The longitudinal association between early-life screen-viewing and abdominal adiposity - findings from a multi-ethnic birth cohort study

Running title: Screen-viewing time and abdominal adiposity

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Abstract

Importance: Screen-viewing in adults has been associated with greater abdominal adiposity, with the magnitude of associations varying by sex and ethnicity, but the evidence is lacking at younger ages. We aimed to investigate sex- and ethnic-specific associations of screen-viewing time at ages 2 and 3 years with abdominal adiposity measured by magnetic resonance imaging at age 4.5 years.

Methods: The Growing Up in Singapore Towards healthy Outcomes is an ongoing prospective mother-offspring cohort study. Parents/caregivers reported the time their child spent viewing television, handheld devices and computer screens at ages 2 and 3 years. Superficial and deep subcutaneous and visceral abdominal adipose tissue volumes were quantified from magnetic resonance images acquired at age 4.5 years. Associations between screen-viewing time and abdominal adipose tissue volumes were examined by multivariable linear regression adjusting for confounding factors.

Results: In the overall sample (n=307), greater total screen-viewing time and handheld device times were associated with higher superficial and deep subcutaneous adipose tissue volumes, but not with visceral adipose tissue volumes. Interactions with child sex were found, with significant associations with superficial and deep subcutaneous and visceral adipose tissue volumes in boys, but not in girls. Among boys, the increases in mean (95% CI) superficial and deep subcutaneous and visceral adipose tissue volumes were 24.3 (9.9, 38.7), 17.6 (7.4, 27.8), and 7.8 (2.1, 13.6) mL per hour increase in daily total screen-viewing time, respectively. Ethnicity-specific analyses showed associations of total screen-viewing time with abdominal adiposity only in Malay children. Television viewing time was not associated with abdominal adiposity.

Conclusion: Greater total screen-viewing time (and in particular, handheld device viewing time) was associated with higher abdominal adiposity in boys and Malay children. Additional studies are necessary to confirm these associations and to examine screen-viewing interventions for preventing excessive abdominal adiposity and its adverse cardiometabolic consequences.

Introduction

Childhood obesity is an ongoing epidemic. The World Health Organization has estimated that forty-one million children aged five years or below are overweight, nearly half of whom live in Asia (1). Many overweight/obese children remain overweight/obese as adults and develop health complications such as cardiometabolic diseases (1, 2). Abdominal fat has been more strongly linked with obesity-related morbidity and mortality than overall body fat mass in adults (3-5). Moreover, within the abdominal compartments, superficial subcutaneous adipose tissue (SSAT), deep subcutaneous adipose tissue (DSAT) and visceral adipose tissue (VAT) may differently associate with health outcomes (6-8). Studies in adults reported that a higher volume of VAT and/or DSAT, but not SSAT, is associated with insulin resistance and higher cardiometabolic risk (5, 9). The accumulation of abdominal fat begins in early life and it may track into adulthood (10, 11). However, because preventive measures in adulthood seem to have limited effect, it is important to prevent the accumulation of excessive abdominal adiposity among young children (7, 12, 13).

Several risk factors contribute to childhood obesity, among which sedentary behaviour makes an important and modifiable contribution (14, 15). Screen-viewing, including television and handheld mobile devices, occupies an increasingly prominent place in young children's leisure-time sedentary activities (16-18). Previous studies have reported that a large proportion (~16 to 50%) of children from high-income countries exceed the recommended limit of ≤1 hour of high-quality content screen-viewing time (SVT) per day between ages 2 and 5 years (17, 19-25). A review of prospective studies in children concluded that greater SVT is associated with higher general adiposity (26). The effect of SVT may not be limited to an increase in general adiposity, though. A previous study using measures of waist circumference suggested that screen (television) viewing time may be associated with abdominal adiposity in children (24). However, waist circumference may not distinguish between the different abdominal adipose tissue compartments in children (27). Magnetic resonance imaging (MRI) is considered the most accurate method to determine abdominal adipose tissue compartment volumes without radiation exposure (28, 29). We are aware of only two cross-sectional studies that have examined associations of the screen (television) viewing time with MRI-measured abdominal adiposity among children and adolescents (aged 5 to 18 years) and the findings were inconsistent: one study reported a positive association and the second no evidence of associations (30, 31).

Moreover, our previous research suggests sex-specific associations between SVT and adiposity in young children (32). Evidence suggests the existence of disparities in childhood adiposity according to sex and ethnicity due to biological and sociocultural factors (33, 34). Previously we observed sex and ethnic differences in abdominal adipose tissue compartment volumes among children in Singapore (6, 7). A recent study in the US adult population suggests that associations of screen-viewing with abdominal adiposity differ by sex and ethnicity (15), warranting further investigation. In this study, we investigated the associations of SVT at ages 2-3 years with abdominal adiposity distribution as measured by MRI at age 4.5 years in children enrolled in a mother-offspring cohort study in Singapore. We considered both television and handheld screen device use, as well as differences in childhood adiposity according to sex and ethnicity.

