Greater energy demand of exercise during pregnancy does not impact mechanical efficiency

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<td>Denize, Kathryn; University of Ottawa, Department of Human Kinetics, Faculty of Health Science, Akbari, Pegah; University of Ottawa, Department of Human Kinetics, Faculty of Health Science, da Silva, Danilo; University of Ottawa, Department of Human Kinetics, Faculty of Health Science, Haman, François; University of Ottawa, Department of Human Kinetics, Faculty of Health Science, Adamo, Kristi; University of Ottawa, Department of Human Kinetics, Faculty of Health Science,</td>
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<td>Novelty bullets: points that summarize the key findings in the work:</td>
<td>1) Energy demand during exercise increases proportionally to weight gain across pregnancy trimesters., 2) However, mechanical efficiency remains unchanged during low- to moderate-intensity walking.</td>
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Title: Greater energy demand of exercise during pregnancy does not impact mechanical efficiency

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ABSTRACT

Pregnant women are recommended to engage in 150 minutes of moderate-intensity physical activity per week to reduce pregnancy complications. Many women struggle to remain physically active throughout pregnancy, and there is no consensus about whether women adopt a less efficient movement pattern as they progress through pregnancy and experience gestational weight gain. This study assessed the change in energy expenditure and mechanical efficiency in pregnant women (PREG; N=10) when performing a walking treadmill task in early-, mid-, and late-pregnancy and also compared to age- and BMI-matched, non-pregnant (CON; N=10) group. On average, the PREG group gained within the Institute of Medicine’s gestational weight gain guidelines (11.6 ± 3.6 kg) and were all inactive (measured using accelerometry) by the third trimester, as per the 2019 Canadian physical activity guidelines for pregnant women. Energy expended to complete the walking task increased throughout pregnancy and was higher than the controls (111.5 ± 24.6 kcal) in mid-and late-pregnancy (139.0 ± 22.2 kcal, \(p=0.02\) and 147.3 ± 24.6 kcal, \(p=0.005\) respectively), but not early pregnancy (129.9 ± 18.9 kcal, \(p=0.08\)). Walking mechanical efficiency was similar within pregnant women at each time point and compared to non-pregnant controls. Our findings add to the growing body of evidence demonstrating that pregnant women can safely perform physical activity by showing that walking mechanical efficiency is unchanged at low to moderate intensities.

NOVEL FINDINGS

1) Energy demand during exercise increases proportionally to weight gain across pregnancy trimesters.

2) However, mechanical efficiency remains unchanged during low- to moderate-intensity walking.
**KEYWORDS:** Pregnancy; mechanical efficiency; exercise; gestational weight gain; energy expenditure, physical activity
INTRODUCTION

Pregnancy is a unique time in a woman’s life in which her body undergoes a wide spectrum of physiological, biochemical, and biomechanical changes over a relatively short time to support the growth of the fetus (Girling 2004). Many early published physical activity-related recommendations for pregnant women were based on limited empirical evidence and reinforced the notion that pregnant women were weak and frail (Downs et al. 2012; Maeder 1977). Popular medical opinion from the late nineteenth century and into the first decades of the twentieth century stated that pregnant women should use extreme caution to avoid fatigue and overexertion (ACOG 1985). In today’s society, most women are expected to continue the same occupational tasks and activities of daily living as they carry their baby to term, despite the increased physiological demands placed on the body. In addition, there is overwhelming evidence that women should remain physically active during pregnancy to promote optimal health for both mother and baby (Ferraro et al. 2012; Hinman et al. 2015; Nascimento et al. 2012; Motolla et al. 2018). Recently, both the American College of Obstetricians and Gynecologists and the Society of Obstetricians and Gynaecologists of Canada have published updated guidelines for physical activity during pregnancy (ACOG 2015; Mottola et al. 2018) recommending that women—without contraindications—achieve 150 minutes of moderate-intensity physical activity per week. However, pregnancy brings forth several physiological and biomechanical changes that may influence the relationship between energy cost and external work to complete a given movement or task (Cavagna & Kaneko 1977). Clearly, if such changes were to occur, physical activity or occupational health guidelines should consider such pregnancy-related changes in mechanical efficiency. Unfortunately to date, there is limited literature examining how pregnancy affects energy expenditure and mechanical efficiency during exercise.
Currently, findings on the effects of pregnancy on energy expenditure and mechanical efficiency are contrary to what would be expected. For example, in scenarios of traditional load carriage, such as wearing a backpack or carrying military equipment, there is a linear and proportional relationship between external load carriage and energy cost, indicating that mechanical efficiency is unchanged when an external load is imposed (Grenier et al. 2012; Huang & Kuo 2014; Taylor et al. 2016). Studies that have characterized mechanical efficiency have concluded that pregnant women use less oxygen for a given task and become more efficient movers as they progress through their pregnancy (Byrne et al. 2011; Clapp 1989; Lotgering et al. 1991). Although pregnancy is distinct from other types of load carriage, because metabolically active tissue contributes, in part, to the increased load (Moya et al. 2014), it is still unexpected to have different results. Moreover, the methodology employed in previous work was suboptimal (Byrne et al. 2011; Clapp 1989; Lotgering et al. 1991): variables known to affect efficiency—treadmill grade and walking speed (Cavagna et al. 1963; Margaria 1968)—were not kept constant throughout the gestational period. Given that efficiency has practical implications for recommendations of physical activity, additional work in this field of physiology is warranted.

