Association of sedentary time and physical activity during pregnancy with maternal and neonatal labour-related outcomes.

Journal:	*Scandinavian Journal of Medicine and Science in Sports*
Manuscript ID	Draft
Manuscript Type:	Original Article
Date Submitted by the Author:	n/a

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Keywords:	gestation, accelerometry, umbilical cord blood gas, caesarean section

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Association of sedentary time and physical activity during pregnancy with maternal and neonatal labour-related outcomes.

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Funding

This study was partially funded by the Regional Ministry of Health of the Junta de Andalucía (PI-0395-2016), the Spanish Ministry of Education, Culture and Sport (FPU13/01993; FPU14/02518) and the University of Granada, Unit of Excellence on Exercise and Health (UCEES). This study is included in the thesis of LBG enrolled in the Doctoral Program in Clinical Medicine and Public Health of the University of Granada.

Conflict of interests: None of the authors declare any conflict of interests.

Key words: gestation; accelerometry; umbilical cord blood gas; caesarean section.

ABSTRACT

Aim: i) To analyse the association of objectively measured sedentary time (ST) and physical activity (PA) during early second trimester of pregnancy with labour-related maternal and neonatal markers; ii) to explore if ST and PA differ between women with vaginal or caesarean section deliveries.

Methods: Ninety-four Caucasian pregnant women (32.9±4.6 years old) participated in this prospective longitudinal study. Triaxial accelerometers were used to assess ST and PA intensity levels for seven consecutive days during second trimester of pregnancy. Labour-related data was collected from the obstetric medical records. Umbilical cord arterial and venous blood gas (pH, partial pressure of carbon dioxide and oxygen, and oxygen saturation) was analyzed after birth.

Results: After adjusting for potential confounders, more ST was associated with higher arterial and venous cord blood partial pressure of carbon dioxide and more acidic arterial and venous pH (all, $p<0.05$). Moderate PA, moderate-to-vigorous PA (MVPA), steps per day and total PA were positively associated with arterial cord blood oxygen saturation (all $p<0.05$). Steps per day were inversely associated with gestational age at delivery ($p<0.01$), duration of first stage of labour and birth weight (all, $p<0.05$). Total and light PA were associated with more alkaline pH in umbilical vein (all, $p<0.05$). Vigorous PA was inversely associated with the Apgar score ($p<0.01$). Women who had caesarean section had expended more time in ST than women who had vaginal deliveries ($p=0.100$).

Conclusion: Increasing PA and decreasing ST during pregnancy might promote better maternal and neonatal labour-related markers.

INTRODUCTION

Uterine blood flow is crucial to meet the nutrient and oxygen requirements of the placenta and the foetus[1]. It should be noted that during delivery, uterine contractions induce metabolic stress in the foetus, whose adaptation can be reflected in the umbilical cord blood gases immediately after birth[2]. Actually, small changes of foetal pH could significantly affect the functioning of the cardiovascular system and central nervous system as well as it could be related to worse score in the Apgar test and a higher risk of neonatal complications in short and long term[3].

Previously, different types and intensities of physical exercise have been related with the neonatal base acid balance, the foetus-placenta blood flow or the birth weight, among others[4]. To date, it is known that exercise during pregnancy can improve blood perfusion and lower peripheral vascular resistance due to increased angiogenesis, increased endothelial vasodilation[5] and placental uterine perfusion[6]. However, no studies have previously associated different intensities of physical activity (PA) objectively measured with umbilical cord blood gases and other health-related maternal and foetal parameters. PA is any body movement produced by the skeletal muscles and that produce an energy expenditure higher than basal metabolic rate[7]. The American College of Obstetricians and Gynaecologists (ACOG) recommends at least 150 minutes per week of moderate PA (with daily amounts of 30 minutes or more) for pregnant women without clinical complications[8]. Therefore, it seems possible that PA levels during early second trimester of pregnancy might influence utero-placental perfusion, which could be reflected in the acid-base balance of the neonate as well as ST can have a relevant negative effect on them.

Hence, it is of clinical and social interest to determine whether ST and PA intensity levels are associated with labour-related outcomes for both, the mother and the neonate.

This might guide future studies to focus on specific active lifestyle interventions as new and alternative therapeutic targets in order to avoid adverse labours, including caesarean sections.

Therefore, the aims of the present study were: i) To explore the association of objectively measured ST and PA levels during early second trimester of pregnancy with labour-related maternal and neonatal markers; ii) to investigate if ST and different PA intensity levels during early second trimester of pregnancy differ between women with vaginal or caesarean section deliveries.

METHODS

Study design and participants

This study is part of the GEStation and FITness (GESTAFIT) project, and its complete methodology as well as inclusion-exclusion criteria **(Table S1)** can be found elsewhere[9]. From the 229 women contacted at "San Cecilio" Hospital in Granada (southern Spain) we recruited 161 pregnant women **(Figure S1)**. Clinical Research Ethics Committee of Granada, Government of Andalusia, Spain (code: GESFIT-0448-N-15) approved this study. A written informed consent was signed by the participants before beginning the study.

