findings warrant discussion. In partial support of the first hypothesis, significant increases were observed in body girth circumference at monitor placement site, as well as in monitor tilt. These increases were expected because as women progress through pregnancy, weight gain occurs primarily at the midsection of the body, ultimately affecting the position of the PA monitor. However, in contrast to the hypothesis, the Actigraph accelerometer yielded significantly different outputs \((ie, \text{counts/min})\) from 20- to 32-weeks gestation for the total 20-minute treadmill protocol, as well as for each of the 4 individual treadmill speeds \((54, 67, 80, \text{ and } 94 \text{ m·min}^{-1})\). Likewise, Actigraph minutes of MVPA derived from the Freedson and Hendelman cut-points,20,21 as well as Yamax steps, NL1000 steps, and NL1000 minutes of MVPA also changed significantly from 20- to 32-weeks gestation. Importantly, the physical changes induced by pregnancy appear to have impacted the outputs from all 3 monitors, despite the fact that the treadmill protocol was kept identical at both time points. While no published studies were located examining the effects of the physical changes of pregnancy on the accuracy of the activity monitor output at different time points in pregnancy, there have been a few studies performed on the effects of BMI category and monitor tilt on pedometer accuracy among normal weight and overweight children and nonpregnant adults.10,11,14–16 Collectively, the results among these studies are inconsistent. While 2 studies found pedometer accuracy to be compromised in overweight and obese nonpregnant adults,15,16 findings from 3 other studies indicated that BMI category had no effect on pedometer accuracy.10,11,14 In the current study, both the SW-200 and NL1000 pedometer outputs changed significantly from 20- to 32-weeks gestation. It is possible that along with increases in body girth and monitor tilt there may also be changes in gait patterns compromising the outputs of these monitors. An assessment of gait was not performed in this study, but is recommended for future research.

After observing significant increases in body girth circumference and monitor tilt from 20- to 32-weeks gestation, a second analysis was performed for the Actigraph activity counts/minute across the 20-minute treadmill protocol, as well as for each of the 4 speeds, adjusting for these potentially confounding factors \(ie, \text{changes in body girth and monitor tilt}\). After controlling for these changes, no significant differences were observed from 20- to 32-weeks gestation for any of the outcomes. Although pregnancy is a relatively short period of time, there are many physical and psychological benefits to being physically active during this time.
However, quantifying PA to more accurately determine a dose-response among pregnant women is challenging. Objective assessments of PA, along with self-report methods, can offer a nonbiased view of PA volume and intensity; however, based on the findings in this study, activity monitor placement is important to take into consideration during pregnancy.

Actigraph minutes of MVPA as indicated by the established cut-points by Freedson and colleagues and Hendelman and colleagues significantly decreased from 20- to 32-weeks gestation, despite that the treadmill protocol was identical at both time points. The differences in intensity categorization in this study, although significant, appear to be minimal (ie, only about 1 minute based on Freedson’s cut-points, and < 1 minute based on Hendelman’s cut-points). However, it is important to mention that these differences are based only on a 20-minute treadmill walking protocol. If extrapolated out to a full day in free-living, the practical significance of these differences is substantial. If accelerometers are not able to accurately and consistently categorize PA intensity (ie, mild, moderate, and vigorous) at different points in pregnancy, their value will be limited for use with this population. Further research should be performed replicating the methods in this study to tease out the specific factor that may have influenced this inconsistency in PA intensity categorization.

Overall, this study provides preliminary evidence of changes in monitor performance across pregnancy that should be considered when using these devices to assess PA among pregnant women. There are, however, a few limitations worthy of mention. First, it is important to note that this study was performed on a small sample of pregnant women in a controlled setting. Future research should extend these study findings to examine the validity and reliability of the Actigraph accelerometer, and NL1000 and Yamax pedometers during pregnancy in controlled and free-living conditions. Only 1 study to date, performed by Stein and colleagues, assessed the convergent validity of accelerometry (ie, Caltrac), heart rate telemetry, and a PA diary at 20- and 32-weeks gestation. They found that absolute energy expenditure as estimated by these 3 methods was not highly convergent among pregnant women, such that PA diaries overestimated energy expenditure, and accelerometry underestimated energy expenditure compared with heart rate estimations. Replication of these methods during free-living, while taking into consideration monitor placement and the physical changes women experience during pregnancy, is necessary.

Second, this study did not assess potential changes in gait patterns across the trimesters. Foti and colleagues conducted the only study, to date, that observed alterations in kinetic parameters during pregnancy revealing compensations employed to maintain normal gait despite substantial weight gain and an anterior shift in the center of gravity. However, they only assessed gait at 1 time point in pregnancy, eliminating the ability to assess changes in gait patterns across the trimesters. Further research examining changes in gait during pregnancy using motion analysis is important to better understand how they may affect the output of objective measures of PA, as well as to more accurately assess activity monitor tilt. It is possible that changes in gait as pregnancy progresses are responsible for the differences in the Actigraph counts/minute from 20- to 32-weeks gestation. In addition, stride frequency (ie, NL1000 and Yamax steps) decreased although the treadmill time and speed

<table>
<thead>
<tr>
<th>Variables</th>
<th>20-weeks gestation</th>
<th>32-weeks gestation</th>
<th>F</th>
<th>df</th>
<th>P-value</th>
</tr>
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<tbody>
<tr>
<td>Actigraph activity counts/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>54 m·min⁻¹</td>
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<td>1.85</td>
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<td>1</td>
<td>0.65</td>
</tr>
<tr>
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<td>1505.3</td>
<td>1.41</td>
<td>1</td>
<td>0.24</td>
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<td>Actigraph min of MVPA</td>
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<td>Freedson cut-points</td>
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<td>Hendelman cut-points</td>
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<td>Yamax steps</td>
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<td>NL1000 steps</td>
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<td>NL1000 min of MVPA</td>
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Abbreviations: M, mean; SD, standard deviation; df, degrees of freedom; m·min⁻¹, meters per minute; min, minutes; MVPA, moderate-to-vigorous physical activity.

*a* Indicates that incomplete VO₂, step, and MVPA data exist because some women were not able to walk at the fastest treadmill speed (ie, 94 m·min⁻¹) at 20-weeks (n = 3) and 32-weeks (n = 5) gestation, and therefore ended the treadmill test following the third speed (ie, 80 m·min⁻¹).
was kept the same at both time points. Therefore, it is possible that the way pregnant women walk changes as pregnancy progresses.

Finally, all women were not able to complete the treadmill protocol at the fourth treadmill speed (94 m·min⁻¹), and therefore, the N’s for the comparisons at 94 m·min⁻¹ were lower than for the first 3 speeds. Importantly, most (ie, 4/5) of the women who failed to complete the full treadmill protocol at 32-weeks were in the overweight/obese BMI category. This finding emphasizes the need for future research examining the link between prepregnancy weight and PA during pregnancy. In addition, this study highlights the significance of considering activity monitor placement and the associated body girth and tilt measures with pregnant populations. While some methods may be ill-suited for assessing validity in pregnant populations (ie, doubly-labeled water method), future research using methods such as video motion analysis or gas analysis via a portable metabolic analyzer could be used to establish construct validity of accelerometry in free-living conditions.

Acknowledgments

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References