The purpose of this study was to quantify changes in energy expenditure and mechanical efficiency during pregnancy using a standardized exercise protocol. Specifically, energy expenditure was assessed in the three trimesters of pregnancy as women completing a standardized progressive exercise walking test on the treadmill at a constant speed. The findings were then compared to a non-pregnant cohort. According to previous literature in other load-carrying contexts, we hypothesized that mechanical efficiency would be unchanged during pregnancy and similar between pregnant and non-pregnant cohorts.
MATERIAL AND METHODS

Participant Recruitment and Ethical Approval

Capitalizing on existing infrastructure and recruitment processes, the participants included in this study were those engaged in the larger Physical Activity and Dietary Implications Throughout Pregnancy (PLACENTA) Study. The protocol was reviewed and approved by the Ottawa Health Science Network (REB# 20160178-01H) and participating recruitment sites. The sub-study of non-pregnant controls was approved by the University of Ottawa (REB# 11-17-190). Participants provided written, informed consent before participation.

Ten pregnant women (PREG group) and ten non-pregnant women (CON group) were recruited in the Ottawa region (Ontario, Canada). Pregnant women included in the study were between 18-40 years old, had a pre-pregnancy body mass index (BMI) between 18.5-29.9 kg/m² (based on self-reported pre-pregnancy weight), weight stable ± 5 kg for at least 6 months prior to pregnancy, carried a singleton fetus, and were cleared for participation by their health care provider, thus not presenting with contraindications to exercise. Women unable to communicate in English or French; who had pregnancy complications such as pre-pregnancy insulin-treated diabetes, untreated thyroid disease, or hypertension requiring medication at the time of recruitment; or planned to have the child adopted were excluded. The CON women were healthy and were age- and BMI-matched to the pregnant women.

Study Protocol

PREG participants visited the lab three times: once during early (T1, 15.4 ± 0.9-weeks gestation), mid (T2, 26.4 ± 1.1-weeks gestation), and late (T3, 35.3 ± 1.1-weeks gestation) pregnancy. CON participants visited the lab one time. Laboratory visits took place in the...
morning between 6h00 and 10h00 and after an 8-hour fast. At all visits, maternal height (HR-200 Wall-Mounted Height Rod, Tanita Corporation of America Inc., Illinois, USA) was measured, and maternal weight (BWB-800 Doctors Scale, Tania Corporation of America Inc., Illinois, USA) was recorded while participants were barefoot and in light clothing. Gestational weight gain was classified according to the 2009 Institute of Medicine gestational weight gain recommendations (IOM, 2009).

Following anthropometric measurements, participants were given a standardized snack (370 kcal, 7g FAT, 74g CHO, 5g PRO). A 20 min assessment of resting metabolic rate was performed before participants completed a submaximal exercise test. The modified HALO submaximal exercise protocol has been explained in detail elsewhere (Breithaupt, Adamo, & Colley, 2012) and has previously been shown to be safe in the pregnant population (Brett et al., 2015). In brief, the 21-minute incremental walking test on the treadmill began with a 4 min warm-up at a speed of 3.2 km/h and a 0% grade. Then, keeping the speed constant at 3.2 km/h, the grade increased by 2% every 3 min. A 2 min cooldown, performed at a speed of 1.6 km/h and 0% grade was completed at the end of the test. External work was calculated ($W_{ex}$), and oxygen consumption ($VO_2$), carbon dioxide production ($VCO_2$), heart rate response (HR) were continuously measured throughout the exercise test. Participants could request to terminate the test at any time; however, all participants, except one, completed the test with no obvious signs of fatigue or discomfort. Participants were instructed to keep conversation to a minimum during the test and to avoid using the handrails on the treadmill for support. All the procedures were performed at sea level, thus under normal acceleration of gravity (i.e. 9.80665 m·s$^{-2}$).