Procedures

After being contacted from the research team in their first gynecologist visit to the Hospital in their 12th gestational week, participants were invited to carry on the study at "Instituto Mixto Universitario Deporte y Salud", University of Granada. In 16th gestational week, a first measurement was carried out. In this evaluation, an initial survey (anamnesis) was performed in order to compile information on the sociodemographic and clinical characteristics.

Measurements

Sociodemographic and clinical data

The collection of sociodemographic (such as number of children, educational level or marital status), reproductive history, and clinical data (hypertension, diabetes, obesity, etc.) was done through a self-reported survey by the participants. The researchers explained how to fill out this questionnaire properly. This information was gathered by means of an auto administered questionnaire, which also included questions about smoking or alcohol habit and indicators of the socioeconomic status. In addition, information about the obstetric history of the pregnant woman, such as the evolution of previous pregnancies and data related to the current gestation were collected. After delivery, data regarding the onset of labour (spontaneous or induced), type of analgesia employed (if any), duration of first and second stage of labour, expulsion of meconium, arterial and venous umbilical cord blood gas analysis and Apgar score in the newborn were collected from medical records. The Apgar test is used to assess the status of the newborn. In this way, the heart rate, respiratory effort, muscle tone, skin color, and reflex irritability are evaluated. It is done at one and five minutes after birth and the maximum score is 10, which means that the newborn is in the best conditions.

Obstetric History

Obstetric and gynecological histories were collected through the "Pregnancy Health Document", which is a document provided to all pregnant women by the Andalusian regional government where data related to the health check-ups are periodically recorded. Hence, information regarding the number and evolution of previous pregnancies, gynecological antecedents and previous births, was obtained from this document. Gestational age was calculated from the date of last menstruation corrected for cycles of 28 days, and subsequently corrected, if needed, by ultrasound.

Maternal anthropometry and body composition

Maternal baseline height was measured with a stadiometer (Seca22, Hamburg) and body weight was measured in the 16^{th} gestational week with a scale (InBody R20, Biospace, Seoul, Korea). Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared.

Sedentary time and physical activity intensity levels

ST and PA were objectively assessed with triaxial accelerometry (ActiGraph GT3X+, Pensacola, Florida, US), using an epoch length of 60 seconds and a frequency rate of 30

Hz. The pregnant women carried the accelerometer around the hip 24 hours per day for 9 consecutive days. A total of 7 days of recording with a minimum registration of≥10hours/day was necessary to be included in the study. The hours of sleep and those in which they did not wear the accelerometer were subtracted from the total registered time for the whole day (usually 1.440 min) obtaining "accelerometer wearing time". Values with recording of ≥20,000 counts/min were excluded because of potential malfunction. Bouts of 90 continuous minutes of 0 activity intensity counts were also excluded from the analyses.

Accumulated time below 200 counts per minute (minimum periods of 10 minutes) was used to calculate ST, and it was expressed in minutes per day[10]. The time involved in PA intensity levels (light, moderate, moderate-to-vigorous and vigorous) were calculated based on recommended PA vector magnitude cut points ≥200-2690, ≥2690-6166, ≥2690 and ≥6167 counts/min[11], respectively, and were expressed in min/day. The minutes of moderate-to-vigorous physical activity (MVPA) bouts per week were also calculated. Bouted MVPA was defined as a period of ≥10 consecutive minutes spent in that behaviour (up to 2 minutes below the cut point allowance). Groups of meeting PA guidelines were established according to the PA recommendations for adults: not meeting PA recommendations (<150min/week of bouted MVPA) and meeting PA recommendations (≥150min/week of bouted MVPA). Data download, reduction, cleaning, and analyses were performed using ActiGraph software (ActiLife v. 6.13.3). In the first assessment, a PA diary was given to participants to register activities that the accelerometer cannot record, such as swimming or cycling.

Labour-related outcomes

After delivery, we collected information about parity, gestational age at delivery, type of labour onset (spontaneous, induced or stimulated by oxytocin or prostaglandins), moment of rupture of the amniotic sac and duration of the first and second stages of labour. Currently, there is little consensus about when the active phase or first stage of labour begins[12]. The duration of the first stage was defined as the period comprising a cervical dilatation of 4 centimeters or more with regular uterine contractions until full dilatation, which was defined by a dilatation of the cervix of 10 centimeters. The second stage of labour or expulsive period occurs between complete dilatation of the uterine cervix and complete delivery of the foetus. Likewise, after delivery of the newborn, we collected information about the type of delivery (eutocic, instrumental or caesarean section).

Umbilical cord blood gas

Samples of arterial and venous blood from the umbilical cord were collected before the delivery of the placenta to assess pH, partial pressure of carbon dioxide (PCO_2), partial pressure of oxygen (PO_2) and oxygen saturation using a blood analyzer (GEM Premier 4000). Double clamping of the umbilical cord is performed by a trained midwife between the first and third minutes life of the neonate, with a minimum distance between both clamps of 10 centimeters. For the extraction of blood, pre-heparinized 1mL syringe is used. The gas analysis is carried out at the time of extraction at room temperature[13].