Methods

Study design

Growing Up in Singapore Towards healthy Outcomes (GUSTO) is an ongoing mother-offspring multi-ethnic Asian cohort study in Singapore with detailed phenotyping of mothers and children. Pregnant women <14 weeks of gestation, Chinese, Malay or Indian ethnicity, attending two major public maternity units in Singapore, National University Hospital or KK Women's and Children's Hospital, were recruited between June 2009 and- October 2010. All participants gave written informed consent. The study was granted ethical approval by the National Healthcare Group Domain Specific Review Board and SingHealth Centralized Institutional Review Board in Singapore (ClinicalTrials.gov: NCT01174875). More details of the study are available elsewhere (35, 36).

Screen-viewing time (SVT)

At age 2 and 3 years, parents or caregivers of children were asked to answer the screen-viewing questions that how much time per day on average their children spent in activities involving screens during one month prior to the study visits as part of the interviewer-administered indoor and outdoor activities questionnaires at ages 2- and 3-years. Time spent in three types of screen media were reported in 5-minute increments for both weekdays and weekends: i) television viewing/playing time (e.g., Xbox™, Wii™, PlayStation®), ii) computer use time (laptop or desktop), and iii) hand-held devices viewing/playing time (e.g., hand-phones, tablets or Game Boy®). Daily television, computer and handheld device viewing time at both ages were calculated [(weekday × 5 + weekend day × 2)/7]. The total SVT, television and handheld device viewing times at ages 2 and 3 years were derived by averaging the times at the two ages to reduce reporting error (17).

Quantification of abdominal adipose tissue compartment volumes

MRI of the abdominal region was performed using a 3T MR scanner (Siemens Skyra, VE11A) at age 4.5 years for the subset of the GUSTO participants who consented for this specific measurement. Water suppressed HASTE sequence (TR=1,000 ms, TE=95 ms) and body matrix coil were used to obtain sixty axial images of 5-mm slice thickness and in-plane resolution of 0.94 × 0.94 mm covering the abdominal region from the top of the liver to upper sacrum (37). A validated and fully automated algorithm based on graph cuts was used for segmentation of SAT and VAT depots (6, 38). SAT was classified into DSAT and SSAT by manual tracing of the fascial plane. Bowel and other misclassified structures were removed by manual editing. The number of voxels in SSAT, DSAT and VAT were summed and multiplied by the image resolution to obtain the fat volumes (in mL) (6).

Covariates

Data on ethnicity, maternal age, educational attainment and self-reported pre-pregnancy weight were obtained at recruitment as part of the interviewer-administered questionnaires. At age 2 and 3 years, parents or caregivers of children answered interviewer-administered questions on outdoor playing/exercising; it included how much time their child spent playing/exercising (activities that require physical exertion) out of doors (e.g. in a backyard, walk, bike riding) per day on weekdays and weekend days during the month prior to the study visit. Time spent in outdoor playing/exercising activities were reported in 5-minute increments for both weekdays and weekends, and time spent per week was calculated (weekday × 5 + weekend day × 2). Time spent at ages 2 and 3 years were then averaged to reduce reporting error and used for analysis. Total energy intake per day was derived from a single 24-hour food recall data collected using the 5-stage multiple-pass interviewing technique at age 3 years (39). Nutrient intakes from 24-hour food recall was analyzed using a nutrient analysis software Dietplan (Forestfield software) that includes a food composition database of locally available foods (40). Alternatively, for the dishes that were not present in the database, nutrient analyses were conducted using recipes or food labels or using a similar composite dish or obtaining nutrient information from the US Department of Agriculture's national nutrient database (41, 42). Maternal height at 26-28 weeks of gestation, paternal height and weight at the 2- or 3- year clinic visit and weight and height of the children at ages 2 and 4.5 years were measured in duplicate by research staff using a weighing scale (SECA model 803) and a stadiometer (SECA model 213, Hamburg, Germany). When the difference between the two measures was >1.0 cm for height or >0.2 kg for weight, a third measurement was taken, and the average of the two closest measures was used. Biceps, triceps, and subscapular skinfold thicknesses (to the nearest 0.2 mm) of the children were measured in triplicate at age 2 years using Holtain skinfold callipers (Holtain Ltd, Crymych, UK) (43, 44). When the three measures varied by more than 1 mm, a fourth reading was taken; the average of the three closest measures were used. Measured height and weight data were used to calculate paternal and child BMIs (kg/m^2). Maternal BMI was calculated based on the mother's self-reported pre-pregnancy weight and her height measured at 26-28 weeks. Biceps, triceps and subscapular skinfolds were added to calculate the sum of skinfolds measures.