A small subset of CON women ($n = 3$) completed the exercise trial at two time points, three months apart, to assess if any change in responses were subject to time. Three months was
chosen because it represents the time between participant visits in the PREG group. The $W_{ext}$, $VO_2$, and mechanical efficiency did not change within participants over time (data not shown).

Habitual physical activity was measured using Actical® accelerometers in the PREG group. Actical® is a small omnidirectional accelerometer that measures and records time-stamped acceleration. Data was collected in 60-second epochs, providing raw data in counts per minute (cpm). Participants wore the accelerometer on their right hip and were instructed to wear the device for seven days, only removing the device for water-based activities (i.e., swimming and bathing) and sleeping. As recommended by Colley and Tremblay (2011), four or more valid days of measurement was used in the final analysis to assess physical activity levels in the cohort. Physical activity levels were compared to the “2019 Canadian guideline for physical activity throughout pregnancy” (Mottola et al. 2018).

**Measurements**

Respiratory gases were measured using a calibrated, pull-through open-circuit indirect calorimeter (FMS Field Metabolic System, Sable Systems International, Las Vegas, USA), with the flow rate set to 100L/min during rest and 200L/min during exercise. The flow rate was validated using the Life Wind flow meter (Polycontrols Inc, QC, Canada). Barometric pressure ($P_B$), and the composition of inspired ($f_i$) and expired ($f_e$) air were measured from a 250mL/min subsample using a field metabolic system (Sable Systems International Inc., Las Vegas, USA). Water vapour pressure (WVP) of $f_i$ and $f_e$ air was measured using a flow-through water vapour analyzer (RH-300 Water Vapour Analyzer, Sable Systems International Inc., Las Vegas, USA). Respiratory data were analyzed using Expedata software (Expedata-P Data Analysis Software, Sable Systems International, Las Vegas, USA). Energy expenditure was calculated using the
thermal equivalents of VO₂ for the non-protein respiratory quotient at each stage of the exercise protocol with the following equation:

\[
\text{Energy expenditure (kcal)} = \text{VO}_2 \times \text{RQ caloric equivalent} \times \text{Time},
\]
where ‘VO₂’ is oxygen consumed in L/min and ‘time’ is the length of the stage in seconds.

The area under the curve (AUC) was calculated for 20 min at rest and 21 min during the exercise protocol using the trapezoid Riemann sum. Resting energy expenditure (REE) is considered here as the energy expended throughout the 20 min resting period. Activity energy expenditure (AEE) is the energy expended over the 21 min exercise test.

HR was continuously measured using a Polar coded wear link and transmitter (Polar V800, Polar Electro, QC, Canada). Room temperature and relative humidity were controlled at 23°C and 20-25%, respectively. External work (W\text{ext}) was calculated from body mass (kg), and vertical distance travelled (m) on a calibrated treadmill when grade was greater than 0%. The following equation was used:

\[
W_{\text{ext}} (\text{kcal}) = [\text{Body mass} \times \text{Speed} \times \text{Time} \times \sin (\theta)] \times 0.000234,
\]
where ‘body mass’ is participants mass in kg, ‘speed’ is treadmill speed is in m·min⁻¹, ‘time’ is in minutes, ‘(θ)’ is the measured angle of the treadmill at each stage, and ‘.000234’ is the conversion factor from kgm to kcal.