Statistical analysis

Descriptive statistics (mean (standard deviation) or number (%)) were employed to show the socio-demographic, clinical characteristics and levels of objectively measured PA of the study sample. The association of MVPA with ST and PA levels with labour-related maternal and neonatal markers was assessed with partial correlations after adjusting for maternal age, parity, BMI and accelerometer wearing time. An analysis of the covariance (ANCOVA) after adjustment for the above mentioned potential confounders was employed to explore the differences in ST and PA levels between women who had vaginal deliveries (eutocics and instrumentals) versus caesarean section. Additionally, standardized effect size statistics were estimated in all the comparisons through Cohen's *d* and its exact confidence interval. The exact confidence intervals for Cohen's d were obtained by means of the non-centrality parameter of the non-central Student's distribution using Wolfram-Mathematica 8.0. The effect size was interpreted as small (~0.25), medium (~0.5) or large (~0.8 or greater). Finally, such as in the GESTAFIT project, a concurrent physical exercise program was carried out, we have also adjusted all the models for the exercise intervention (control or intervention).

The statistical analyses were performed with SPSS (IBM SPSS Statistics for Windows, version 20.0; Armonk, NY, USA) and the statistical significance was set at α=0.05.

RESULTS

From all the participants who met the eligibility criteria, 161 were cited for the first assessment and 94 Caucasian pregnant women (age 32.9±4.6 years old, BMI 24.9 ±4.1kg/m^2) accepted to participate and presented valid data for the present analyses. The flowchart of the participants for this specific study aims is shown in Figure S1.

The sociodemographic and clinical characteristics of the study participants are shown in Table 1. Fifty-four percent of the participants had University studies and half of the sample worked full-time (47%). Regarding the type of delivery, 61% of the women had eutocic deliveries, 15% had instrumental deliveries and 24% had caesarean section. The deliveries took place around 39.7±1.2 week of gestation, with a mean neonate body weight at birth of 3310±468.3 grams. Mean Apgar test score at the first minute of life was 8.7±0.9. Participants expend around 3598±682.4 minutes per week in sedentary time, and 95±115.2 minutes per week in MVPA in bouts of at least 10 minutes.

Pearson´s partial correlations of ST and PA levels during early second trimester of pregnancy with labour-related maternal and neonatal markers are shown in Table 2. After adjusting for maternal age, parity, BMI, accelerometer wearing time and the exercise intervention, ST was associated with a more acidic arterial (r=-0.262, p<0.05) and venous (r=-0.267, p<0.05) cord blood pH and higher arterial (r=0.335, p<0.01) and venous (r=0-.299, p<0.01) cord blood partial pressure of carbon dioxide. Higher levels of light PA were associated with less acidic venous cord blood pH concentrations (r=0.251, p<0.05). Moderate and bouted MVPA were positively associated with arterial oxygen saturation (r=0.251, p<0.05 and r=0.266, p<0.05, respectively) as well as moderate PA (r=0.251, p<0.05) and greater total PA (r=0.263, p<0.05), which is also associated with less acidic venous cord blood pH (r=0.264, $p<0.05$). Nevertheless vigorous PA levels were inversely associated with the Apgar test at first minute (r=-0.365, $p<0.01$), and at five minutes (r=-0.342, $p<0.01$) of life. Finally, steps per day were associated with lower length of the first stage of labour (r=-0.274, $p<0.05$), lower neonate body weight (r=-0.208, $p<0.05$) and greater arterial cord blood oxygen saturation (r=0.318, $p<0.05$).

Differences on ST and PA levels of the study participants by delivery mode (vaginal or caesarean section) are shown in Table 3. A borderline significant difference was observed in ST between women who had caesarean sections and those who had vaginal deliveries (mean difference with 95%CI**,** p=0.091 for the unadjusted model and p=0.112 for the adjusted model; Cohen´s d=0.39). Women who had caesarean sections spent less minutes on PA, regardless of the intensity level: light PA (mean difference with 95% CI p=0.088 for the unadjusted model and p=0.223 for the adjusted model, Cohen´s d=0.29), Moderate PA (mean difference with 95% CI p=0.695 for the unadjusted model and p=0.605 for the adjusted model, Cohen´s d=0.12), vigorous PA (mean difference with 95% CI p=0.046 for unadjusted model and p=0.269 for the adjusted model, Cohen´s d=0.26) and MVPA (mean difference with 95% CI p=0.489 for the unadjusted model and p=0.315 for the adjusted model, Cohen´s d=0.24). In addition, women who had caesarean section had less weekly total PA than those who had a vaginal delivery (mean difference with 95% CI p=0.073 for the unadjusted model and p=0.189 for the adjusted model , Cohen´s d=0.31)

DISCUSSION

As far as we know, this is the first study exploring the association of objectively measured ST and PA intensity levels during early second trimester of pregnancy with labour-related health markers of the mother and foetus. A major finding of the present study is that more ST is associated with a lower pH as well as higher partial pressure of carbon dioxide in both umbilical artery and vein. Likewise, higher levels of total, moderate, MVPA and steps per day are associated with greater umbilical arterial oxygen saturation, and greater total and light PA are related to higher levels of venous cord blood pH. It is also noteworthy that women who had caesarean presented more ST during early second trimester of pregnancy.

