



Trajectories of objectively-measured physical activity and sedentary time over the course of pregnancy in women self-identified as inactive

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ABSTRACT

There is a need for investigations that document the *daily* course of pregnancy-related changes in PA and sedentary behavior. The purpose of this study was to describe the trajectory of PA and sedentary behavior and whether they differ among weight status in pregnant women self-identified as inactive. Eighty inactive pregnant women (8–16 weeks) were recruited from a nationwide text-message intervention. PA was measured using a Fitbit. Chi-square analyses and *t*-tests were used to analyze univariate demographic and PA variables. Mixed model-repeated measures ANOVA was used to analyze trajectory changes in *daily* PA and sedentary behavior. Light activity (beta [SE] = 2.79 [0.30], $p < .001$), active time (b [SE] = 1.62 [0.16], $p < .001$), and steps (b [SE] = 112.21 [10.66], $p < .001$) increased during the second trimester followed by a precipitous decline during the third trimester. Sedentary behavior followed an opposite pattern (b = -9.88 [1.07], $p < .001$). Overweight and obese women took significantly fewer steps/day (b [SE] = -742.37 [362.57], $p < .05$ and -855.94 [381.25], $p < .05$, respectively) than normal weight women, and obese women had less “active” minutes/day (\sim 3.0 metabolic equivalents; b [SE] = -12.99 [5.89], $p < .05$) than normal weight women (P 's < 0.05). Women who self-identify as inactive, become more sedentary and less physically active as pregnancy progresses. This study was among the first to describe the trajectory of *daily* PA and sedentary behavior throughout pregnancy. This study may help inform health care provider and patient communication related to PA, sedentary behavior, and the time in which to communicate about these behaviors.

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1. Introduction

There is considerable evidence that physical activity participation during pregnancy has beneficial effects for both the mother and fetus (Borodulin et al., 2008; Ferraro et al., 2012). For the mother, physical activity may help prevent gestational diabetes, pre-eclampsia, support healthy weight, and improve mental health (Borodulin et al., 2008; Ferraro et al., 2012). Regular physical activity may also help maintain cardiovascular fitness during pregnancy and may positively impact postpartum recovery (Evenson, 2011). Fetal benefits include reduced stress response and healthier birth weight (Mudd et al., 2013).

Current recommendations for pregnant women are based upon evidence and recommendations for healthy adults (Physical Activity Guidelines Advisory Committee Report, 2008). According to the Physical Activity Guidelines for Americans, healthy women should get at least 150 min per week of moderate-intensity aerobic activity, such as brisk

walking, during and after their pregnancy. The American College of Obstetricians and Gynecologists (ACOG) recommends that pregnant women, with uncomplicated pregnancies, engage in regular physical activity (both aerobic and strength-conditioning exercises) (Physical Activity Guidelines Advisory Committee Report, 2008; American College of Obstetricians and Gynecologists, 2015) while avoiding activities such as contact sports and supine position activities after 20-week gestation.

Studies estimate that most pregnant women (>50%) do not participate in recommended physical activity despite the benefits to both the mother and fetus (Evenson et al., 2004; Harrison et al., 2011; Zhang and Savitz, 1996). Borodulin and colleagues (2008) have suggested the prevalence of pregnant women meeting physical activity guidelines varies across studies from 6% to 78% (Pereira et al., 2007; Petersen et al., 2005). There is limited data available on the relationship between weight status (i.e., normal, overweight, obese) and physical activity patterns in pregnant women (Sui, 2013). However, the CDC suggests that women and obese adults are less likely to meet physical activity guidelines (Centers for Disease Control and Prevention, 2015). One longitudinal study reported 65% of their sample of overweight and obese pregnant women met PA guidelines (i.e., 30 min of moderate to vigorous physical activity (MVPA) per day) throughout their pregnancy

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(McParlin et al., 2010). Findings from this study were limited due to small sample size and power. Furthermore, retrospective and prospective studies suggest that both self-reported leisure and occupational-related physical activities decrease throughout pregnancy (Downs et al., 2009) with the largest changes occurring during the third trimester (Borodulin et al., 2008; Evenson et al., 2004; Evenson et al., 2002; Mottola and Campbell, 2003; Poudevigne and O'Connor, 2006). However, these studies have only collected physical activity data at specific time points for a short duration (3–7 days) and haven't collected data at the daily level across trimesters.

Physical activity estimates in pregnancy are also mostly based on studies that use self-report measures of physical activity (Schmidt et al., 2006). Self-report measures have known limitations and poor reliability and validity relative to objective measures (i.e., accelerometers) (Poudevigne and O'Connor, 2006). This is especially true for measuring light and sedentary activities, which are more common activity intensity levels during pregnancy yet are not commonly observed (Borodulin et al., 2008; Schmidt et al., 2006). A few studies have used both self-reported and objective measures to quantify physical activity levels during pregnancy (Ruifrok et al., 2014). Bell et al. measured physical activity using self-report and accelerometer measures in 59 pregnant women at one time point (12-week gestation) (Bell et al., 2013). Self-reported MVPA was significantly higher (81–127 min/day) than that recorded using accelerometers (35 min/day). Oostdam et al. also found self-reported physical activity to be higher than accelerometer data in overweight and obese pregnant women (Oostdam et al., 2013).

Studies using either self-report and/or objective measures are further limited by their lack of continuous measurement of physical activity (i.e., daily across trimesters) (Bell et al., 2013). Studies using self-reported physical activity relied on single recalls of overall activity during various points throughout pregnancy (e.g., trimesters) and studies with objective measures have not tracked physical activity patterns beyond single estimates in each trimester (Schmidt et al., 2006). Additionally, the few studies that have assessed physical activity patterns in overweight and obese pregnant women lack comparison with normal weight pregnant women and differences between weight status are inconclusive (Sui, 2013; McParlin et al., 2010; Van Poppel et al., 2013). Such methods do not offer the full picture of physical activity trajectories or patterns over the course of pregnancy or by weight status. Examining how physical activity trajectories may be unique during pregnancy and weight status is important given known fluctuations over time in physical activity among non-pregnant adults (Centers for Disease Control and Prevention, 2015; Adams et al., 2013; Bassett et al., 2015), changes to priorities and demands on pregnant women's time, and rapidly changing physiological, psychological, social conditions as pregnancy develops.