Mechanical efficiency was calculated by using the ratio of external work (W\text{ext}, expressed in kcal) to active energy expenditure (AEE, also expressed in kcal). As we defined efficiency based on the ratio of work performed to the total energy expended during the treadmill exercise and expressed this as a percentage, we can consider mechanical efficiency a measure of
gross efficiency (Amati et al., 2008). This ratio allowed us to present mechanical efficiency as a percentage. The equation representation is:

\[
\text{Mechanical efficiency (\%) = } \frac{W_{\text{ext}}}{AEE}
\]

**Statistical Analysis**

Data are expressed as means ± SD. The assumption of normality was assessed using the Shapiro-Wilk test; repeated measures ANOVAs were conducted for normal distributions, and Friedman’s test was used for non-normal distributions when comparing variables across pregnancy. Student’s independent paired \( t \)-tests and Mann Whitney U tests were used to compare the control group to the pregnant group at the different stages of pregnancy for normally and non-normally distributed data, respectively. Pearson’s correlation coefficients were run to determine relationships among anthropometric measurement, REE and AEE. Statistical significance was set at \( p < 0.05 \) (two-tailed). All analyses were performed using SPSS, version 24 (SPSS Inc., Chicago, IL, USA). In order to supplement the \( p \)-values, Cohen’s \( d \) was calculated to determine the effect sizes (ES) between the different time points across pregnancy and the non-pregnant group (Cohen, 1988). The interpretation of ES followed conventional rules; trivial (<0.2), small (0.2 to <0.6), moderate (0.6 to <1.2), or large (≥1.2) (Hopkins et al., 2009).

**RESULTS**

**Participants**

Participant characteristics are described in Table 1. As designed, women in CON were similar in age, body mass, and BMI as compared to the PREG group (\( P > 0.05 \)). All PREG women had a pre-pregnancy BMI classified as normal. Half of the women gained within the 2009 Institute of
Medicine gestational weight gain recommendations, one exceeded recommendations, and four under-gained; on average, women gained 11.6 ± 3.8 kg. One PREG participant requested to terminate the exercise test early during her T3 visit due to hip pain (which she was regularly seeing a healthcare practitioner about), and therefore, she was excluded from the analysis. A total of twenty participants, 10 per group, are included in the final analysis.

**Heart Rate**

Resting HR values are presented in Table 1. Resting HR increased from the beginning to end of pregnancy ($P = 0.03$; ES = 0.86), and PREG had higher resting HR than CON during T2 and T3 ($P = 0.03$; ES = 1.12 and $P = 0.02$; ES = 1.23, respectively). At the end of the exercise protocol, PREG reached a higher HR with moderate ES in T3 (148.6 ± 11.8 bpm) compared to T2 (138.2 ± 11.5 bpm; $P < 0.001$; ES = 0.89) and T1 (136.2 ± 14.5 bpm; $P < 0.001$; ES = 0.94). PREG had similar HR to CON at T1 ($P = 0.07$), but higher HR at the end of the test in T2 ($P = 0.02$) and T3 ($P < 0.001$). Change in HR, measured as the difference from rest to maximum HR achieved at the end of the exercise protocol, was similar between PREG and CON, and across trimesters (all $P > 0.05$).

**Energy Expenditure**

REE and AEE are depicted in Figure 1 and Figure 2, respectively. REE was similar between CON and PREG at T1 (27.7 ± 4.9 kcal vs 29.5 ± 5.1 kcal, $P = 0.45$; ES = 0.36), but was higher at T2 (32.0 ± 5.2 kcal, $P = 0.04$; ES = 0.85) and T3 (34.8 ± 6.2 kcal, $P = 0.01$; ES = 1.28). REE increased from T1 to T3 (5.3 ± 1.1 kcal), but this increase was not significant ($P = 0.06$; ES = 0.94). AEE increased throughout pregnancy (T1=129.9 ± 18.9 kcal; T2=138.9 ± 22.2 kcal;
T3 = 147.3 ± 24.6, \( P = 0.02 \); ES between T1 x T2 = 0.44; ES between T1 x T3 = 0.80) and was higher than CON (111.5 ± 24.6 kcal) at both T2 and T3 (\( P = 0.02 \); ES = 1.17 and \( P = 0.005 \); ES = 1.46, respectively), but not at T1 (\( P = 0.08 \); ES = 0.85). Gestational weight gain was highly correlated with the change in AEE over the course of the exercise test from T1 to T3 (\( r = 0.84; P < 0.05 \)). Pearson correlations between anthropometric measurements and energy expenditure are presented in Table 2.