Association of ST and PA levels with labour-related outcomes

We found that greater number of steps per day were associated with shorter duration of the first stage of labour, lower gestational age and weight at birth, and better oxygen saturation in the umbilical artery. A lower weight of the newborn influences the reduction of the time of the first stage of delivery, as other studies have previously shown[14]. Avoiding a prolonged duration of the first stage of labour is important, since it has been associated with more obstetric interventions, instrumented deliveries, and caesareans sections[15]. In addition, the shorter time of cervical dilatation might have influenced the better saturation of oxygen in the umbilical artery after delivery, which is a positive sign of foetal well-being, since uterine contractions during labour produce acute restrictions of blood flow from the placenta to the fetus[2]. A lower neonate weight might be related to lower gestational age[16]. In fact, when this correlation is adjusted for gestational age at at labour, the steps per day are not linked with the newborn weight. However, taking into account that both, the age and weight of the newborn were within normal parameters, the reduction of these parameters could be interpreted as positive effects[17]. Indeed, foetal macrosomia has been associated with increased risk of caesarean section, shoulder dystocia and longer duration of the first stage of labour, among others[18].. Findings regarding the associations of steps per day with the labour length cannot be commented with regard to other studies, since it has never been explored in pregnant women. It is possible that women who walked more during second trimester of pregnancy, were more active during late pregnancy too. Hence, since aerobic exercise performed regularly during pregnancy shortens the first phase of labour[19], a plausible explanation could be that PA, which is a similar stimulus to aerobic walking, even at low intensity[20], might influence the shortening of the first stage of labour.

Association of ST and PA levels with neonate-related outcomes

In agreement with our results, Ruifrok et al.[21] observed that objectively measured ST was not associated with gestational age or birth weight. We also observed that greater ST during early second trimester pregnancy was associated with higher arterial partial pressure of carbon dioxide (PCO_2), and more acidic pH in both arterial and venous cord blood. This is a relevant finding because umbilical arterial cord blood gas at birth is a gold standard in the determination of the acid-base balance in the foetus[22]. Consequently, measuring PCO_2 in the umbilical cord blood is useful to identify foetal acidosis[23]. Rate of CO_2 production is proportional to foetal oxygen consumption[24] and the higher cord blood PCO_2 and decrease in pH indicate a state of foetal acidosis[2]. If this acidosis is reflected exclusively in the umbilical artery, it would be a consequence of the own labour, or other acute situations, and usually affects only peripheral tissues[25]. However, venous umbilical cord blood gas indicates the state of the placenta, so that increases of PCO_2 and decreases of pH could be related to a chronic decrease in blood flow, probably from the mother to the placenta[26]. Therefore, our results suggest that higher ST might be related with increased foetal acidosis during delivery, which may be indicative of a worse placental perfusion[3,6].

Otherwise, in this study, vigorous PA has been associated with a worse score in the Apgar test at one and five minutes of life. Apgar test has been shown to be effective on predicting neonatal morbidity and mortality in term babies with normal birth weight[27]. Low scores in the Apgar test have also been related to dysfunctions in cognitive ability[28]. This finding requires further studies and should be taken into account by health professionals in the counselling and monitoring of pregnant women.

Results regarding the positive associations found between total and bouted MVPA with neonatal outcomes suggest that the practice of total PA or MVPA may have beneficial influence on the newborn. Currently, more studies are needed to explore which specific maternal factors, including sedentary behaviours and PA, could influence placental blood flow. However, several studies suggest that regular exercise during pregnancy increases placental growth and its ability to perfuse oxygen and nutrients to the foetus[29]. These statements are consistent with our findings, in which oxygen saturation was better in women with greater low to moderate PA levels, perhaps because increasing PA has a similar effect on placental angiogenesis during early pregnancy. The increase in PA intensity (which indirectly represents the muscle mass involved in the contractile activity, such as increased aerobic exercise intensity) might lead to a generally transient reduction of uterine-placental blood flow, which could overcome the compensatory mechanisms of the placenta[30]. This could have influenced the lower score in the Apgar test observed in those newborns whose mothers performed more minutes of vigorous PA. Other studies have previously evaluated the association of PA with other neonatal parameters, such as birth weight[31]. However, more studies are needed to analyze the association of vigorous PA with the Apgar test score for a better understanding of these results.

Finally, findings observed in relation to ST and PA levels among different types of delivery (i.e. caesarean or vaginal) need to be highlighted. The fact that women who had a caesarean section had expended, overall, more ST and less time in total PA is of clinical and social relevance. Our results agree with those described by Nielsen et al.[32] who found a decrease in the rate of caesarean sections in women who had greater PA levels during the first and second trimesters of pregnancy. These results could be explained by an improvement in placental function in exercised pregnant women[6]. Indeed, the study carried out by Jackson et al.[33] found that PA during mid pregnancy increased the parenchymal component of the placenta as well as capillary and total vascular volumes. Moreover, our results suggest that neonates of more active women have a better acid-base balance, which might reduce the risk of caesarean section due to loss of foetal well-being.