There is also a scarcity of information about sedentary time in pregnant women (i.e., sitting/reclining with low energy expenditure) (Ruifrok et al., 2014; Di Fabio et al., 2015; Franks et al., 2011; Sedentary Behaviour Research Network, 2012). Sedentary time has emerged as an important and independent risk factor for chronic disease and may have negative health implications during pregnancy (Franks et al., 2011). These include gestational diabetes, hypertension and preeclampsia in the mother and low/high birth weight in the baby (Franks et al., 2011). A recent study reported pregnant women spend approximately 70% of their wake time sedentary (Di Fabio et al., 2015). However, like physical activity, the trajectory of change in sedentary time during pregnancy is undocumented.

Knowing how the progression of pregnancy affects physical activity and sedentary time over trimesters could help with the design of interventions, yet longitudinal investigations that document the course of pregnancy-related changes in physical activity and sedentary time using objective measures at frequent intervals during pregnancy does not exist (Poudevigne and O'Connor, 2006). This information could help to determine the optimal time during pregnancy in which to intervene and the appropriate intensity to improve physical and mental

health outcomes. Therefore, the purpose of this observational study was to examine the trajectory of physical activity behavior and sedentary time in pregnant women self-identified as inactive, throughout the pregnancy time course (i.e., daily across trimesters and up to 40 weeks). A secondary purpose was to test whether these trajectories differed among weight status (i.e., normal, overweight, obese at entry to study).

2. Methods

This study was approved by the Institutional Review Board at a University in the Southwestern United States. Participants were women recruited for a text message intervention (i.e., Text4baby (T4b)) aimed at improving physical activity in pregnant women. The intervention is published elsewhere (Huberty et al., in review; Huberty et al., 2015) and found no intervention effects and no differences across groups (Huberty et al., 2015). Briefly, the study was a 4-arm randomized controlled trial. Specifically, participants were randomly assigned to one of four groups and stratified according to ethnicity to facilitate equal representation of minorities in each of the four groups: (a) *Standard* (three T4b SMS from the original content (original cT4b content included only two PA SMS across entire pregnancy) per week (M,W,F) at noon); (b) *Plus One* (three SMS; two T4b and one PA per week (M,W,F) at noon); (c) *Plus Six* (seven SMS; one T4b and six PA per week (Su-Sa) at noon); and (d) *Plus Six Choice* (seven SMS; one T4b and six PA per week (Su-Sa) at the time of day they choose).

Physical activity was measured from entry into the study (8–16 weeks pregnant) until the end of the pregnancy (36–40 weeks). Pregnant women were recruited through social media sites (e.g., Facebook, Twitter), fliers posted in health care provider offices, word of mouth, email listservs and discussion boards (e.g., BabyCenter). Interested participants were directed to an eligibility questionnaire on Qualtrics (Provo, Utah) that took three to 5 min to complete.

Women were eligible to participate if they were: 1) at least 18 years of age, 2) between 8 and 16 weeks pregnant, 3) owned a smartphone with text message capability, 4) had regular access to a computer, 5) able to speak/read/understand English, 6) resided in the United States, 7) willing to provide a cell phone number to receive text messages, 8) willing to wear a physical activity monitor throughout their pregnancy, and 9) were not meeting recommendations for physical activity (i.e., 30 min of moderate physical activity on at least five days/week) before their pregnancy or currently (Physical Activity Guidelines Advisory Committee Report, 2008). Women were ineligible if they were: 1) considered a high risk pregnancy (defined by The ACOG's Position Statement on Exercise During the Pregnancy and Postpartum Period (Artal and O'Toole, 2003)), and 2) physically limited to exercise or instructed by a physician not to participate in exercise. Recruitment took place between June and September 2014.

After eligibility was confirmed, participants were asked to sign an online consent form, complete a demographic questionnaire (e.g., age, race, ethnicity, income, education, number of chronic conditions, days of wear, and gestational age at enrollment), self-report physical activity using the Modifiable Activity Questionnaire (Kriska, 1997), and schedule a telephone intake appointment. Online consent and the demographic and physical activity questionnaire were completed using Qualtrics (Provo, Utah).

After the intake appointment, each participant was mailed a Fitbit Flex (San Francisco, CA) and instructions about how to wear and sync the monitor. Participants were instructed to wear the Fitbit throughout pregnancy (up to 40 weeks), 24 h a day (except during showers or swimming) on their non-dominant wrist. When sleeping or taking a nap, women were instructed to switch the Fitbit mode to "Sleep". Physical activity was measured using the Fitbit device. The Fitbit has been shown to be valid measure of steps under laboratory conditions (Patel et al., 2015; Takacs et al., 2014). The Fitbit provides estimates of "sedentary", "light", "fairly active" and "very active" minutes as daily

accumulated totals. Fitbit describes fairly active minutes to represent activities occurring at >3.0 metabolic equivalents (METs) and very active minutes >6.0 METs (Help Article, in review). While no precise definition of sedentary and light categories are provided by Fitbit, common activities <3.0 METs include leisurely walking, household chores, and other lifestyle activities (Ainsworth et al., 2011). Sedentary behavior has been defined as seated activities at <1.5 METs (Sedentary Behaviour Research Network, 2012). Researchers registered participants Fitbits online while creating user accounts authorizing access to the Fitbit data for study personnel. For purposes of analysis, “fairly active” and “very active” were combined to form an “active time” category that may be analogous to moderate-vigorous physical activity. Fitbit data (i.e., steps, activity monitoring) were blinded to the participants. The Fitbit online account access was only available to study personnel (user account login information unknown to participants) and the Fitbit device has no visible monitoring screen. Participants were instructed to download Fitbit software and sync/charge every five days. Research assistants monitored compliance of participants by syncing their Fitbit and were sent an email reminder if they hadn’t synced the Fitbit within the last five days. Days with ‘0’ minutes of registered activity were considered non-valid and set to missing. Women were able to keep the Fitbit as compensation for participating.