**External Work**

Figure 3 illustrates group differences in \( W_{\text{ext}} \) for CON and PREG. CON and PREG completed similar \( W_{\text{ext}} \) at T1 (11.8 ± 1.3 kcal vs 12.2 ± 1.8 kcal; \( P = 0.65 \); ES = 0.26) and T2 (13.3 ± 1.9 kcal; \( P = 0.07 \); ES = 0.94). At T3, PREG completed more \( W_{\text{ext}} \) than CON with a large ES (14.3 ± 2.2 kcal; \( P = 0.007 \); ES = 1.43). \( W_{\text{ext}} \) increased as pregnancy progressed (\( P < 0.001 \); ES between T1 x T3 = 1.05; ES between T2 x T3 = 0.49; ES between T1 x T2 = 0.59).

**Mechanical Efficiency**

Overall, mechanical efficiency was unchanged throughout pregnancy (Figure 4; \( P = 0.74 \); trivial ES varying from 0.00 to 0.12); however, CON had superior mechanical efficiency than PREG with moderate ES at all time points (CON = 10.4 ± 0.69, T1 = 9.6 ± 0.84%, T2 = 9.5 ± 0.97%, T3 = 9.6 ± 0.70%, all \( P < 0.05 \); ES between CON x T1 = -1.05; ES between CON x T2 = -1.08; ES between CON x T3 = -1.15).

**Physical Activity**
Three out of the 10 PREG women who participated in the study did not wear their accelerometer for a minimum of four days during the seven day period and were excluded from the analysis. Therefore, we present the results for physical activity data on seven participants. On average, PREG women participated in 21.7 ± 14.0 min/day at T1, 14.0 ± 10.5 min/day at T2, and 6.1 ± 5.9 min/day at T3 of moderate-intensity physical activity, with significant differences and large ES between T1 and T3 ($P < 0.05$; ES = -1.57). Four participants were classified as physically active in T1; however, no participants met the guideline in T3. Women reduced their activity levels as pregnancy progressed (range -1.0 to -31.2 min/week reduction from T1 to T3).

**DISCUSSION**

The results of our study build on the evidence reporting that pregnant women expend more energy to perform the same walking task and completed more $W_{ext}$ for the task as they progress from early to late pregnancy. The novel finding of our study is that pregnant women have a proportional increase in AEE and $W_{ext}$ and therefore, do not experience a change in mechanical efficiency. Compared to CON, PREG women exhibited lower mechanical efficiency at all three time points during their pregnancy.

Using estimates of changes in energy expenditure and mechanical work, our study reports only a 1% difference in walking mechanical efficiency between PREG and CON women during a standardized progressive treadmill test. Translating this into energy, PREG women expended approximately 15 kcal more than the CON group to complete the walking task. Given that pregnant women expend an additional 400 kcal per day compared to non-pregnant women (Butte et al. 2004; Durnin 1991), this small increase in energy requirement likely has little impact on overall daily energy expenditure. Since our CON and PREG groups consisted of two separate...
cohorts of women, inter-individual variation in movement patterns is more likely the cause of this small difference (Cavanagh & Kram 1985; Pedotti, 1977; Simonsen & Alkjaer 2012). Therefore, we conclude that the CON and PREG exhibit similar walking mechanical efficiency.

Our results refute those reported previously (Byrne et al. 2011; Clapp 1989; Lotgering et al. 1991) suggesting that pregnant women use less oxygen for a task and therefore adopt a more efficient movement pattern as pregnancy progresses. A potential explanation for our opposing findings could be methodological differences. Improving on previous work, we employed an exercise protocol with a constant treadmill grade and walking speed between trimesters. The importance of keeping both grade and speed consistent has been highlighted when analyzing mechanical efficiency over time (Margaria 1968). In the pregnant population, this requirement has greater importance since pregnant women tend to reduce their walking pace in late pregnancy (Branco et al. 2016; Davies et al. 2002). Results derived by protocols using self-selected speeds, such as the previous works by Lotgering et al. (1991) and Bryne et al. (2011), should be interpreted with caution. A standardized speed must be employed to ensure accurate measures in longitudinal study designs.

