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► To cite this version:

Jonathan Bernard, Sharon Ng, Padmapriya Natarajan, See Ling Loy, Izzuddin Aris, et al.. Associations of physical activity levels and screen time with oral glucose tolerance test profiles in Singaporean women of reproductive age actively trying to conceive: the S-PRESTO study. *Diabetic Medicine*, Wiley, 2019, 36 (7), pp.888-897. 10.1111/dme.13948 . hal-02367153

HAL Id: hal-02367153

<https://hal.archives-ouvertes.fr/hal-02367153>

Submitted on 17 Nov 2019

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*Associations of physical activity levels and screen time with oral glucose tolerance test profiles
in Singaporean women of reproductive age actively trying to conceive: the S-PRESTO study*

Short running title: Preconception physical activity, screen time and glucose levels in Singaporean women

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Manuscript word count: 3,217 words

Abstract word count: 250 words

Conflicts of interest disclosures

YSC, LS, KMG and SYC have received reimbursement for speaking at conferences sponsored by companies selling nutritional products, and/or been part of an academic consortium that has received research funding from Abbott Nutrition, Nestec and Danone. JYB, SN, PN, SLL, IMA, MTT, JC, CMK, MKSL, FMR have no competing interests to disclose.

What is already known? Physical inactivity and television time have been associated with insulin resistance and type 2 diabetes in adults and with gestational diabetes mellitus in pregnant women.

What this study has found? In a Singapore preconception cohort study of a thousand women trying to conceive, this study found that women engaging in ≥ 75 min/week of vigorous physical activity had lower fasting and post-load glucose levels than inactive women. Device-specific screen time was not associated with glucose levels

What are the clinical implications of the study? Engaging in vigorous physical activity may, independently of moderate physical activity and screen time, be a modifiable factor to improve glucose regulation in women of Asian ethnicities attempting to conceive.

Acknowledgments

We thank the S-PRESTO study group, which includes Anne Eng Neo Goh, Anne Rifkin-Graboi, Anqi Qiu, Bee Wah Lee, Bernard Chern, Bobby Cheon, Christiani Jeyakumar Henry, Ciaran Gerard Forde, Claudia Chi, Doris Fok, Elaine Quah Phaik Ling, Elizabeth Tham, Evelyn Chung Ning Law, Evelyn Xiu Ling Loo, Fabian Yap, Faidon Magkos, Falk Mueller-Riemenschneider, George Seow Heong Yeo, Helen Chen, Heng Hao Tan, Hugo P S van Bever, Izzuddin Bin Mohd Aris, Jerry Kok Yen Chan, Joanne Yoong, Jonathan Tze Liang Choo, Jonathan Y. Bernard, Keith M. Godfrey, Kenneth Kwek, Kok Hian Tan, Kuan Jin Lee, Leher Singh, Lieng Hsi Ling, Ling-Wei Chen, Lourdes Mary Daniel, Lynette P Shek, Marielle V. Fortier, Mary Foong-Fong Chong, Mei Chien Chua, Melvin Khee-Shing Leow, Michael Meaney, Mya Thway Tint, Neerja Karnani, Ngee Lek, Oon Hoe Teoh, Peter D. Gluckman, Queenie Ling Jun Li, See Ling Loy, S. Sendhil Velan, Seng Bin Ang, Sharon Ng, Shiao-Yng Chan, Shirong Cai, Shu-E Soh, Sok Bee Lim, Stella Tsotsi, Chin-Ying Stephen Hsu, Sue Anne Toh, Teng Hong Tan, Tong Wei Yew, Victor Samuel Rajadurai, Wee Meng Han, Wei Wei Pang, Yap-Seng Chong, Yin Bun Cheung, Yiong Huak Chan and Yung Seng Lee.

This research is supported by the Singapore National Research Foundation under its Translational and Clinical Research (TCR) Flagship Programme and administered by the Singapore Ministry of Health's National Medical Research Council (NMRC), Singapore- NMRC/TCR/004-NUS/2008; NMRC/TCR/012-NUHS/2014. Additional funding is provided by the Singapore Institute for Clinical Sciences, Agency for Science Technology and Research (A*STAR), Singapore. KMG is supported by the UK Medical Research Council (MC_UU_12011/4), the National Institute for Health Research (NIHR Senior Investigator (NF-SI-0515-10042) and NIHR Southampton Biomedical Research Centre) and the European Union (Erasmus+ Capacity-Building ENeA^{SEA} Project). Funders played no role in study design, data collection, data analysis, manuscript preparation and publication decisions.

Abstract

Aims: Whether low physical activity levels and high sedentary behaviour impair glucose metabolism before conception remains insufficiently documented, especially in at-risk populations such as Asian women. We examined the associations of physical activity and screen time, a proxy for sedentary behaviour, with fasting and post-load glucose levels of Singaporean women enrolled in a multi-ethnic Asian preconception study.

Methods: Moderate and vigorous physical activity and screen time (television and other electronic devices) were self-reported by women enrolled in the S-PRESTO cohort. Fasting, 30-min and 120-min glucose levels before/during an oral 75-g glucose tolerance test were measured. Associations of physical activity and screen time with glucose levels were analysed using generalized estimating equations.