It should be noted that 24.5% of births in the present study occurred by caesarean section, which is similar to the rate described in the pregnant population of the same geographical area[34]. However, the World Health Organization establishes that caesarean rates above 10% are not associated with a reduction in maternal or neonatal morbidity and mortality[35], so its abuse is not clinically justified. This is clinically relevant because caesarean incidence rates in Spain are extremely high, which implies greater health costs and risk for both, the mother and the newborn[36,37]. In a study carried out in Canada, a saving of $27 million, in just four years, was achieved by implementing a program aimed at reducing caesarean sections[38]. Taking also into account that only a quarter of the women who participated in the present study met PA recommendations, we may considerate that there is still a large room for behavioural changes in order to improve maternal and newborn labour-related markers.

Limitations and strengths

This study presents several limitations that must be underlined. Firstly, the cross-sectional design precludes determination of causality. Secondly, the results should be interpreted with caution due to the small size of the sample, and is advisable to recruit a greater number of pregnant women to render the obtained results statistically more relevance. Third, accelerometry does not register activities such as biking or swimming, but pregnant women did not report to practice these activities in their personal PA notebook. This study has also several strengths. Firstly, to the best of our knowledge, this is the first study providing a comprehensive examination of the association of objectively measured ST and PA during early second trimester of pregnancy with maternal and foetal relevant labour-related outcomes. Secondly, the measurement of gases in the artery umbilical cord bloodis a gold standard in the determination of the acid-base status in the foetus. Thirdly, paired samples have been taken (venous and arterial blood) that allow a better interpretation of the results. Fourthly, the analysis of different PA intensities (including vigorous PA levels) is a strength, since it has previously been pointed out that the analysis of vigorous PA together with moderate PA could mask the true effects of a higher PA intensity[39]. Finally, our measurement tool to objectively assess ST and PA intensity levels (i.e. triaxial accelerometry) is widely valid and reliable, if not the gold standard.

CONCLUSION

Overall, in this population of pregnant women at low-risk, we found that the greater levels of light, moderate, moderate-to-vigorous, and total PA as well as steps per day, during early second trimester of pregnancy, were associated with better labour-related maternal and neonatal markers. Contrary, ST and vigorous PA could have harmful influence on labour-related outcomes on both, the mother and the newborn.

PERSPECTIVES

The findings of the present study might be considered relevant for the clinical practice. Our results contribute to a better understanding of the associations between PA and labour related outcomes, both in the mother and the newborn. Consequently, increasing PA and decreasing ST could be also useful obstetric tools. More studies, performed in different populations of pregnant women and in greater sample sizes, are needed to confirm or contrast the present findings. Moreover, future research is warranted to explore whether intervention based on increasing PA or decreasing ST during pregnancy improve these labour-related outcomes.

ACKNOWLEDGEMENTS

For financial support, we thank the Regional Ministry of Health of the Junta de Andalucía, the Spanish Ministry of Education, Culture and Sport and the University of Granada, Unit of Excellence on Exercise and Health.

REFERENCES

1. Mayhew TM, Charnock-Jones DS, Kaufmann P. Aspects of human fetoplacental vasculogenesis and angiogenesis. III. Changes in complicated pregnancies. *Placenta*. 2004;25(2-3):127-139. doi:10.1016/j.placenta.2003.10.010.

2. Armstrong L, Stenson BJ. Use of umbilical cord blood gas analysis in the assessment of the newborn. *Arch Dis Child Fetal Neonatal Ed*. 2007;92(6). doi:10.1136/adc.2006.099846.

3. Omo-Aghoja L. Maternal and fetal acid-base chemistry: A major determinant of perinatal outcome. *Ann Med Health Sci Res*. 2014;4(1):8. doi:10.4103/2141-9248.126602.

4. Clapp JF. The effects of maternal exercise on fetal oxygenation and feto-placental growth. In: *European Journal of Obstetrics Gynecology and Reproductive Biology*. ; 2003. doi:10.1016/S0301-2115(03)00176-3.

5. Schuler G, Adams V, Goto Y. Role of exercise in the prevention of cardiovascular disease: Results, mechanisms, and new perspectives. *Eur Heart J*. 2013;34(24):1790-1799. doi:10.1093/eurheartj/eht111.

6. Reyes LM, Davenport MH. Exercise as a therapeutic intervention to optimize fetal weight. *Pharmacol Res*. 2018;132(April):160-167. doi:10.1016/j.phrs.2018.04.016.

7. Brubaker P, Otto R, Whaley M. American College of Sports Medicine: ACSM's guidelines for exercise testing and prescription. *Am Coll Sport Med*. 2006.

8. American College of Obstetricians and Gynecologists. ACOG Committee Opinion No. 650: Physical Activity and Exercise During Pregnancy and the Postpartum Period. *Obs Gynecol*. 2015;126(6):e135-e142. doi:10.1097/AOG.0000000000001214.

9. Aparicio VA, Ocón O, Padilla-Vinuesa C, Soriano-Maldonado A, Romero-Gallardo L, Borges-Cósic M, Coll-Risco I, Ruiz-Cabello P, Acosta-Manzano P, Estévez-López F, Álvarez-Gallardo IC, Delgado-Fernández M, Ruiz JR, Van Poppel MN, Ochoa-Herrera JJ. Effects of supervised aerobic and strength training in overweight and grade I obese pregnant women on maternal and foetal

health markers: the GESTAFIT randomized controlled trial. *BMC Pregnancy Childbirth*. 2016;16(1):290. doi:10.1186/s12884-016-1081-y.