Specific to pregnancy, we must also consider the impact that gestational weight gain has on energy expenditure. For example, women with obesity have a higher absolute VO$_2$ than their non-obese counterparts for a given task; but, when scaled to body mass, women with obesity have a lower VO$_2$ per kilogram of body weight (Hulens et al. 2001; Loftin et al. 2001). Calculating mechanical efficiency using VO$_2$ relative to body mass, when comparing individuals of different body weights, leads to a weight-dependent reduction in energy expenditure, resulting in the incorrect interpretation that mechanical efficiency is improved. The same principles apply in pregnancy due to the impact of gestational weight gain on energy dynamics.
Considering other scenarios of increased load carriage, such as wearing a backpack, the relationship between external load and energy expenditure is proportional, resulting in no change in mechanical efficiency (Grenier et al. 2012; Huang & Kuo 2014; Taylor et al. 2016). However, it should be highlighted that the unchanged mechanical efficiency does not undermine the fact that a woman will be carrying more weight as they progress through pregnancy – some of which is metabolically active tissue (Moya et al. 2014) – and will, therefore, expend more energy. Considering this, the intensity and duration of physical activity a pregnant woman is capable of performing may still decrease. In our cohort, pregnant women expended 12% more energy at the end of pregnancy compared to early pregnancy to complete the same task.

In our cohort, PREG women reduced their physical activity between T1 and T3. This finding is not surprising and has been reviewed elsewhere (Gaston & Cramp 2011). However, the present study indicated that this reduction in physical activity did not impact the efficiency of the walking task. This result suggests that even when women are inactive throughout pregnancy, they should still be encouraged to be physically active and meet the physical activity guidelines, as mechanical efficiency is stable and should not contribute to any harmful effect. It is also worth mentioning that no PREG women in the present study were unable to complete the exercise protocol due to physiological strain, supporting the notion that moderate-intensity physical activity can be safely performed across pregnancy.

The lack of an association between measured physical activity and walking mechanical efficiency is supported by Margaria (1963), who compared mechanical efficiency of running in athletes and non-athletes and found no differences. In contrast, McBride et al. (2015) and Hintzy et al. (2005) reported an increased mechanical efficiency in repetitive jumping tasks and endurance cycling in those with more experience in the task, suggesting that knowledge and
experience may play a role in the relationship between activity and mechanical efficiency. However walking and running, compared to jumping and cycling, are more common to daily activities, which could explain the discrepant findings. Recognizing the specificities of various exercise modalities, our result may only be relevant to walking. Nevertheless, walking is the most common physical activity chosen by the pregnant population (Gaston & Vamos 2013) and is likely the one with the greatest practical application in real-world settings. In our cohort, the max HR PREG women reached when completing the task, at all three visits, was between 135-150 bpm. This HR range corresponds to the moderate-intensity HR range for women aged 30 and above in the new Canadian guideline for physical activity during pregnancy (Mottola et al. 2018) suggesting that our exercise task could be performed as a way to meet physical activity guidelines and improve maternal-newborn health outcomes.

**Strengths & Limitations**

Our study implemented a more discernable methodology than in previous studies seeking to measure the change in mechanical efficiency throughout pregnancy. One challenge we faced was the recruitment of women in the early stages of pregnancy. We do acknowledge that our sample size is small, and we did not provide any *a priori* sample size calculation, although there has been previously published work on the field (e.g., Byrne et al. 2011; Lotgering et al. 1991). The reason for not providing a sample size calculation is that these studies adopted a self-selected speed to assess energy cost, and these major methodological differences could have biased a sample size calculation. We also acknowledge that we did not consider internal work to calculate mechanical efficiency, and it could have changed throughout pregnancy. Internal work measurement requires complex analyses, such as biomechanical and cinematography techniques.
that consider how energy is transferred throughout the body. For this reason, research settings often only include external work measurements (Cavagna & Kaneko 1977). Another shortcoming from our study is the absence of body composition (i.e., lean and fat mass) measurements. Although it would have adjusted our analyses for specific changes in these components, the measurement of body composition and its interpretation in pregnant women throughout gestation still requires further validation (Most et al. 2018).

An important strength of our study was that we were able to follow our cohort from the early stages of pregnancy until delivery, which is superior to a cross-sectional design. The addition of the healthy, age- and BMI-matched non-pregnant controls allowed us to have a reasonable comparator in the absence of being able to recruit women before conception—something that presents extreme logistical challenges. As we develop a deeper understanding of body composition and its assessment in pregnant women (Most et al. 2018), future research could consider specific fat and lean mass changes across pregnancy and their association with changes in energy expenditure and, consequently, in work efficiency.