Results: 946 women aged 31.4 ± 3.7 years were examined; 72% of Chinese, 15.5% Malay, 9.3% Indian and 3.2% of mixed ethnicities. 32% of women reported being active, 36% watching television ≥ 2 h/day and 26% using electronic devices ≥ 3 h/day. In adjusted models, vigorous, but not moderate physical activity, was associated with lower overall glucose levels, and more strongly with post-challenge than fasting glucose levels. Compared to women not engaging in vigorous physical activity, those engaging in ≥ 75 min/week had lower fasting (-0.14 [-0.28, -0.01] mmol/L), 30-min (0.35 [-0.68, -0.02]) and 120-min (-0.53 [-0.16, -0.90]) glucose levels (overall p-value=0.05). We found no associations of screen time with glucose levels.

Conclusions: Independently of the time spent in non-vigorous physical activity and using screens, engaging in vigorous physical activity may be a modifiable factor to improve glucose regulation in women of Asian ethnicities attempting to conceive.

Keywords: physical activity, sedentary behaviour, screen time, television, electronic device, glucose metabolism, diabetes mellitus, preconception, pregnancy, cohort studies, S-PRESTO.

Introduction

The prevalence of diabetes mellitus has dramatically increased in recent decades, affecting more than 400 million adults worldwide and causing several million deaths per year [1]. Representing 60% of the world population, Asians are disproportionately affected by the diabetes mellitus epidemic and its associated morbidity and mortality [2]. Of concern is the rise in diabetes mellitus prevalence in women of reproductive age. Around conception and during pregnancy, even mildly impaired glucose metabolism manifests as gestational diabetes mellitus and poorly controlled diabetes mellitus. It may cause adverse pregnancy and neonatal outcomes, including altered placental function, gestational hypertension, macrosomia and congenital malformations [3]. More worrying is the increasing evidence that in utero exposure to hyperglycaemia is associated with the offspring's risk of later developing diabetes mellitus, cardiovascular disease and obesity [4]. There is a risk continuum across the maternal glycaemic spectrum and even a modest reduction in glycaemia during pregnancy may lead to significant risk reduction [5]. In the Asia-Pacific region, an estimated 76 million reproductive-age women have diabetes mellitus or pre-diabetes mellitus [3]. Unhealthy lifestyle factors such as high levels of physical inactivity and sedentary behaviour can, independent from each other, play etiological roles in impaired glucose metabolism and insulin resistance that can lead to diabetes mellitus [6, 7].

Physical inactivity is postulated to impair glucose disposal and insulin signalling, consequently impairing plasma glucose levels, whereas greater physical activity time is associated with lower glucose levels in women [8]. World Health Organization recommends healthy adults to be physically active by engaging weekly in ≥ 150 minutes of moderate physical activity, or ≥ 75 minutes of vigorous physical activity, or an equivalent combination of moderate-to-vigorous physical activity achieving ≥ 600 metabolic equivalent task (MET)-minutes [9]. It remains, however, unclear whether moderate (i.e. walking) and vigorous (i.e. running) intensities have identical beneficial effects on glucose metabolism, as they are generally not analysed separately. Differing from physical inactivity, sedentary behaviour is defined as any waking activity spent in a sitting or reclining position with an energy expenditure ≤ 1.5 MET, such as reading, socializing, sitting in a car or public transport, watching television and using a computer or any screen device [10]. Television, but not computer use and reading time, has been associated with insulin resistance and other cardiometabolic risk markers [11], including in a multi-ethnic Asian sample of Singaporean adults [12]. Mobile screens such as smartphones and tablets have now become massively widespread and used in high-income Asian countries, particularly in Singapore [13, 14]. Empirical evidence shows that Singaporeans use mobile screens while being engaged in other non-screen sedentary activities such as eating, socializing and sitting in public transport. In Singaporean adults, screen time has become the most common daily activity and the first contributor to sedentary behaviour, with an estimated average of 12.7 hours, including 3.2 hours using a mobile phone [14].

To date, the majority of studies examining the associations of physical activity and sedentary behaviour with glucose metabolism were conducted among pregnant women or women from the general population [6, 15-

17], but there are hardly any completed studies focusing on women planning a pregnancy. A recent review also highlighted the lack of information about optimal duration, frequency and types of physical activity for promotion of health and well-being in preparation for pregnancy and in pregnancy [18]. Preconception advice promoting healthy lifestyles have largely focussed on lifestyle changes such as quitting smoking, stopping alcohol, consumption of folic acid, healthier diets, weight loss if overweight and general, non-specific advice on increasing physical activity. Few have investigated the impact of different levels of physical activity and sedentary behaviour.

In the present study, we examined the associations of physical activity and sedentary behaviour with glucose metabolism in a multi-ethnic Asian sample of women of reproductive age planning for a pregnancy recruited from the general population. We hypothesized that lower moderate and vigorous physical activity, and longer time spent watching television and using electronic devices would be associated with increased plasma glucose levels at fasting, 30-min and 120-min in an oral glucose tolerance test (OGTT).

Participants and Methods

Study design and participants

The Singapore PREconception Study of long-Term maternal and child Outcomes (S-PRESTO) is a preconception cohort study designed to examine the influences of events prior to and during pregnancy on later mother's and offspring's metabolic health outcomes [19]. In this study, women from the general population of Singapore who were planning a pregnancy were enrolled between February 2015 and October 2017. The inclusion criteria were (1) aged 18-45 years, (2) of Chinese, Malay, Indian or any combination of these three ethnic groups, (3) planning to conceive within one year from recruitment, and (4) intending to reside in Singapore within the next five years. The main exclusion criteria were (1) being pregnant at the first screening visit, (2) having been actively trying to conceive for more than 18 months, (3) having been diagnosed with Type 1 or Type 2 diabetes mellitus, (4) having received assisted fertility treatment or taken contraceptive treatment in the past month, and (5) received systemic steroids, anticonvulsants, HIV, Hepatitis B or C medications in the past one month.