10. Aguilar-Farías N, Brown WJ, Peeters GMEEG. ActiGraph GT3X+ cut-points for identifying sedentary behaviour in older adults in free-living environments. *J Sci Med Sport*. 2014;17(3):293-299. doi:10.1016/j.jsams.2013.07.002.

11. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. *J Sci Med Sport*. 2011;14(5):411-416. doi:10.1016/j.jsams.2011.04.003.

12. Hanley GE, Munro S, Greyson D, Gross MM, Hundley V, Spiby H, Janssen PA. Diagnosing onset of labor: A systematic review of definitions in the research literature. *BMC Pregnancy Childbirth*. 2016;16(1). doi:10.1186/s12884-016-0857-4.

13. Butterwegge M, Kappen R, Rath W. [Changes in umbilical cord blood acid-base status after delivery in dependence on time intervall--a continuing forensic problem]. *Z Geburtshilfe Neonatol*. 2012;216(6):253-258. doi:10.1055/s-0032-1323794.

14. Gunnarsson B, Skogvoll E, Jónsdóttir IH, Røislien J, Smárason AK. On predicting time to completion for the first stage of spontaneous labor at term in multiparous women. *BMC Pregnancy Childbirth*. 2017;17(1). doi:10.1186/s12884-017-1345-1.

15. Ängeby K, Wilde-Larsson B, Hildingsson I, Sandin-Bojö A-K. Prevalence of Prolonged Latent Phase and Labor Outcomes: Review of Birth Records in a Swedish Population. *J Midwifery Womens Health*. 2018;63(1):33-44.

doi:10.1111/jmwh.12704.

16. Mikolajczyk RT, Zhang J, Betran AP, Souza JP, Mori R, Gülmezoglu AM, Merialdi M. A global reference for fetal-weight and birthweight percentiles. *Lancet*. 2011;377(9780):1855-1861. doi:10.1016/S0140-6736(11)60364-4.

17. Bisson M, Croteau J, Guinhouya BC, Bujold E, Audibert F, Fraser WD, Marc I. Physical activity during pregnancy and infant's birth weight: results from the 3D Birth Cohort. *BMJ Open Sport Exerc Med*. 2017;3(1):e000242. doi:10.1136/bmjsem-2017-000242.

18. Walsh J. Hehir M. Robson M. Mahony R. Mode of delivery and outcomes by birth weight among spontaneous and induced singleton cephallic nulliparous labors. *Int J Gynecol Obs*. 2014;dx.doi.org:22-25.

19. Barakat R, Franco E, Perales M, López C, Mottola MF. Exercise during pregnancy is associated with a shorter duration of labor. A randomized clinical trial. *Eur J Obstet Gynecol Reprod Biol*. 2018. doi:10.1016/j.ejogrb.2018.03.009.

20. Ruchat SM, Davenport MH, Giroux I, Hillier M, Batada A, Sopper MM, Hammond JA, Mottola M. Walking program of low or vigorous intensity during pregnancy confers an aerobic benefit. *Int J Sports Med*. 2012. doi:10.1055/s-0032-1304635.

21. Ruifrok AE, Althuizen E, Oostdam N, Van Mechelen W, Mol BW, De Groot CJM, Van Poppel MNM. The relationship of objectively measured physical activity and sedentary behaviour with gestational weight gain and birth weight. *J Pregnancy*. 2014;2014. doi:10.1155/2014/567379.

22. Thorp JA, Rushing RS. UMBILICAL CORD BLOOD GAS ANALYSIS. *Obstet*

Gynecol Clin North Am. 1999;26(4):695-709. doi:http://dx.doi.org/10.1016/S0889-8545(05)70107-8.

23. Neonatal Professional Committee of Chinese Medical Doctor Association. [Experts' consensus on the criteria for the diagnosis and grading of neonatal asphyxia in China]. *Zhongguo Dang Dai Er Ke Za Zhi*. 2013;15(1):1. doi:10.7499/j.issn.1008-8830.2013.01.002.

24. Blechner JN. Maternal-fetal acid-base physiology. *Clin Obstet Gynecol*. 1993;36(1):3-12. doi:10.1097/00003081-199303000-00004.

25. Hagelin A, Leyon J. The effect of labor on the acid-base status of the newborn. *Acta Obstet Gynecol Scand*. 1998;77(8):841-844. doi:10.1080/j.1600-0412.1998.770810.x.

26. Johnson JWC, Richards DS, Cook WA, Hopwood HG, Devoe LD. The etiology of fetal acidosis as determined by umbilical cord acid- base studies. In: *American Journal of Obstetrics and Gynecology*. Vol 177. ; 1997:274-282. doi:10.1016/S0002-9378(97)70187-X.

27. Finster M, Wood M. The Apgar score has survived the test of time. *Anesthesiology*. 2005;102(4):855-857. doi:10.1097/00000542-200504000-00022.

28. Ehrenstein V, Pedersen L, Grijota M, Nielsen GL, Rothman KJ, Sørensen H. Association of Apgar score at five minutes with long-term neurologic disability and cognitive function in a prevalence study of Danish conscripts. *BMC Pregnancy Childbirth*. 2009;9. doi:10.1186/1471-2393-9-14.