2.1. Data analysis

Chi-square analyses and *t* tests were used to analyze univariate demographic and physical activity variables. We followed analytical steps for the assessment of a cohort-sequential research design where participants had varying entry and exit points in the study and contributed varying amount of physical activity data (Duncan et al., 2007). Mixed model-repeated measures analysis of variance was used to analyze trajectory changes in daily physical activity variables (i.e., sedentary, light, active, and steps), independently (Singer and Willett, 2003). Mixed model analyses were chosen because of the intensive repeated measures design and statistical power within this framework. Mixed model analyses have been shown to be more robust to missing data than standard general linear model approaches where subjects are excluded listwise (Raudenbush and Xiao-Feng, 2001). Model building steps included entering stepwise into the model:

a) day within pregnancy, to assess trajectory of change in physical activity variables over the course of the pregnancy (linear and quadratic time parameterizations were tested); b) Body Mass Index (BMI) status and its interaction with day within pregnancy; to assess whether overall activity and change trajectories varied by BMI status; and c) trimester and its interaction with day within pregnancy, to assess whether activity levels and change trajectories varied within each trimester. Full-information maximum likelihood estimation was used as part of the SPSS version 22.0 software to accommodate missing data in the models. All models were adjusted for age, race, ethnicity, income, education, number of chronic conditions, days of wear, and gestational age at enrollment. In addition we controlled for group assignment with no differences across groups (Huberty et al., in review; Huberty et al., 2015). The significance level for all statistical analyses was set at $p < 0.05$.

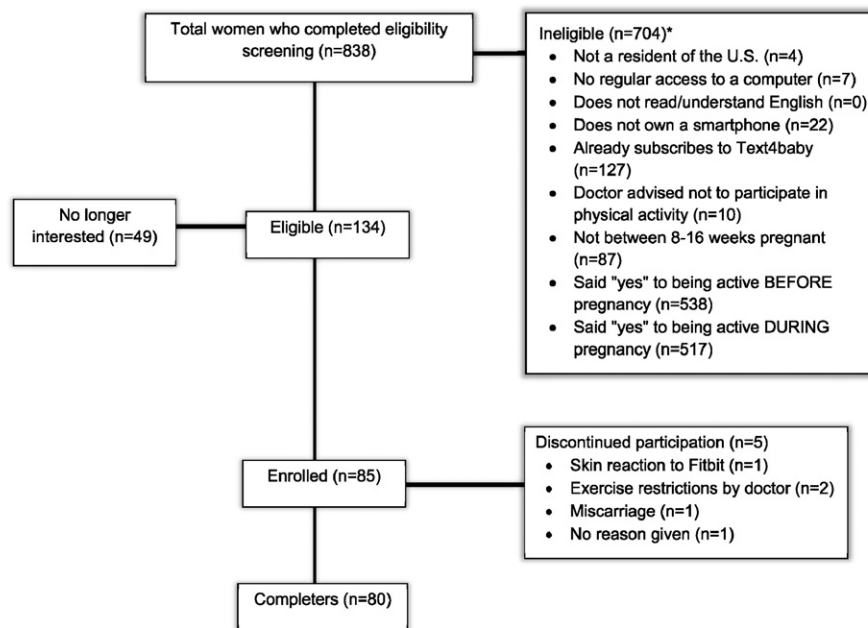
3. Results

3.1. Participants

Fig. 1 describes participant flow. Among women completing eligibility screening, 84.0% were not eligible (see Fig. 1). This was mainly due to being too active before or during the first 8–16 weeks of pregnancy. An additional 5.8% were eligible but no longer interested after learning more about the study. Eighty-five women (10.1% of total screened) were enrolled in the study and 80 (94.1%) completed the study. Table 1 describes participant demographics by weight status. Women were split relatively similar across weight categories; primarily Caucasian and non-Hispanic; well-educated with higher levels of income; and few reported chronic conditions. Women enrolled in the study and began wearing their activity monitor at the end of the first trimester. Modal gestational age at enrollment was 13 weeks and 75% of the sample was enrolled between 11 and 15 weeks of the pregnancy (Table 1).

3.2. Descriptive physical activity and sedentary behavior results

Women on average wore the monitor just over 100 days throughout their pregnancy. Women spent the majority of the day sedentary with fewer minutes in light, fairly active, and very active behaviors,



*Participants may have been ineligible for more than one reason

Fig. 1. Participant enrollment flow chart.

Table 1
Sample characteristics by weight status.

Variable	Weight status						Total	
	Normal		Overweight		Obese			
N	31		25		24		80	
Age, years (M ± SD)	30.67	± 4.83	32.11	± 5.05	30.89	± 5.41	31.19	± 5.05
Race, n (%)								
Caucasian	28	−90.32	21	−84	20	−83.33	69	−86.25
African-American	1	−3.23	0	0	2	−8.33	3	−3.75
Asian	1	−3.23	1	−4	0	0	2	−2.5
American Indian	0	0	0	0	1	−4.17	1	−1.25
Other	1	−3.23	3	−12	1	−4.17	5	−6.25
Ethnicity, n (%)								
Hispanic	2	−6.45	3	−12	2	−8.33	7	−8.75
Non-Hispanic	29	−93.55	22	−88	22	−91.67	73	−91.25
Education, n (%)								
<High school	0	0	1	−4	2	−8.33	3	−3.75
High school diploma	0	0	1	−4	0	0	1	−1.25
Some college	11	−35.48	3	−12	7	−29.17	21	−26.25
Associates/2-year degree	0	0	2	−8	2	−8.33	4	−5
Bachelors degree	13	−41.94	7	−28	9	−37.5	29	−36.25
Graduate school or above	7	−22.58	11	−44	4	−16.67	22	−27.5
Household income, n (%)								
≤\$20 k/year	1	−3.23	0	0	2	−8.33	3	−3.75
\$21 k–\$40 k/year	3	−9.68	3	−12	7	−29.17	13	−16.25
\$41 k–\$60 k/year	5	−16.13	5	−20	5	−20.83	15	−18.75
≥\$61 k/year	22	−70.97	17	−68	10	−41.67	51	−63.75
# of chronic conditions, n (%)								
0	27	−87.1	23	−92	16	−66.67	66	−82.5
1	4	−12.9	2	−8	7	−29.17	13	−16.25
2	0	0	0	0	1	−4.17	1	−1.25
Gestational age at enrollment, weeks (M ± SD)	12.65	± 4.83	13.6	± 2.63	12.83	± 2.5	12.99	± 2.52
All physical activity at enrollment (reported), MET·h/wk (M ± SD)	5.05	± 6.1519	5.22	± 3.86	5.58	± 5.45	5.26	± 5.25
Walking at enrollment (reported), MET·h/wk (M ± SD)	2.74	± 5.78	3.93	± 3.63	3.11	± 3.80	3.22	± 4.60