Written informed consent was obtained from each participant. The eligible women were scheduled for their first interview session with measurements in the clinic at the KK Women's and Children's Hospital, Singapore. This research study was conducted in accordance with the guidelines depicted in the Declaration of Helsinki. Ethical approval was obtained from the SingHealth Centralised Institutional Review Board (reference 2014/692/D). This study was registered on www.clinicaltrials.gov under the identifier NCT03531658.

Physical activity levels and screen time

Physical activity was assessed by an interview with the short form of the International Physical Activity Questionnaire (IPAQ) [20]. Additional examples of activities (i.e., dancing and swimming) were suggested to

fit better with the most common activities in the local context. Briefly, women were asked about the time they spent walking and in moderate and vigorous intensity physical activities during the last 7 days. For each activity, they reported the weekly frequency and the duration of any activity session. The women's overall physical activity level was derived following the IPAQ data processing guideline, which enabled classifying women in three groups (inactive, minimally active and active). We then merged the two least active groups to obtain two groups (insufficiently active vs active) for analysis. Additionally, we derived their weekly times spent in moderate (not including walking) and vigorous physical activity, which we categorized as follows: never, <150 and ≥ 150 min/week for moderate, and never, <75 and ≥ 75 min/week for vigorous physical activity.

Sedentary behaviour was assessed during the same interview using a questionnaire asking about times spent i) sitting at work (where applicable), ii) sitting/lying down while watching television in one's leisure time, iii) sitting/lying down viewing electronic devices other than television and computer use at work, and iv) sitting/lying down while having meals, driving, reading or others than previously listed. We focused on the leisure time items, i.e. television watching and electronic devices use, which have commonly been used as proxies of sedentary behaviour time [6, 21, 22]. We categorised those variables as follows based on their frequency distribution: never, <2 and ≥ 2 h/day for television watching, and <1, 1-3 and ≥ 3 h/day for electronic devices use.

Oral glucose tolerance test and assessment of plasma glucose levels

Women underwent a 75-g OGTT after an overnight fast at the recruitment visit during which venous fasting blood, 30-minute and 120-minute post-glucose load blood were collected. Plasma glucose levels were measured by colorimetry (Architect c8000 analyser, Abbott, North Chicago, Illinois, USA).

Covariates

At enrolment, sociodemographic characteristics were obtained by interview. These included: ethnicity (Chinese, Malay, Indian, or mixed), date of birth, education (primary/secondary, post-secondary, or university), occupational status (unemployed, daytime work, or night shift work), parity (nulliparous or parous), family history of diabetes mellitus (yes, no/do not know), personal history of gestational diabetes mellitus (yes, no) and smoking status (never, past smoker, current).

Statistical analysis

Women's main sociodemographic characteristics were compared according to physical activity levels and screen time. Associations between physical activity (overall level, and times spent in moderate and vigorous physical activity) and screen time (television watching and electronic devices use) were examined to identify potential interrelationship between those variables. Glucose levels at fasting, and 30-min and 120-min post-OGTT were described and pairwise correlations were examined.

Associations of physical activity and screen time (the exposures of interest) with continuous glucose levels were examined using a marginal model fitted using generalized estimating equations with an unstructured working correlation matrix; i.e. glucose levels at fasting, 30 minutes and 120 minutes were treated as repeated measurements. This statistical method allowed us to retain in the analysis the participants with one or two missing measurements out of the three repeated outcomes. Time point was treated as a categorical covariate. Each model included an *exposure* term, a *time-point* term and an *exposure*time-point* interaction term. Unstructured variance-covariance matrix was selected. Potential confounding factors were accounted for in two stages. Model 1 was adjusted for ethnicity, age, body mass index, education, occupational status, parity, family history of diabetes mellitus, personal history of gestational diabetes mellitus and smoking status, as specified earlier. Model 2 was further adjusted for physical activity and screen time variables (mutual adjustment). Adjusted means (95% CI) at each time point were reported together with the level of statistical significance for both the *exposure* and the *exposure*time-point* terms: the former reflects the overall association at any time point, while the latter reflects whether mean differences were observed between time points. Statistical interactions between physical activity and screen time variables were also explored.

Results

Description of the study population

Of the 1046 women recruited, 946 with at least one glucose level measure and a complete dataset of exposures and covariates were included in this analysis. Seventy-two percent of women were of Chinese, 15.5% Malay, 9.3% Indian and 3.2% of mixed ethnicities. Women's mean (SD) age and BMI were 31.4 (3.7) years and 23.8 (5.3) kg.m², respectively, and 14% were unemployed. About two thirds (67.7%) reported being insufficiently active, 35.2% watching television for at least 2 h per day, and 23.8% using electronic devices for at least 3 h per day. Compared to insufficiently active women, physically active women were younger (30.9 vs 31.6 years old), less likely of Chinese ethnicity (66.0% vs 74.7%) and being a non-smoker (85.3% vs 91.6%), and more likely working night shifts (18.6% vs 5.6%) (**Table 1**).