Statistical analyses

We used chi-square test to compare the characteristics of the GUSTO children with and without MRI-measured abdominal adiposity data. Then, we compared screen-viewing time and abdominal adiposity between boys and girls and between Chinese, Malay and Indian ethnicity using independent t-test and one-way ANOVA, respectively. Among children with MRI measures, 30.3% had missing data for one or more of the covariates, with a range from 1% to 15.6% on the individual covariates. We used multiple imputations of 50 datasets using chained equations for these missing covariates (45). SVT and MRI-measured abdominal adiposity data were not imputed, leading to a final analysis sample of 307 children with data on both SVT and MRI-measured abdominal adiposity (Figure 1) (46).

Multivariable linear regression models were used to estimate associations of total SVT, television time and handheld devices time at age 2-3 years with SSAT, DSAT and VAT at age 4.5 years. Computer time was not analyzed separately as more than two-thirds of the participants were not exposed to computer-based screen time at ages 2 and 3 years [median (Interquartile range): 0 (0-0.25)] (17). All models were adjusted for potential socio-demographic and lifestyle confounding factors suggested by the literature, i.e., sex (boy, girl), ethnicity (Chinese, Malay, Indian), child sum of skinfold thicknesses at age 2 years (in mm), maternal age at delivery (in year), maternal education (≤secondary, post-secondary and university and others) and pre-pregnancy BMI (in kg/m^2), and paternal BMI (in kg/m^2) (32, 47). In models with television viewing time or handheld device viewing time as exposures, each was adjusted for the other. The published literature suggests that magnitude of associations between SVT and adiposity may change according to sex and ethnicity (15, 33, 34); we, therefore, tested in separate models interaction terms between each SVT exposure and child sex (SVT*sex) and ethnicity (SVT*ethnicity), and subsequent analyses were stratified by sex or ethnicity. We also carried out sensitivity analyses with complete case analyses for the above-mentioned regression models, to assess the potential influence of the multiple imputation procedure on the results. In models with statistical interaction with child sex, we considered interaction p-values $p<0.20$ as suitable for sex stratification. In sensitivity analyses, we repeated the above models with further adjustment for potential mediators of the associations of interest, including time spent in outdoor playing/exercising activities at age 2-3 years (in hours per week) and daily energy intake at age 3 years. All statistical analyses were carried out using SPSS v25 (IBM, Chicago, IL, USA).

Results

At age 2-3 years 987 (84.2%) children in the cohort had SVT data; 307 (31.1%) of these children underwent MRI scans of the abdominal region at age 4.5 years and were included in the present analysis (Figure 1). Table 1 compares the children with and without MRI adiposity measurements. Children with MRI data were less likely to be boys or of Chinese ethnicity, and their mothers were less likely to have a university education. Among included children, boys had higher SVT [Mean total SVT: 3.0 (Standard deviation: 2.0) vs 2.5 (1.6) h/day, p=0.046] and lower SSAT [366.7 (206.9) vs 447.9 (247.6) mL, p=0.002] and DSAT [129.6 (143.7) vs 184.9 (182.3) mL, p=0.004], but not VAT [196.2 (72.2) vs 186.9 (83.1) mL, p=0.298], compared to girls. Malay and Indians had higher total and device-specific SVT and higher SSAT and DSAT, but not VAT, compared to Chinese children (Table 2).

Associations of total SVT with abdominal adipose tissue compartment volumes

In the overall sample, total SVT was positively associated with SSAT and DSAT but not with VAT. Based on the observed interaction terms, child sex modified the association of SVT with SSAT (p for interaction=0.042), with suggestive interactions for DSAT (p=0.101) and VAT (p=0.085). Sex-stratified analyses revealed that total SVT was associated with SSAT, DSAT and VAT in boys; the addition of one hour of SVT per day was associated with an increase in mean (95% confidence interval) SSAT [24.3 (9.9, 38.7) mL], DSAT [17.6 (7.4, 27.8) mL] and VAT [7.8 (2.1, 13.6) mL] in boys. No associations were found in girls [SSAT: 1.3 (-15.9, 18.6), DSAT: 2.7 (-10.9, 16.4) and VAT: -0.3 (-7.2, 6.5) mL]. Ethnicity-stratified analyses revealed stronger estimates with SSAT, DSAT and VAT in Malay children than in Chinese or Indian children, but no interactions were observed (p for interaction >0.20) (Table 3).