respectively. Women took just over 4000 steps/day on average. The majority of physical activity data sampled was in the second trimester (n observations = 4645, n participants = 80, 61.2% of overall data) followed by the third (n observations = 2570, n participants = 58, 33.8% of overall data) and first (n observations = 380, n participants = 30, 5.0% of overall data) trimesters (Table 2).

3.3. Trajectories of change in physical activity and sedentary behavior variables

Our primary aim was to examine trajectories of change in physical activity variables over the course of pregnancy (see Table 3 and Fig. 2). For sedentary time, the significant positive linear and significant negative quadratic trends in Table 3 suggest increasing levels of sedentary time throughout pregnancy with accelerated increases at the end of pregnancy (Fig. 2, Panel A). For light activity, the small but significant positive linear trend and a significant positive quadratic trend suggest initially there is a slight increase in the amounts of light intensity activity followed by accelerated decreases at the end of pregnancy (Fig. 2, Panel B). For active time, a significant negative linear trend and a significant positive quadratic trend suggest a decrease in active time throughout pregnancy with an accelerated decrease toward the end of pregnancy (up to 40 weeks) (Fig. 2, Panel C). Finally, for steps, there

was no linear effect present, however, there was a significant positive quadratic trend. This pattern suggests relatively stable number of steps with an accelerated decrease in steps toward the end of pregnancy (Fig. 2, Panel D).

3.4. Trajectory differences by BMI status and trimester

We further explored whether the physical activity variables varied by BMI status. After accounting for linear and quadratic trajectories and adjusting for covariates, overweight and obese women took significantly fewer steps throughout pregnancy than normal weight women. Obese women had less active time than normal weight women. No differences were observed between overweight and obese women. No BMI status by time in pregnancy interaction was observed, suggesting the trajectory of change was constant by BMI status (data not shown). For trimester differences in trajectories, there was not substantial data represented in the first trimester to warrant comparisons; thus, these data were collapsed with second trimester data. There were no significant differences in the physical activity variables by trimester. However, there was significant trimester by time in pregnancy interactions for all four physical activity variables in the expected directions. This pattern suggested accelerated increases in sedentary time and decreases

Table 2
Means and standard deviations of physical activity variables.

Variable	BMI status						Total	
	Normal		Overweight		Obese			
Monitoring period, days	108.3	± 48.02	94.92	± 56.02	97.08	± 52.67	100.73	± 51.71
Sedentary, min/day	993.77	± 180.52	977.93	± 186.33	961.82	± 166.29	979.23	± 176.49
Light activity, min/day	115.43	± 43.86	106.45	± 45.84	117.32	± 42.64	113.18	± 43.81
Fairly active, min/day	54.01	± 23.40	47.38	± 24.36	51.3	± 24.97	51.12	± 24.03
Very active, min/day	5.77	± 5.25	4.47	± 4.42	3.96	± 3.29	4.82	± 4.49
Steps/day	4408.48	± 1750.02	3847.02	± 1668.42	4092.25	± 1730.01	4138.15	± 1713.52

Table 3
Regression coefficients (standard errors) for modeling change in physical activity variables by BMI status and trimester.

	Sedentary	Light	Active	Steps
Time (linear)	0.66 (0.18)**	0.09 (0.02)**	−0.04 (0.02)*	−2.36 (1.27)
Time (quadratic)	−9.88 (1.07)***	2.79 (0.30)***	1.62 (0.16)***	112.21 (10.66)***
BMI status				
Normal (ref)	–	–	–	–
Overweight	17.67 (58.97)	−5.49 (9.90)	−10.19 (5.61)	−742.37 (362.57)*
Obese	−25.58 (61.64)	−1.70 (10.38)	−12.99 (5.89)*	−855.94 (381.25)*
Trimester				
First/second (ref)	–	–	–	–
Third	326.60 (323.46)	−56.08 (63.78)	−14.93 (41.67)	−42.74 (26.11)
First/second × time (ref)	–	–	–	–
Third × time	−20.13 (5.80)**	7.23 (1.16)***	3.07 (0.75)***	223.75 (51.23)*

Note. All models were adjusted for age, race, ethnicity, income, education, number of chronic conditions, days of wear, gestational age at enrollment, and intervention arm.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

in light activity, active time, and steps in the third trimester relative to the first and second trimesters.

4. Discussion

The purpose of this study was to examine and describe the trajectories of objectively-measured physical activity behavior and sedentary time in pregnant women during pregnancy (i.e., daily across trimesters - up to 40 weeks). A secondary purpose was to test whether these trajectories differed by initial weight status. Our findings reveal that, as pregnancy progresses, physical activity follows an inverse U-shaped curve. In the first and second trimesters, women are increasing their physical activity, but by the third trimester they spend more time sedentary and less time being active. The time course of change indicates more precipitous declines in physical activity (and increase in sedentary time) in the latter half of the third trimester. This longitudinal information confirms snapshots observed in cross-sectional studies (Evenson and Wen, 2011), and adds to the literature in the following ways.

First, our primary aim was to observe physical activity patterns throughout pregnancy. Light activity (<3 METs) (Ainsworth et al., 2011) increased slightly throughout pregnancy (until midway of third trimester) with an accelerated decrease at the end of the pregnancy. This result is consistent with cross-sectional studies using self-reported physical activity measures that have documented indoor household, caregiving, and recreational activities (i.e., light activity) constitute the largest proportion of total activity reported by pregnant women (Borodulin et al., 2008; Schmidt et al., 2006). We are unaware of any studies that have followed women over time during pregnancy in which to compare our findings. Little attention has been paid to light activity as a portion of total activity in pregnant women (Di Fabio et al., 2015). Research suggests that increasing light activities of daily living (i.e., non-exercise activity thermogenesis) may have an important role in the management of body weight in non-pregnant adults (Ainsworth et al., 2011). These same behaviors may positively influence health outcomes in pregnant women (Di Fabio et al., 2015).