Associations of covariates with physical activity and screen time

Sociodemographic characteristics associated with both higher television watching and higher electronic devices use were a lower education level, being unemployed and being nulliparous. Women who never watched television were younger. Use of electronic devices was associated with higher BMI and smoking. In general, screen time variables were not linked to moderate, vigorous and overall physical activity levels, except for a longer use of electronic devices in insufficiently active women (**Table 2**). Use of electronic devices and television watching were related to each other in a complex way: moderate (1-3 h/day) and frequent (≥ 3 h/day) electronic device users were more likely to either never watch television or to watch it ≥ 2 h/day ($p < 0.0001$).

Associations of physical activity with glucose levels

In our cohort, the mean (SD) fasting, 30-min and 120-min glucose levels were 4.8 (0.8), 8.3 (1.8) and 6.0 (2.1) mmol/L, respectively (**Supplemental Table 1**). Pairwise correlations between glucose levels were 0.69 for fasting vs 30-min, 0.76 for fasting vs 120-min, and 0.70 for 30-min vs 120-min (data not shown).

Table 3 shows the associations of physical activity with glucose levels adjusted for covariates (model 1) and additionally adjusted for screen time (model 2). Overall, sufficiently active women tended to have lower glucose levels throughout the time points (overall p -value=0.07 in both models), with more robust associations at 30-min (β [95% CI]: -0.30 [-0.55, -0.06] mmol/L) compared to fasting and 120-min glucose levels (interaction p -value=0.05). Compared to women not engaging in vigorous physical activity, those engaging in ≥ 75 min/week had lower glucose levels throughout the time points (model 1 overall p -value=0.01), including at fasting (-0.14 [-0.27, 0.00] mmol/L), 30-min (-0.37 [-0.71, -0.04] mmol/L) and 120-min (-0.53 [-0.90, -0.16] mmol/L), with evidence of more robust association at 120-min (interaction p -value=0.09). This remained after adjusting for screen time. Moderate physical activity was not associated with glucose levels in any models.

Associations of screen time with glucose levels

As shown in **Table 4**, there was no evidence of associations between television watching or electronic devices use and glucose levels (all overall p -values >0.34): in models adjusted for both moderate and vigorous physical activity, the strongest differences in mean glucose levels that we observed between women watching television and those never watching television were 0.09, -0.15 and 0.24 mmol/L at fasting, 30-min and 120-min, respectively. Models comparing women according to their electronic devices using time yielded, overall, even weaker differences in glucose levels. Lastly, we found no evidence of statistical interactions between physical activity and screen time variables (data not shown).

Discussion

We found that active women had, overall, lower fasting and post-challenge glucose levels, regardless of screen time, among 946 relatively inactive women from Singapore and attempting to conceive. Engaging in vigorous, but not in moderate physical activity, was associated with lower glucose levels at fasting, 30-min and 120-min. Conversely, times spent watching television and using mobile electronic devices were not associated with glucose levels. It suggests that, in the absence of any vigorous physical activity, attempting to reduce screen time alone would not be protective against hyperglycaemia.

Our results showed that engaging in vigorous physical activity was associated with lower glucose levels, with more robust associations with regards to the postprandial response compared to fasting. Although the effect sizes and absolute reductions in glucose levels appear modest (0.14 mmol/L at fasting and 0.53 mmol/L at 120-min), if a similar reduction occurred during pregnancy, it could have an appreciable impact on pregnancy and the developing offspring. A reduction of maternal fasting glucose by 0.10 mmol/L and 120-min post-

challenge by 0.30 mmol/L could have the effect of reducing the odds of foetal macrosomia by 10% and the odds of an elevated cord C-peptide >90th centile by 20% [5]. Several studies in various populations have examined the health effects of intensity-specific physical activity and outlined greater beneficial effects when intensity increases [23, 24]. Our findings show that engaging in vigorous physical activity may also provide benefits on glucose metabolism in reproductive age Asian women. Despite existing evidence in favour of lower intensity physical activity in improving glucose handling, we found no association of moderate physical activity independent from vigorous physical activity in our study. Our sample may be insufficiently large and our moderate physical activity assessment might carry larger measurement error compared to vigorous physical activity; both features may have led to insufficient power to detect associations with moderate physical activity. Considering that 86% of our sample were workers and 68% were inactive, a recommendation to engage in ≥ 75 -min vigorous physical activity could represent an effective and time-efficient intervention strategy to act on glucose metabolism in women planning a pregnancy [25].

Contrary to our hypothesis, we found no associations between screen time and glucose levels. Many studies in adolescent and adult women have reported that greater television time and total sitting time are related to impaired glucose metabolism independent of physical activity level [11, 12, 26-29]. Television time may be a weak surrogate of sedentary behaviour in the Singaporean context, where portable devices have revolutionized screen behaviours [14]. Evidence on the potential effects of other types of screen such as computer and mobile devices is scarcer and not as conclusive, however [11, 12, 26, 27]. Time spent using mobile electronic devices may have different effects on health than television time. Compared to television viewing, using mobile electronic devices is more interspersed by nature and may be related to shorter sedentary behaviour bouts. It may impact less on temporal replacement of physical activity by sedentary behaviour. As mobile devices are finger-operated screens that can be used anywhere, their use might also give less opportunities for snacking, a behaviour associated with both television watching and glucose metabolism. The recent rise of mobile electronic devices' use warrants further studies to disentangle the health effects of device-specific screen time and sedentary behaviour.