29. Krause Neto W, Gama EF. Exercise Effect on Placental Components: Systematic Review and Meta-Analysis. *Rev Bras Med do Esporte*. 2015;21(6):485-489.

doi:10.1590/1517-869220152106142913.

30. Erkkola RU, Pirhonen JP, Kivijärvi AK. Flow velocity waveforms in uterine and umbilical arteries during submaximal bicycle exercise in normal pregnancy. *Obstet Gynecol*. 1992;79(4):611-615.

31. Takito MY, D'Aquino Benício MH, de Cassya Lopes Neri L. Physical activity by pregnant women and outcomes for newborns: A systematic review. *Rev Saude Publica*. 2009;43(6):1-10. doi:10.1590/S0034-89102009005000074.

32. Nielsen EN, Andersen PK, Hegaard HK, Juhl M. Mode of Delivery according to Leisure Time Physical Activity before and during Pregnancy: A Multicenter Cohort Study of Low-Risk Women. *J Pregnancy*. 2017;2017. doi:10.1155/2017/6209605.

33. Jackson MR, Gott P, Lye SJ, Ritchie JW, Clapp JF. The effects of maternal aerobic exercise on human placental development: placental volumetric composition and surface areas. *Placenta*. 1995;16(2):179-191. doi:10.1016/0143-4004(95)90007-1.

34. Márquez-Calderón S, Ruiz-Ramos M, Juárez S, López JL. Caesarean delivery in Andalusia, Spain. Relationship with social, clinical and health services factors (2007-2009). *Rev Esp Salud Publica*. 2011;85(2):205-215. doi:10.1590/S1135-57272011000200008.

35. Organización Mundial de la Salud. *Declaración de La OMS Sobre Tasa de Cesárea*.; 2015. doi:10.1016/j.rhm.2015.07.007.

36. Kodakkattil S, Annaiah TK. Re: Perinatal and maternal morbidity and mortality among term singletons following midcavity operative vaginal delivery versus

caesarean delivery. *BJOG: An International Journal of Obstetrics and Gynaecology*. 2017.

37. Hobbs AJ, Mannion CA, McDonald SW, Brockway M, Tough SC. The impact of caesarean section on breastfeeding initiation, duration and difficulties in the first four months postpartum. *BMC Pregnancy Childbirth*. 2016;16(1). doi:10.1186/s12884-016-0876-1.

38. Bermúdez-Tamayo C, Johri M, Chaillet N. Budget impact of a program for safely reducing caesarean sections in Canada. *Midwifery*. 2018;60:20-26. doi:10.1016/j.midw.2018.01.022.

39. Bisson M, Tremblay F, St-Onge O, Robitaille J, Pronovost E, Simonyan D, Marc I. Influence of maternal physical activity on infant's body composition. *Pediatr Obes*. 2017;12:38-46. doi:10.1111/ijpo.12174.

Table 1. Sociodemographic and clinical characteristic of the study sample (n=94).

Maternal outcomes	**Mean (SD)**
Age, years	32.9 (4.6)
Body mass index at 16th gestational week, Kg/m^2	24.9 (4.1)
Living with a partner, n (%)	92 (97.9)
Educational status, n (%)	
Primary or high-school	26 (27.7)
Professional training	17 (18)
University studies	51 (54.3)
Working status, n (%)	
Homework/unemployed	26 (27.6)
Partial-time employed/student	24 (25.6)
Full-time employed	44 (46.8)
Type of delivery, n (%)	
Spontaneous	57 (60.6)
Instrumental vacuum/forceps	14 (14.9)
Caesarean	23 (24.5)
Parity, n (%)	
Primiparous	58 (61.7)
Multiparous	36 (38.3)
Sedentary time and PA, min/week	
Sedentary time	3598 (682.4)
Light PA	2733 (631.2)
Moderate PA	255 (148.4)
Vigorous PA	8 (21.5)
*Moderate-to-vigorous PA**	95 (115.2)
Total PA	2997 (653.2)
Steps per day, mean (SD)	7745 (2559.6)
Meeting PA guidelines, n (%)	25 (26.6)
Smoker during pregnancy, n (%)	8 (8.5)
Neonatal outcomes	
Sex (female, n (%))	47 (50)
Gestational age at birth, wk	39.7 (1.2)
Birth weight, grams	3310 (468.3)
Apgar Test 1 minute	8.7 (0.9)
Apgar Test 5 minutes	9.6 (0.7)
Umbilical Cord blood Gas	
Arterial pH	7.2 (0.7)
Arterial Partial Pressure CO_2, mmHg	50.4 (9.9)

Arterial Partial Pressure O_2, mmHg	19.7 (8.8)
Arterial O_2 saturation, %	36.7 (22.4)
Venous pH	7.3 (0.6)
Venous Partial Pressure CO_2, mmHg	39.2 (7.3)
Venous Partial Pressure O_2, mmHg	25.7 (7.2)
Venous O_2 saturation, %	56.1 (17)

Values shown as mean (SD, standard deviation) unless otherwise indicated; BMI, body mass index; CO_2, carbon dioxide; O_2, oxygen *accounted in bouts of at least 10 minutes; min, minute; wk, week; PA, physical activity.