Second, to our knowledge, this study was one of the first to explore the trajectory of sedentary time across trimesters. The few studies to date examining sedentary time in pregnant women have been limited to cross-sectional designs (Petersen et al., 2005; Di Fabio et al., 2015; Evenson and Wen, 2011; Haakstad et al., 2007). Our study suggests sedentary time increases even in those that maintain their physical activity during pregnancy, similar to what was reported in only one of the aforementioned cross-sectional studies (Di Fabio et al., 2015). Findings in a study by Di Fabio and colleagues reported that pregnant women in their sample ($n = 46$) spend up to 70% of their day (time awake) in sedentary behaviors regardless of meeting physical activity guidelines

(i.e., 2008 Department of Health and Human Services prenatal physical activity guidelines) (Di Fabio et al., 2015). Our findings also suggest sedentary behavior has a marked acceleration during the last half of the third trimester. Sedentary time has known harmful effects in pregnant women including excessive weight gain, increased risk of pre-eclampsia, gestational diabetes, and hypertension (Ruifrok et al., 2014; Di Fabio et al., 2015; Haakstad et al., 2007; Chasan-Taber et al., 2007; Cramp and Bray, 2009; Evenson et al., 2009; Haakstad et al., 2009; Loprinzi et al., 2013).

Finally, in our study, obese women had less active time than normal weight women and overweight and obese women took significantly fewer steps throughout pregnancy than normal weight women. Few studies have explored activity during pregnancy based on weight status at beginning of pregnancy (Chasan-Taber et al., 2007; Fell et al., 2009; Hinton and Olson, 2001) and findings are inconclusive. One study suggested that women with higher pre-pregnancy BMI were significantly more likely to discontinue sports and exercise during the first 20 weeks of pregnancy (Fell et al., 2009) while in another study higher pre-pregnancy BMI predicted increasing exercise behavior from pre-pregnancy to pregnancy (Hinton and Olson, 2001). The findings from our study specifically highlight the need for interventions among overweight and/or obese women, a specific population at increased risk for many obstetric complications (i.e., gestational diabetes, preeclampsia, macrosomia) (Gaudet et al., 2014). Despite the difference in levels of physical activity between obese and normal weight women illustrated in our study, the trajectories were similar suggesting interventions and improved communication are needed for all pregnant women, regardless of BMI (i.e., gestational weight status).

4.1. Implications

Our findings emphasize the fast rate of increased sedentary time and decreased activity that occurs as pregnancy progresses. These findings provide useful information to health care providers and health promotion professionals and underscore the need for future interventions to consider promoting reductions in sitting time and increases in habitual lower-intensity types of activity in addition to increasing MVPA. For example HCPs may encourage more household chores or yardwork and other light activity that can be easily incorporated into daily life or at work (e.g., walk while talking on the phone, take the stairs, stand at your desk) in addition to recommendations for increasing time spent in MVPA. Sedentary time has emerged as an important and independent risk factor for chronic disease and may have negative health implications during pregnancy (Franks et al., 2011). However, to date, there has been little focus on decreasing sedentary time as opposed to achieving recommendations for physical activity (150 min per week of