To our knowledge, this study is the first to examine in an Asian urban context the association between physical activity and device-specific screen time with glucose metabolism in reproductive age women planning to conceive. Chinese and Indian ethnic groups are the most populous worldwide but remain understudied despite their previously reported increased risk of impaired glucose metabolism and diabetes mellitus [3]. China, India, Malaysia and Indonesia, where populations are predominantly comprised of these three ethnicities, have been experiencing fast urbanisation and broader access to technological equipment, which goes along with decreased moderate-to-vigorous physical activity, increased screen time and higher prevalence of impaired glucose metabolism [30]. Secondly, we were able to estimate electronic devices use separately from television time, which is novel in relation to glucose metabolism of adults. Smartphones and tablets are now widespread and, contrary to television, are designed to be used 'anywhere, anytime', hence expanding screen-based sedentary behaviour opportunities. Context-specific studies are needed to determine

whether mobile electronic device time adds up to television time or tends to replace it. Finally, the availability of a 30-min glucose measure enabled analysing the kinetics of glucose response to an OGTT using repeated-measure models, which is uncommon in large observational studies examining physical activity and screen time.

Study limitations include that our physical activity and screen time data were self-reported. They may therefore be affected by recall bias, lack refinement and remain subjective in nature. Subjective measurement methods are widely recognised as less reliable and valid than objective ones, such as accelerometry. Also, electronic device use may be a poorer proxy of sedentary behaviour than television time. Indeed, mobile electronic devices can be used in non-sedentary situations like standing, walking or training at the gym, and this may blur the line with screen-based sedentary behaviour. The intrusion of mobile electronic devices into our lives may provide new research opportunities to better disentangle the cardiometabolic health effects of screen time and sedentary behaviour. Second, we have not accounted for the women's consumption of high glycaemic index foods or sugar-sweetened beverages and snacks, known to be a key confounding factor. Other potential confounders were not controlled for, including assessment of household income, working time and sleeping habits. Third, our study remains a cross-sectional analysis of a modest epidemiological sample, from which causal conclusions cannot be drawn readily. Longitudinal follow up of the participants during and after pregnancy will, however, allow us to account for more potential confounders and study changes in glucose metabolism alongside changes in physical activity and sedentary behaviour.

In conclusion, we found that higher activity, especially vigorous physical activity, but not moderate physical activity or sedentary behaviour as assessed by screen time, was associated with lower glucose levels in women of Chinese, Malay or Indian ethnicities who were trying to conceive. The magnitude of reduction in blood glucose levels, if replicated during pregnancy, could have a beneficial clinical impact on the pregnancy and the foetus. Engaging weekly in vigorous physical activity of ≥ 75 minutes represents an achievable and suitable modifiable factor to act on to improve glucose metabolism in woman planning a pregnancy, with potential implications for the health of the next generation.

References

1. World Health Organization. Global report on diabetes. World Health Organization 2016.
2. Rhee EJ. Diabetes in Asians. *Endocrinology and metabolism* 2015; **30**:263-269.
3. Tutino GE, Tam WH, Yang X, Chan JC, Lao TT, Ma RC. Diabetes and pregnancy: perspectives from Asia. *Diabet Med* 2014; **31**:302-318.
4. Dabelea D. The predisposition to obesity and diabetes in offspring of diabetic mothers. *Diabetes Care* 2007; **30 Suppl 2**:S169-174.
5. HAPO Study Cooperative Research Group, Metzger BE, Lowe LP, Dyer AR, Trimble ER, Chaovarindr U, *et al*. Hyperglycemia and adverse pregnancy outcomes. *N Engl J Med* 2008; **358**:1991-2002.
6. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. *JAMA* 2003; **289**:1785-1791.
7. Ekelund U, Luan J, Sherar LB, Esliger DW, Griew P, Cooper A, *et al*. Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA* 2012; **307**:704-712.
8. Harrison AL, Shields N, Taylor NF, Frawley HC. Exercise improves glycaemic control in women diagnosed with gestational diabetes mellitus: a systematic review. *Journal of physiotherapy* 2016; **62**:188-196.
9. World Health Organization. Global recommendations on physical activity for health. 2010.
10. Sedentary Behaviour Research Network. Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". *Appl Physiol Nutr Metab* 2012; **37**:540-542.
11. Whitaker KM, Buman MP, Odegaard AO, Carpenter KC, Jacobs DR, Jr., Sidney S, *et al*. Sedentary Behaviors and Cardiometabolic Risk: An Isotemporal Substitution Analysis. *Am J Epidemiol* 2018; **187**:181-189.
12. Nang EE, Salim A, Wu Y, Tai ES, Lee J, Van Dam RM. Television screen time, but not computer use and reading time, is associated with cardio-metabolic biomarkers in a multiethnic Asian population: a cross-sectional study. *Int J Behav Nutr Phys Act* 2013; **10**:70.
13. Google, TNS. 2017 Google Consumer Barometer. 2017.
14. EY. Savvy Singapore - Decoding a digital nation. 2017.
15. Padmapriya N, Bernard JY, Liang S, Loy SL, Cai S, Zhe IS, *et al*. Associations of physical activity and sedentary behavior during pregnancy with gestational diabetes mellitus among Asian women in Singapore. *BMC Pregnancy Childbirth* 2017; **17**:364.
16. Sanabria-Martinez G, Garcia-Hermoso A, Poyatos-Leon R, Alvarez-Bueno C, Sanchez-Lopez M, Martinez-Vizcaino V. Effectiveness of physical activity interventions on preventing gestational diabetes mellitus and excessive maternal weight gain: a meta-analysis. *BJOG* 2015; **122**:1167-1174.
17. van der Ploeg HP, van Poppel MN, Chey T, Bauman AE, Brown WJ. The role of pre-pregnancy physical activity and sedentary behaviour in the development of gestational diabetes mellitus. *J Sci Med Sport* 2011; **14**:149-152.
18. Harrison CL, Brown WJ, Hayman M, Moran LJ, Redman LM. The Role of Physical Activity in Preconception, Pregnancy and Postpartum Health. *Semin Reprod Med* 2016; **34**:e28-37.
19. Loy SL, Cheung YB, Soh SE, Ng S, Tint MT, Aris IM, *et al*. Female adiposity and time-to-pregnancy: a multiethnic prospective cohort. *Hum Reprod* 2018.
20. Craig CL, Marshall AL, Sjostrom M, Bauman AE, Booth ML, Ainsworth BE, *et al*. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* 2003; **35**:1381-1395.
21. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, *et al*. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *The Lancet* 2016; **388**:1302-1310.
22. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary Behaviors and Subsequent Health Outcomes in Adults. *Am J Prev Med* 2011; **41**:207-215.
23. Chastin SFM, De Craemer M, De Cocker K, Powell L, Van Cauwenberg J, Dall P, *et al*. How does light-intensity physical activity associate with adult cardiometabolic health and mortality? Systematic review with meta-analysis of experimental and observational studies. *Br J Sports Med* 2018.
24. Batacan RB, Jr., Duncan MJ, Dalbo VJ, Tucker PS, Fenning AS. Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies. *Br J Sports Med* 2017; **51**:494-503.