Table 2. Partial correlations of sedentary time and physical activity levels with labour-related maternal and neonatal markers (n=94).

	Sedentary time	Light PA	Moderate PA	Vigorous VA	MVPA	Total PA	Steps per day
Labour-related outcomes							
Week of gestation (at birth) (n=88)	.120	-.140	-.125	.127	-.105	-.156	-.286**
Duration of first stage of labour (n=57)	.030	-.150	-.184	.043	-.179	-.188	-.274*
Duration of second stage of labour (n=60)	-.152	.106	.037	-.014	.040	.111	.133
Neonate-related outcomes							
Birth weight (n=87)	.018	-.052	-.144	-.088	-.156	-.084	-.208*
Apgar Test 1 minute (n=87)	.024	-.004	.032	-.365**	-.025	0.01	.029
Apgar Test 5 minutes (n=87)	-.040	.031	-.018	-.342**	-.070	.015	-.013
Cord blood arterial pH (n=67)	-.262*	.207	.016	.037	.024	.205	.058
Cord blood arterial partial pressure of CO_2 (n=65)	.335**	-.198	-.071	-.015	-.076	-.207	-.069
Cord blood arterial partial pressure of O_2 (n=61)	-.164	.191	.179	-.027	.177	.222	.228
Cord blood arterial oxygen saturation (n=59)	-.217	.209	.251*	.093	.266*	.263*	.318*
Cord blood venous pH (n=80)	-.267*	.251*	.099	-.012	.101	.264*	.166
Cord blood venous partial pressure of CO_2 (n=79)	.299**	-.185	-.088	.102	-.078	-.195	-.071
Cord blood venous partial pressure of O_2 (n=69)	-.044	.032	.079	-.219	.056	.044	.023

Model adjusted for age, parity, maternal body mass index, accelerometer wearing time and the exercise intervention; PA, physical activity; Carbon dioxide; O_2, Oxygen.
$^{*}P<0.05$; $^{**}P<0.01$;

Table 3. Differences in sedentary time and physical activity levels (min/week) of the pregnant women by delivery mode (vaginal or caesarean section).

	Vaginal (n=71)	**Caesarean (n=23)**	**P**	**P***	**Effect size *d*-Cohen**
Sedentary time (min/day)	503.3 (11.5)	542.2 (20.1)	0.091	0.112	0.39 (-0.01, 0.79)
Light physical activity (min/wk)	2800.0 (72.6)	2617.1 (127.0)	0.088	0.223	0.29 (-0.10, 0.69)
Moderate physical activity (min/wk)	255.4 (16.4)	237.8 (28.8)	0.695	0.605	0.12 (-0.27, 0.52)
Vigorous physical activity (min/wk)	9.13 (2.5)	3.47 (4.3)	0.046	0.269	0.26 (-0.13, 0.66)
Moderate-to-vigorous physical activity ¥ (min/wk)	99.5 (12.0)	74.6 (21.0)	0.489	0.315	0.24 (-0.15, 0.64)
Total physical activity (min/wk)	3064 (75.8)	2858 (132.8)	0.073	0.189	0.31 (-0.08, 0.71)
Steps per day (number)	7865 (285.7)	7105 (500.2)	0.180	0.199	0.31 (-0.09, 0.71)

*Model adjusted for maternal age, parity, maternal body mass index, accelerometer wearing time and the exercise intervention; Values shown as mean (standard error); ¥, in bouts of at least 10 minutes.

SUPPLEMENTARY MATERIAL

Table S1. Inclusion and exclusion criteria in the GESTAFIT project.

Inclusion criteria
- Pregnant women aged 25-40 years old with a normal pregnancy course.
- Answering "no" to all questions on the PARmed-X for pregnancy.
- Being able to walk without assistance.
- Being able to read and write properly.
- Informed consent: Being capable and willing to provide written consent.
*In addition, specific inclusion criteria for data analysis are: gestational age at delivery of 37-42 weeks with single foetus, spontaneous or instrumental vaginal delivery, and caesarean without maternofoetal pathology (or any other indication that does not involve maternofoetal risk, such as disproportion, failed induction, no foetal progression or non-cephalic presentation), newborn with appropriate weight, Apgar score>7 in the 1st and 5th minute of life, cord blood pH (normal>7.20), and normal monitoring results.
Exclusion criteria
- Acute or terminal illness.
- Malnutrition.
- Inability to conduct tests for assessing physical fitness or exercise during pregnancy.

- Underweight.
- Pregnancy risk factors (such as hypertension, type 2 diabetes, etc.).
- Multiple pregnancy.
- Chromosopathy or foetal malformations.
- Uterine growth restriction.
- Foetal death.
- Upper or lower extremity fracture in the past 3 months.
- Presence of neuromuscular disease or drugs affecting neuromuscular function.
- Being registered in another exercise program.
- Doing more than 300 minutes of at least moderate physical activity per week.
- Unwillingness either to complete the study requirements or to be randomised into the control or intervention group.

Figure S1. Flowchart of the participants for the specific study aims.