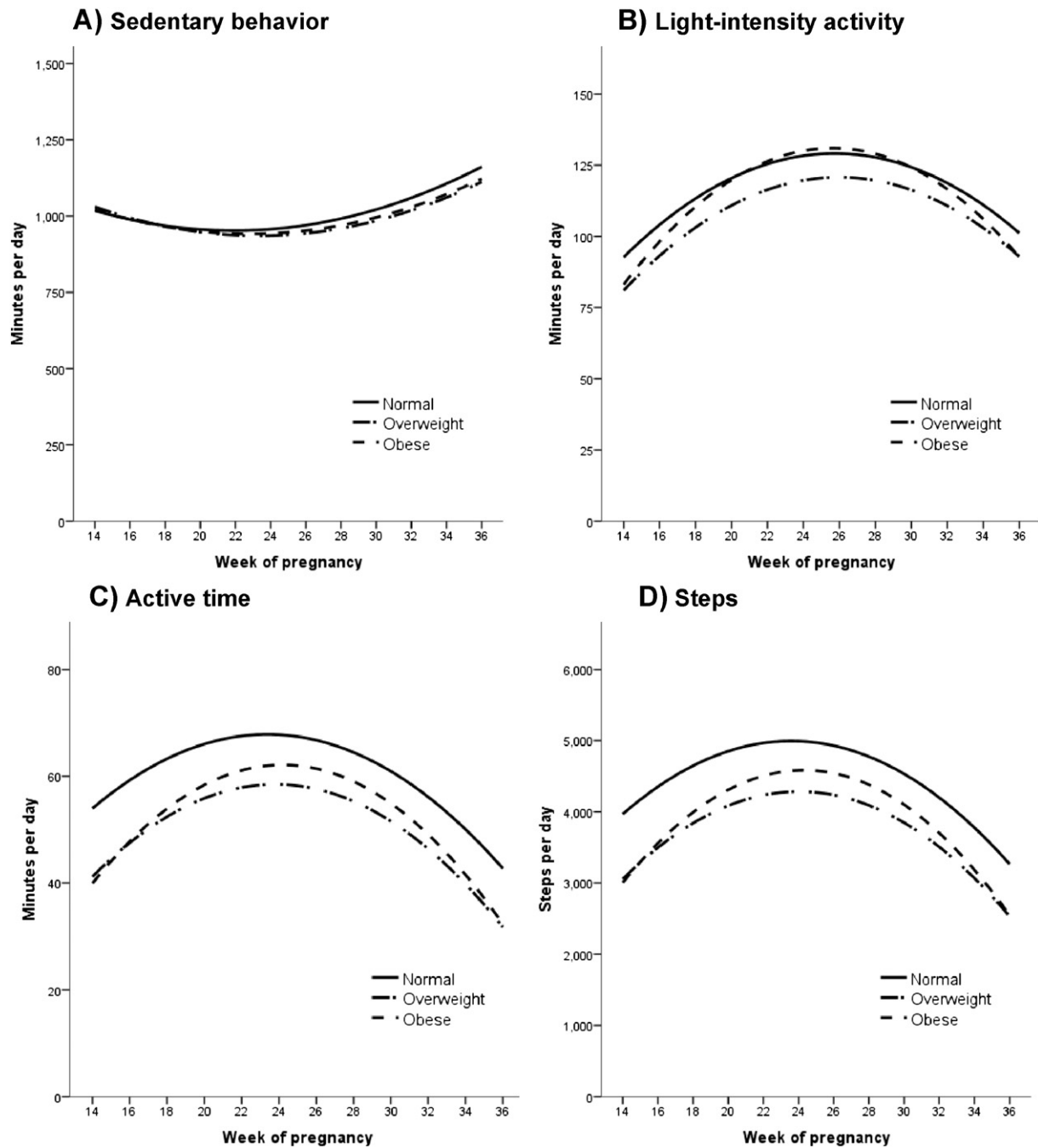


Fig. 2. Changes in sedentary behavior (Panel A), light-intensity activity (Panel B), active time (Panel C), and steps (Panel D) per day over the course of pregnancy. Data are model-based estimates adjusted for age, race, ethnicity, income, education, number of chronic conditions, days of wear, gestational age at enrollment, and intervention arm.

moderate intensity activity) (Physical Activity Guidelines Advisory Committee Report, 2008). Our study and work by others (Di Fabio et al., 2015) present important information that may help health care providers communicate more effectively with their patients to get them to not only be more active during pregnancy but to consider sitting less (i.e., sedentary activity). There is a need for interventions and healthcare messaging that specifically target reductions in sedentary behaviors (i.e., sitting), especially during the end of pregnancy (Di Fabio et al., 2015; Evenson and Wen, 2011; Loprinzi et al., 2013). This may be an effective way to curtail some of the negative health outcomes in both the mother and baby associated with sedentary behaviors (i.e., gestational diabetes, large and small for gestational age infants). In particular, health care providers may emphasize reductions in sitting

time and simple movement within the home as pregnancy progresses into the third trimester to mitigate the rapid increase in sedentary behavior toward the end of pregnancy. Especially considering reducing sedentary behavior (i.e., sitting time) may seem more attainable than participating in physical activity toward the end of pregnancy when a mother is likely to be most uncomfortable (Evenson et al., 2009; Haakstad et al., 2009).

Interventions aimed at improving health behaviors (i.e., physical activity) in pregnant women and information that health care providers utilize to counsel patients should also focus on encouraging light activities in addition to moderate levels of physical activity. Pregnant women report barriers to activity that are similar to non-pregnant women (e.g., time, motivation, social support) but additionally report physical

barriers (Cramp and Bray, 2009) such as discomfort (e.g., pelvic and low back pain, swollen feet) and fatigue (Gaston and Cramp, 2011). Moreover, many pregnant women report feeling “limited” often due to mixed messages related to what types and amounts of exercise are safe during pregnancy (Leiferman et al., 2012). Messaging that clearly conveys that even light activity is beneficial may encourage pregnant women who would not normally participate in MVPA. This may especially be true for activities they associate with being easier and comfortable to do while pregnant (i.e., gardening, childcare). Encouragingly, many pregnant women believe engaging in light activity is beneficial. In one study, 98% of women ($n = 1306$; 27–30 weeks gestation) agreed that there were benefits to participation in light activity during pregnancy, with fewer agreeing that there were benefits to moderate (73%) and vigorous (13%) activity (Evenson and Bradley, 2010). However, it is important to note, that many of the extant studies on prenatal physical activity report only moderate and vigorous physical activity with few focusing on participation in light activities (Evenson et al., 2002; Oostdam et al., 2013; Leiferman et al., 2012).

4.2. Limitations and methodological considerations

Despite this study's contribution there are a few limitations. First, while our sample was predominantly white and educated and may not represent a diverse sample of women, it was geographically diverse with women participating from across the U.S. adding to the external validity of the findings. Additionally, our findings are consistent with cross-sectional studies of diverse pregnant women (Lynch et al., 2012) suggesting that similar trajectories may be seen in women of racial/ethnic minority. The use of objective monitor and the continuous (i.e. daily) nature of measurement were all strengths compared to previous studies using self-reported measures, and thus the current study results were not affected by recall bias. Although there are few validation studies demonstrating the accuracy of Fitbit Flex for classifying activity by intensity, the device has shown good validity for measuring steps (Takacs et al., 2014). This places less confidence in the precise estimates of activity time by intensity. However, the patterns of findings were consistent across intensity levels, clearly suggesting a pattern of decline in physical activity and increase in sedentary time throughout pregnancy. However, it is important to note these data could not have been measured using an Actigraph or other research grade accelerometer at the time of this study because data collected in this study was continuous over a 40-week period (with varying contributions by participants). Research grade accelerometers did not have the battery life for this study duration or capability to transmit their data remotely to researchers. There is also variation in the number of monitoring days because of the differing times of gestation at enrollment (8–16 weeks). Finally, because continuous data was collected over the course of pregnancy, the large day-to-day variability observed may not have represented important variation. We examined weekly-level models with similar results to the daily-level models we reported; however, it is still possible that long-term, high resolution data that were collected may have picked up on non-informative, natural variation in physical activity patterns.

Another limitation is that there are no established approaches for determining non-wear time from sedentary time with the Fitbit; therefore, it's possible that some sedentary or light activity time was misclassified. However, we do not believe this had a large impact on our results given our elimination of days where the device was not worn at all and intensive repeated measures design which was not influenced by periodic days of missing data or partial missingness. Because the modal gestational age at enrollment was 13 weeks, true observation of change between the first trimester to second or third are not possible and therefore results should be interpreted with caution. The small sample size of those classified as “very active” limits the interpretation of results for this group. Finally, the participants in this study were part of a broader intervention study. However, there

were no intervention effects or differences between groups (Huberty et al., in review; Huberty et al., 2015).