25. Stephenson J, Heslehurst N, Hall J, Schoenaker DAJM, Hutchinson J, Cade JE, *et al.* Before the beginning: nutrition and lifestyle in the preconception period and its importance for future health. *The Lancet* 2018; **391**:1830-1841.
26. Grontved A, Ried-Larsen M, Moller NC, Kristensen PL, Wedderkopp N, Froberg K, *et al.* Youth screen-time behaviour is associated with cardiovascular risk in young adulthood: the European Youth Heart Study. *European journal of preventive cardiology* 2014; **21**:49-56.
27. Goldfield GS, Saunders TJ, Kenny GP, Hadjiyannakis S, Phillips P, Alberga AS, *et al.* Screen Viewing and Diabetes Risk Factors in Overweight and Obese Adolescents. *Am J Prev Med* 2013; **44**:S364-S370.
28. Reeves MM, Healy GN, Owen N, Shaw JE, Zimmet PZ, Dunstan DW. Joint associations of poor diet quality and prolonged television viewing time with abnormal glucose metabolism in Australian men and women. *Prev Med* 2013; **57**:471-476.
29. Yates T, Khunti K, Wilmot EG, Brady E, Webb D, Srinivasan B, *et al.* Self-Reported Sitting Time and Markers of Inflammation, Insulin Resistance, and Adiposity. *Am J Prev Med* 2012; **42**:1-7.
30. Popkin BM. Nutrition Transition and the Global Diabetes Epidemic. *Curr Diab Rep* 2015; **15**:64.

Table 1 Sociodemographic characteristics by levels of physical activity, television watching and electronic devices use in women from the S-PRESTO cohort