**Conclusion**

Mechanical efficiency for the same incremental walking task does not change as PREG women progress through the early-, mid-, and late-stages of pregnancy, despite an increase in body mass due to gestational weight gain. PREG women did exhibit a lower mechanical efficiency for the walking task and although this difference was statistically significant, the small difference does not have practical significance and is most likely related to inter-individual differences. Our findings contribute to the growing body of evidence and add practical value to the current
Canadian guideline for physical activity throughout pregnancy by demonstrating that pregnant women are able to walk at a moderate-intensity without any undue physiological stress.
ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.
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2015-0486. PMID: 27277563.
Table 1. Participant characteristics for CON and PREG groups

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<td>Resting RQ</td>
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<td>0.85 ± 0.08</td>
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Values are presented as mean ± SD. CON = non-pregnant women, N=10; PREG = pregnant women, N=10; BMI = body mass index; RQ = respiratory quotient; *Body mass can be converted to from kg to N by multiplying by 9.80665; **Based off of self-reported body mass and measured height at initial study.
Table 2. Pearson’s correlation for anthropometric measurement, resting and activity energy measures

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<td>0.218</td>
<td>0.735</td>
<td>0.167</td>
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<tr>
<td>GWG</td>
<td>-0.147</td>
<td>0.605</td>
<td>0.136</td>
<td>0.844</td>
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<td></td>
</tr>
<tr>
<td>REE&lt;sub&gt;T1&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ΔREE</td>
<td></td>
<td>-0.603</td>
<td></td>
<td>0.768</td>
<td>-0.221</td>
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</tr>
<tr>
<td>AEE&lt;sub&gt;T1&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.588</td>
<td>0.588</td>
</tr>
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</table>

Bolded font indicates $P < 0.05$. pBMI = pre-pregnancy BMI; GWG = gestational weight gain; ΔREE = change in resting energy expenditure from T1 to T3; REE<sub>T1</sub> = resting energy expenditure at T1; AEE<sub>T1</sub> = activity energy expenditure at T1; ΔAEE = change in activity energy expenditure from T1 to T3; ME<sub>T1</sub> = mechanical efficiency at T1
Figure Captions

Figure 1. Resting Energy expenditure (kcal). CON, non-pregnant women, N=10; T1, early pregnancy, N=10; T2, mid pregnancy, N=10; T3, late pregnancy, N=10. *p < 0.05, significantly different from CON; error bars represent SD.

Figure 2. Energy expended (kcal) over the 21-minute standardized exercise task. CON, non-pregnant women, N=10; T1, early pregnancy, N=10; T2, mid pregnancy, N=10; T3, late pregnancy, N=10. *p < 0.05, significantly different from CON; †p < 0.05, significantly different from T1; error bars represent SD.

Figure 3. Total external work completed over the 21-minute standardized exercise task. CON, non-pregnant women, N=10; T1, early pregnancy, N=10; T2, mid pregnancy, N=10; T3, late pregnancy, N=10. *p < 0.01, significantly different from CON; †p < 0.01, significantly different from T1; #p < 0.01, significantly different from T2; error bars represent SD.

Figure 4. Mechanical efficiency of treadmill walking in pregnancy and in non-pregnant controls. CON, non-pregnant women, N=10; T1, early pregnancy, N=10; T2, mid pregnancy, N=10; T3, late pregnancy, N=10. *p < 0.05, significantly different from CON; error bars represent SD.
Figure 1. Resting Energy expenditure (kcal). CON, non-pregnant women, N=10; T1, early pregnancy, N=10; T2, mid pregnancy, N=10; T3, late pregnancy, N=10. *p < 0.05, significantly different from CON; error bars represent SD.
**Figure 2. Energy expended (kcal) over the 21-minute standardized exercise task.** CON, non-pregnant women, N=10; T1, early pregnancy, N=10; T2, mid pregnancy, N=10; T3, late pregnancy, N=10. *p < 0.05, significantly different from CON; †p < 0.05, significantly different from T1; error bars represent SD.
Figure 3. Total external work completed over the 21-minute standardized exercise task. CON, non-pregnant women, N=10; T1, early pregnancy, N=10; T2, mid pregnancy, N=10; T3, late pregnancy, N=10. *p < 0.01, significantly different from CON; †p < 0.01, significantly different from T1; #p < 0.01, significantly different from T2; error bars represent SD.
Figure 4. Mechanical efficiency of treadmill walking in pregnancy and in non-pregnant controls. CON, non-pregnant women, N=10; T1, early pregnancy, N=10; T2, mid pregnancy, N=10; T3, late pregnancy, N=10. *p < 0.05, significantly different from CON; error bars represent SD.