5. Conclusions

As pregnancy progresses, women spend more time being sedentary than physically active. A more pronounced decline in physical activity (and increase in sedentary time) was observed in the latter half of the third trimester. This study was among the first to describe the trajectory of daily physical activity and sedentary behaviors during most of the course of pregnancy and provides important information about the trajectory of physical activity behavior and sedentary time during pregnancy. The data from this study may inform how health care providers communicate with their patients related to participation in healthy lifestyle behaviors (i.e., sit less, move more) for optimal maternal and fetal health outcomes. This data may also help inform the time of the pregnancy in which interventions to improve physical activity and/or reducing sedentary behaviors in pregnant women is most necessary.

Author disclosure statement

The authors report that Ms. Jessica Bushar was an employee of the ZERO TO THREE one of the founding partners of Text4baby (the Healthy Mothers, Healthy Babies operation of Text4baby was transitioned to ZERO TO THREE in 2015), at the time of this work and no other authors report any conflicts of interest.

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References

- Adams, M., Sallis, J., Norman, G., Hovell, M., Hekler, E., Perata, E., 2013. An adaptive physical activity intervention for overweight adults: a randomized controlled trial. *PLoS ONE* 8, e82901.
- Ainsworth, B.E., Haskell, W.L., Herrmann, S.D., et al., 2011. 2011 compendium of physical activities: a second update of codes and MET values. *Med. Sci. Sports Exerc.* 43, 1575.
- American College of Obstetricians and Gynecologists. Physical activity and exercise during pregnancy and the postpartum period. *Obstet. Gynecol.* 2015; (Committee Opinion No. 650:e135–42).
- Artal, R., O'Toole, M., 2003. Guidelines of the American College of Obstetricians and Gynecologists for exercise during pregnancy and the postpartum period. *Br. J. Sports Med.* 37, 6–12.
- Bassett, D.R., Frayssse, F., Rowlands, A.V., et al., 2015. Introducing novel approaches for examining the variability of individuals' physical activity. *J. Sports Sci.* 33, 457–466.
- Bell, R., Tennant, P.W.G., McParlin, C., et al., 2013. Measuring physical activity in pregnancy: a comparison of accelerometry and self-completion questionnaires in overweight and obese women. *Eur. J. Obstet. Gynecol. Reprod. Biol.* 170, 90–95.
- Borodulin, K., Evenson, K., Wen, F., Herring, A., Benson, A., 2008. Physical activity patterns during pregnancy. *Med. Sci. Sports Exerc.* 40, 1901–1908.
- Centers for Disease Control and Prevention. One in Five Adults Meet Overall Physical Activity Guidelines. Available at: <http://www.cdc.gov/media/releases/2013/p0502-physical-activity.html>. 2015.
- Chasan-Taber, L., Schmidt, M.D., Pekow, P., Sternfeld, B., Manson, J., Markenson, G., 2007. Correlates of physical activity in pregnancy among Latina women. *Matern. Child Health J.* 11, 353–363.
- Cramp, A.G., Bray, S.R., 2009. A prospective examination of exercise and barrier self-efficacy to engage in leisure-time physical activity during pregnancy. *Ann. Behav. Med.* 37, 325–334.
- Di Fabio, D.R., Blomme, C.K., Smith, K.M., Welk, G.J., Campbell, C.G., 2015. Adherence to physical activity guidelines in mid-pregnancy does not reduce sedentary time: an