	Physical activity level			Television watching				Electronic devices use			
	Insufficiently active (n=640)	Active (n=306)	<i>p</i> -value	Never (n=230)	0-2 h/day (n=383)	≥2 h/day (n=333)	<i>p</i> -value	≤1 h/day (n=434)	1-3 h/day (n=287)	≥3 h/day (n=225)	<i>p</i> -value
Ethnicity			0.04				0.06				0.32
Chinese	478 (74.7%)	202 (66.0%)		181 (78.7%)	269 (70.2%)	230 (69.1%)		304 (70.0%)	210 (73.2%)	166 (73.8%)	
Malay	90 (14.1%)	59 (19.3%)		26 (11.3%)	59 (15.4%)	64 (19.2%)		68 (15.7%)	43 (15.0%)	38 (16.9%)	
Indian	52 (8.1%)	35 (11.4%)		14 (6.1%)	43 (11.2%)	30 (9.0%)		48 (11.1%)	27 (9.4%)	12 (5.3%)	
Mixed	20 (3.1%)	10 (3.3%)		9 (3.9%)	12 (3.1%)	9 (2.7%)		14 (3.2%)	7 (2.4%)	9 (4.0%)	
Age (year)	31.6 ± 3.6	30.9 ± 3.8	0.01	30.8 ± 3.6	31.7 ± 3.7	31.4 ± 3.7	0.01	31.8 ± 3.6	31.1 ± 3.5	30.8 ± 4.1	0.002
BMI (kg/m ²)	23.7 ± 5.2	24.1 ± 5.4	0.29	23.3 ± 5.2	23.9 ± 5.3	24 ± 5.3	0.28	23.4 ± 4.9	23.7 ± 5.1	24.6 ± 6.0	0.03
Education			0.48				0.01				0.0003
Primary/Secondary	82 (12.8%)	43 (14.1%)		17 (7.4%)	51 (13.3%)	57 (17.1%)		47 (10.8%)	30 (10.5%)	48 (21.3%)	
Post-secondary	143 (22.3%)	77 (25.2%)		51 (22.2%)	91 (23.8%)	78 (23.4%)		104 (24.0%)	59 (20.6%)	57 (25.3%)	
University	415 (64.8%)	186 (60.8%)		162 (70.4%)	241 (62.9%)	198 (59.5%)		283 (65.2%)	198 (69.0%)	120 (53.3%)	
Occupational status			<0.0001				0.0037				<0.0001
Unemployed	92 (14.4%)	42 (13.7%)		32 (13.9%)	38 (9.9%)	64 (19.2%)		41 (9.4%)	33 (11.5%)	60 (26.7%)	
Night shift work	36 (5.6%)	57 (18.6%)		21 (9.1%)	34 (8.9%)	38 (11.4%)		34 (7.8%)	37 (12.9%)	22 (9.8%)	
Daytime work	512 (80.0%)	207 (67.6%)		177 (77.0%)	311 (81.2%)	231 (69.4%)		359 (82.7%)	217 (75.6%)	143 (63.6%)	
Parity			0.13				0.002				0.02
Nullipara	425 (66.4%)	188 (61.4%)		132 (57.4%)	243 (63.4%)	238 (71.5%)		266 (61.3%)	184 (64.1%)	163 (72.4%)	
Primi/multipara	215 (33.6%)	118 (38.6%)		98 (42.6%)	140 (36.6%)	95 (28.5%)		168 (38.7%)	103 (35.9%)	62 (27.6%)	
Familial history of diabetes mellitus			0.94				0.83				0.46
Yes	17 (2.7%)	8 (2.6%)		8 (3.5%)	10 (2.6%)	7 (2.1%)		15 (3.5%)	6 (2.1%)	3 (1.3%)	
No/Do not know	306 (47.8%)	149 (48.7%)		124 (53.9%)	181 (47.3%)	150 (45.0%)		153 (35.3%)	97 (33.8%)	59 (26.2%)	
History of gestational diabetes mellitus ¹			0.74				0.87				0.49
Yes	197 (30.8%)	91 (29.7%)		72 (31.3%)	113 (29.5%)	103 (30.9%)		125 (28.8%)	88 (30.7%)	75 (33.3%)	
No	443 (69.2%)	215 (70.3%)		158 (68.7%)	270 (70.5%)	230 (69.1%)		309 (71.2%)	199 (69.3%)	150 (66.7%)	
Smoking status			0.0044				0.09				0.01
Current	19 (3.0%)	22 (7.2%)		9 (3.9%)	14 (3.7%)	18 (5.4%)		15 (3.5%)	10 (3.5%)	16 (7.1%)	
Past smoker	35 (5.5%)	23 (7.5%)		9 (3.9%)	20 (5.2%)	29 (8.7%)		28 (6.5%)	10 (3.5%)	20 (8.9%)	
Never	586 (91.6%)	261 (85.3%)		212 (92.2%)	349 (91.1%)	286 (85.9%)		391 (90.1%)	267 (93.0%)	189 (84.0%)	

Values are n (%) and Mean ± SD for categorical and continuous variables, respectively; *p*-values are from chi square tests, and t-tests (two-category variables) and ANOVAs (three-category variables), respectively. ¹In parous women. Abbreviations: BMI, body mass index; S-PRESTO, Singapore PREconception Study of long-Term maternal and child Outcomes.

Table 2 Relationships between levels of physical activity and television watching and electronic devices use in women from the S-PRESTO cohort

	Overall physical activity level			Television watching			Electronic devices use			<i>p</i> -value	
	Insufficiently active (n=640)	Active (n=306)	<i>p</i> -value	Never (n=230)	0-2 h/day (n=383)	≥2 h/day (n=333)	<i>p</i> -value	≤1 h/day (n=434)	1-3 h/day (n=287)		≥3 h/day (n=225)
Vigorous physical activity			0.0044				0.28				0.19
Never	472 (73.8%)	205 (67.0%)		176 (76.5%)	264 (68.9%)	237 (71.2%)		300 (69.1%)	206 (71.8%)	171 (76.0%)	
<75 min/week	92 (14.4%)	40 (13.1%)		30 (13.0%)	56 (14.6%)	46 (13.8%)		72 (16.6%)	38 (13.2%)	22 (9.8%)	
≥75 min/week	76 (11.9%)	61 (19.9%)		24 (10.4%)	63 (16.4%)	50 (15.0%)		62 (14.3%)	43 (15.0%)	32 (14.2%)	
Moderate physical activity			<0.0001				0.84				0.22
Never	256 (40.0%)	57 (18.6%)		80 (34.8%)	128 (33.4%)	105 (31.5%)		137 (31.6%)	91 (31.7%)	85 (37.8%)	
<150 min/week	244 (38.1%)	83 (27.1%)		73 (31.7%)	135 (35.2%)	119 (35.7%)		162 (37.3%)	101 (35.2%)	64 (28.4%)	
≥150 min/week	140 (21.9%)	166 (54.2%)		77 (33.5%)	120 (31.3%)	109 (32.7%)		135 (31.1%)	95 (33.1%)	76 (33.8%)	
Television watching			0.16				-				-
Never	164 (25.6%)	66 (21.6%)									
0-2 h/day	263 (41.1%)	120 (39.2%)									
≥2 h/day	213 (33.3%)	120 (39.2%)									
Electronic devices use			0.01				<0.0001				-
<1 h/day	303 (47.3%)	131 (42.8%)		80 (34.8%)	224 (58.5%)	130 (39.0%)					
1-3 h/day	175 (27.3%)	112 (36.6%)		82 (35.7%)	97 (25.3%)	108 (32.4%)					
≥3 h/day	162 (25.3%)	63 (20.6%)		68 (29.6%)	62 (16.2%)	95 (28.5%)					

p-values are from chi square tests. Abbreviations: S-PRESTO, Singapore PREconception Study of long-Term maternal and child Outcomes.

Supplemental Table 1 Fasting, 30-min and 2-hour post-OGTT glucose levels (in mmol/L) in women from the S-PRESTO cohort

	n	Mean \pm SD	Median (IQR)
Fasting glucose	944	4.83 \pm 0.75	4.70 (4.50 - 5.00)
30-min glucose	828	8.28 \pm 1.79	8.20 (7.20 - 9.10)
120-min glucose	939	6.04 \pm 2.10	5.70 (4.90 - 6.60)

Abbreviations: OGTT, oral glucose tolerance test; S-PRESTO, Singapore PREconception Study of long-Term maternal and child Outcomes.

Table 3 Associations of levels of physical activity with glucose levels (mmol/L) in women from the S-PRESTO cohort

	Fasting	30-min	120-min	Overall <i>p</i> -value	Interaction <i>p</i> -value
Overall physical activity level (ref: insufficiently active)					
Model 1				0.07	0.05
Active	-0.06 (-0.16, 0.04)	-0.30 (-0.55, -0.06)	-0.14 (-0.41, 0.14)		
Model 2				0.07	0.05
Active	-0.06 (-0.16, 0.04)	-0.31 (-0.56, -0.06)	-0.15 (-0.42, 0.13)		
Vigorous physical activity (ref: never)					
Model 1				0.01	0.09
<75 min/week	-0.09 (-0.22, 0.05)	-0.25 (-0.59, 0.08)	-0.19 (-0.56, 0.19)		
≥75 min/week	-0.14 (-0.27, 0.00)	-0.37 (-0.71, -0.04)	-0.53 (-0.90, -0.16)		
Model 2 ^a				0.02	0.13
<75 min/week	-0.08 (-0.22, 0.05)	-0.21 (-0.55, 0.13)	-0.15 (-0.53, 0.23)		
≥75 min/week	-0.14 (-0.28, -0.01)	-0.35 (-0.68, -0.02)	-0.53 (-0.90, -0.16)		
Moderate physical activity (ref: never)					
Model 1				0.53	0.73
<150 min/week	-0.05 (-0.17, 0.06)	-0.11 (-0.39, 0.17)	-0.11 (-0.42, 0.20)		
≥150 min/week	-0.04 (-0.15, 0.08)	0.06 (-0.23, 0.34)	0.05 (-0.27, 0.37)		
Model 2 ^b				0.77	0.88
<150 min/week	-0.04 (-0.15, 0.08)	-0.06 (-0.34, 0.23)	-0.06 (-0.37, 0.26)		
≥150 min/week	-0.04 (-0.15, 0.08)	0.06 (-0.23, 0.34)	0.05 (-0.26, 0.37)		

Values are mean differences (95% CI) from repeated-measure linear regression models. Overall *p*-values are for the overall effects of exposure on glucose levels, interaction *p*-values are for the interaction term exposure*time-point. Model 1: adjusted for ethnicity, age, body mass index, education, occupational status, parity, familial history of diabetes mellitus, history of gestational diabetes mellitus and smoking status. Model 2: model 1 additionally adjusted for television watching and electronic devices use. ^a Additionally adjusted for moderate physical activity; ^b Additionally adjusted for vigorous physical activity. Abbreviations: S-SPRESTO Singapore PREconception Study of long-Term maternal and child Outcomes.

Table 4 Associations of television watching and electronic devices use with glucose levels (mmol/L) in women from the S-PRESTO cohort

	Fasting	30-min	120-min	Overall <i>p</i> -value	Interaction <i>p</i> -value
Television watching (ref: never)					
Model 1				0.58	0.05
0-2 hours/day	0.07 (-0.04, 0.19)	-0.23 (-0.53, 0.06)	0.03 (-0.30, 0.36)		
≥2 hours/day	0.06 (-0.07, 0.18)	-0.07 (-0.37, 0.23)	0.20 (-0.14, 0.54)		
Model 2 ^a				0.70	0.14
0-2 hours/day	0.09 (-0.03, 0.21)	-0.15 (-0.45, 0.15)	0.11 (-0.22, 0.45)		
≥2 hours/day	0.06 (-0.06, 0.19)	-0.04 (-0.34, 0.27)	0.24 (-0.10, 0.58)		
Electronic devices use (ref: never)					
Model 1				0.23	0.13
1-3 hours/day	-0.02 (-0.13, 0.09)	0.19 (-0.08, 0.46)	0.09 (-0.08, 0.58)		
≥3 hours/day	0.02 (-0.10, 0.14)	0.29 (0.00, 0.59)	0.25 (-0.19, 0.51)		
Model 2 ^b				0.34	0.35
1-3 hours/day	-0.01 (-0.12, 0.10)	0.15 (-0.12, 0.43)	0.09 (-0.22, 0.39)		
≥3 hours/day	0.02 (-0.10, 0.15)	0.24 (-0.06, 0.54)	0.23 (-0.10, 0.56)		

Values are mean differences (95% CI) from repeated-measure linear regression models. Overall *p*-values are for the overall effects of exposure on glucose levels, interaction *p*-values are for the interaction term exposure*time-point. Model 1: adjusted for ethnicity, age, body mass index, education, occupational status, parity, familial history of diabetes mellitus, history of gestational diabetes and smoking status. Model 2: model 1 additionally adjusted for vigorous and moderate physical activities. ^a Additionally adjusted for electronic devices use. ^b Additionally adjusted for television watching. Abbreviations: S-PRESTO, Singapore PREconception Study of long-Term maternal and child Outcomes.