- observational study. *The International Journal of Behavioral Nutrition and Physical Activity* 12, 191.
- Downs, D.S., LeMasurier, G.C., DiNallo, J.M., 2009. Baby steps: pedometer-determined and self-reported leisure-time exercise behaviors of pregnant women. *J. Phys. Act. Health* 6, 63–72.
- Duncan, S.C., Duncan, T.E., Strycker, L.A., Chaumeton, N.R., 2007. A cohort-sequential latent growth model of physical activity from ages 12 to 17 years. *Ann. Behav. Med.* 33, 80–89.
- Evenson, K.R., 2011. Towards an understanding of change in physical activity from pregnancy through postpartum. *Psychology of Sport & Exercise* 12, 36–45.
- Evenson, K.R., Bradley, C.B., 2010. Beliefs about exercise and physical activity among pregnant women. *Patient Educ. Couns.* 79, 124–129.
- Evenson, K.R., Wen, F., 2011. Prevalence and correlates of objectively measured physical activity and sedentary behavior among US pregnant women. *Prev. Med.* 53, 39–43.
- Evenson, K., Siega-Riz, A., Savitz, D., Leiferman, J., Thorp, J., 2002. Vigorous leisure activity and pregnancy outcome. *Epidemiology* 13, 653–659.
- Evenson, K.R., Savitz, A., Huston, S.L., David, 2004. Leisure-time physical activity among pregnant women in the US. *Paediatr. Perinat. Epidemiol.* 18, 400–407.
- Evenson, K.R., Moos, M., Carrier, K., Siega-Riz, A.M., 2009. Perceived barriers to physical activity among pregnant women. *Matern. Child Health J.* 13, 364–375.
- Fell, D.B., Joseph, K., Armon, B., Dodds, L., 2009. The impact of pregnancy on physical activity level. *Matern. Child Health J.* 13, 597–603.
- Ferraro, Z.M., Gaudet, L., Adamo, K.B., 2012. The potential impact of physical activity during pregnancy on maternal and neonatal outcomes. *Obstet. Gynecol. Surv.* 67, 99–110.
- Franks, P.W., Pomeroy, J., Wright, A., et al., 2011. Physical activity, sedentary behaviors, and estimated insulin sensitivity and secretion in pregnant and non-pregnant women. *BMC Pregnancy and Childbirth* 11, 44.
- Gaston, A., Cramp, A., 2011. Exercise during pregnancy: a review of patterns and determinants. *Journal of Science and Medicine in Sport* 14, 299–305.
- Gaudet, L., Ferraro, Z.M., Wen, S.W., Walker, M., 2014. Maternal obesity and occurrence of fetal macrosomia: a systematic review and Meta-analysis. *BioMed Research International* 2014, 1–22.
- Haakstad, L.A.H., Voldner, N., Henriksen, T., Bø, K., 2007. Physical activity level and weight gain in a cohort of pregnant Norwegian women. *Acta Obstet. Gynecol. Scand.* 86, 559–564.
- Haakstad, L.A.H., Voldner, N., Henriksen, T., Bø, K., 2009. Why do pregnant women stop exercising in the third trimester? *Acta Obstet. Gynecol. Scand.* 88, 1267.
- Harrison, C.L., Thompson, R.G., Teede, H.J., Lombard, C.B., 2011. Measuring physical activity during pregnancy. *Int. J. Behav. Nutr. Phys. Act.* 8, 1.
- Help Article: What are active minutes? Fitbit Web site. Available at: http://help.fitbit.com/articles/en_US/Help_article/What-are-very-active-minutes/. (Accessed April 7, 2015).
- Hinton, P.S., Olson, C.M., 2001. Predictors of pregnancy-associated change in physical activity in a rural white population. *Matern. Child Health J.* 5, 7–14.
- Huberty, J., Rowedder, L., Hekler, E., et al., 2015. Development and design of an intervention to improve physical activity in pregnant women using Text4baby. *Translational Behavioral Medicine* 1–10.
- Huberty J.L., Buman M.P., Leiferman J.A., Buschar J., Hekler E., Adams M.A. Encouraging physical activity in pregnant women: findings from a text message intervention. *Translational Behavioral Medicine* (in review).
- Kriska, A., 1997. Modifiable activity questionnaire. *Med. Sci. Sports Exerc.* 29, 73–78.
- Leiferman, J., Gutilla, M., Paulson, J., Pivarnik, J., 2012. Antenatal physical activity counseling among healthcare providers. *Open Journal of Obstetrics and Gynecology* 2, 346–355.
- Loprinzi, P.D., Fitzgerald, E.M., Woekel, E., Cardinal, B.J., 2013. Association of physical activity and sedentary behavior with biological markers among U.S. pregnant women. *J. Women's Health* 22, 953–958 (2002).
- Lynch, K.E., Landsbaugh, J.R., Whitcomb, B.W., Pekow, P., Markenson, G., Chasan-Taber, L., 2012. Physical activity of pregnant Hispanic women. *Am. J. Prev. Med.* 43, 434–439.
- McParlin, C., Robson, S.C., Tennant, P.W.G., et al., 2010. Objectively measured physical activity during pregnancy: a study in obese and overweight women. *BMC Pregnancy and Childbirth* 10, 76.
- Mottola, M.F., Campbell, M.K., 2003. Activity patterns during pregnancy. *Can. J. Appl. Physiol.* 28, 642–653.
- Mudd, L.M., Owe, K.M., Mottola, M.F., Pivarnik, J.M., 2013. Health benefits of physical activity during pregnancy: an international perspective. *Med. Sci. Sports Exerc.* 45, 268–277.
- Oostdam, N., van Mechelen, W., Van Poppel, M., 2013. Validation and responsiveness of the AQuAA for measuring physical activity in overweight and obese pregnant women. *Journal of Science and Medicine in Sport* 16, 412–416.
- Patel, M.S., Burwick, H.A., Case, M.A., Volpp, K.G., 2015. Accuracy of smartphone applications and wearable devices for tracking physical activity data. *J. Am. Med. Assoc.* 313, 625–626.
- Pereira, M.A., Rifas-Shiman, S.L., Kleinman, K.P., Rich-Edwards, J.W., Peterson, K.E., Gillman, M.W., 2007. Predictors of change in physical activity during and after pregnancy. *Project Viva. Am. J. Prev. Med.* 32, 312–319.
- Petersen, A.M., Leet, T.L., Brownson, R.C., 2005. Correlates of physical activity among pregnant women in the United States. *Med. Sci. Sports Exerc.* 37, 1748–1753.
- Physical Activity Guidelines Advisory Committee Report, 2008: to the Secretary of Health and Human Services. U.S. Dept. of Health and Human Services, Washington, DC.
- Poudevigne, M., O'Connor, P., 2006. A review of physical activity patterns in pregnant women and their relationship to psychological health. *Sports Med.* 36, 19–38.
- Raudenbush, S.W., Xiao-Feng, L., 2001. Effects of study duration, frequency of observation, and sample size on power in studies of group differences in polynomial change. *Psychol. Methods* 6, 387–401.
- Ruifrok, A.E., Althuisen, E., Oostdam, N., et al., 2014. The relationship of objectively measured physical activity and sedentary behaviour with gestational weight gain and birth weight. *Journal of Pregnancy*.
- Schmidt, M.D., Pekow, P., Freedson, P.S., Markenson, G., Chasan-Taber, L., 2006. Physical activity patterns during pregnancy in a diverse population of women. *J. Women's Health* 15, 909–918.
- Sedentary Behaviour Research Network, 2012. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". *Appl. Physiol. Nutr. Metab.* 37, 540–542.
- Singer, J.D., Willett, J.B., 2003. *Applied Longitudinal Data Analysis: Modeling Change and Event Occurrence*. Oxford. Oxford University Press, New York.
- Sui, Z., 2013. Exercise in obese pregnant women: positive impacts and current perceptions. *International Journal Of Women's Health* 389–398.
- Takacs, J., Pollock, C.L., Guenther, J.R., Bahar, M., Napier, C., Hunt, M.A., 2014. Validation of the Fitbit one activity monitor device during treadmill walking. *Journal of Science and Medicine in Sport* 17, 496–500.
- Van Poppel, M.N.M., Oostdam, N., Eekhoff, M.E.W., Wouters, M.G.A.J., Van Mechelen, W., Catalano, P.M., 2013. Longitudinal relationship of physical activity with insulin sensitivity in overweight and obese pregnant women. *J. Clin. Endocrinol. Metab.* 98, 2929–2935.
- Zhang, J., Savitz, D.A., 1996. Exercise during pregnancy among US women. *Ann. Epidemiol.* 6, 53–59.