Associations of device-specific SVT with abdominal adipose tissue compartment volumes

Television viewing time was not associated with SSAT, DSAT and VAT in the overall sample, and no interactions with child sex or ethnicity were observed (Table 3). Handheld device viewing time was associated with SSAT and DSAT, but not with VAT in the overall sample. Interactions with child sex were observed for SSAT (p=0.004), DSAT (p=0.016) and VAT (p=0.052): these were driven by associations in boys [SSAT: 61.9 (29.9, 93.8), DSAT: 44.5 (21.8, 67.1) and VAT: 13.9 (0.8, 27.0) mL] but not in girls [SSAT: -12.4 (-50.6, 25.7), DSAT: -3.3 (-33.5, 26.9) and VAT: -3.4 (-18.7, 11.8) mL]. No interaction with ethnicity was observed (p for interaction >0.20) (Table 3).

Sensitivity analyses based on complete case data showed stronger effect sizes of associations of total SVT and handheld device viewing time with SSAT, DSAT and VAT and among boys and Malay children compared to results on the imputed data set (Supplementary Table 1). Further adjustment for time spent in outdoor playing/exercising activities at age 2-3 years and total energy intake at age 3 years did not change the above results (Supplementary Table 2).

Discussion

In this prospective multi-ethnic cohort study, we found associations between greater total and device-specific SVT at age 2-3 years and higher MRI-measured abdominal adiposity compartment volumes at age 4.5 years. Total SVT, and particularly handheld device viewing time, were significantly associated with all three abdominal compartmental adipose tissue volumes in boys, but not in girls, and associations were stronger in Malay children than in Chinese or Indian children. Television time was not associated with abdominal adiposity, either in the overall sample or among either sex.

To our knowledge, this is the first study to examine screen-viewing behaviour in early childhood with the distribution of MRI-measured abdominal adipose tissue. A previous cross-sectional study in US children and adolescents aged 5 to 18 years reported that higher television viewing time was associated with greater subcutaneous and visceral abdominal adiposity (30). In contrast, another cross-sectional study in adolescents aged 14 to 18 years reported no associations between television/movie viewing time and VAT (31). Consistent with this latter study (31), we found that television time was not associated with SSAT, DSAT and VAT. Multiple factors could explain the differences between our findings and the existing literature. For instance, although television remains the dominant screen device among children, a temporal shift is occurring in screen-time habits, with an increase in handheld device use (17). In our study, we accounted for the time spent on handheld devices while investigating the association between television viewing time and abdominal adiposity. Furthermore, previous cross-sectional studies may have been affected by reverse causation, included predominantly older children and adolescents (5 to 18 years), whereas our study was longitudinal, and focused on younger children.

Our study suggests that greater total and handheld SVT is associated with higher SSAT, DSAT and VAT in boys. The mechanisms of these associations are not fully understood, and current data do not explain why different types of screen-viewing are differentially associated with SSAT, DSAT and VAT. However, it has been suggested that concurrent eating, while watching screens and the influence of food advertisements, and insufficient physical activity and sleep due to longer duration of

SVT might explain the observed associations (18). Handheld digital media, in particular, may prompt children to watch even while eating and engaging in other leisure activities, which may increase the uninterrupted sitting time. This prolonged sitting may increase abdominal adiposity in children. Alternatively, bedtime screen usage may reduce the duration and quality of sleep, and that lack of sleep might lead to high-energy intake and greater abdominal adiposity (18, 24, 48). Moreover, literature suggests that screen-based activities requiring a significant cognitive effort, such as playing video games or performing school homework, may cause neurogenic stress, which could increase spontaneous energy intake without detectable changes in energy expenditure (49-52). This positive energy balance mechanism may explain the stronger associations observed with handheld devices compared to television. Further research is required to examine these hypotheses.

We observed sex- and ethnicity-specific associations between SVT and abdominal adiposity. These results are in line with those reported in a US adult population; SVT (television) was associated with VAT in White men but not in women or Black men, and associated with subcutaneous adipose tissue in White women only (15). In our study, total screen-viewing and handheld device viewing times were associated with SSAT, DSAT and VAT only in boys, but not in girls. The underlying mechanisms driving the observed sex-specific findings are unknown. We have previously reported sex and ethnic differences in abdominal adipose tissue volumes among children at early infancy and at age 4.5 years (6, 7). Hence, anatomical differences and the role of sex hormones in the metabolic profile and accumulation of subcutaneous and visceral tissue could explain the sex-differences in these associations (53-56). An alternative hypothesis is that SVT may be a better proxy of total time spent in sedentary behaviour in boys than in girls. Boys might be naturally or socially encouraged to engage in physical activity when they are not watching screen devices, whereas girls might engage in other sedentary activities more frequently, as reported in a study with older children (57). Ethnicity-specific associations are even more challenging to explain and may reflect residual confounding by genetic differences in fat metabolism or by cultural factors that affect diet and exercise patterns (17, 54, 58, 59). These hypotheses warrant further clinical and epidemiological studies.

Strengths of our study include its longitudinal study design, measurement of abdominal adiposity compartment volumes using MRI in young children under 5 years of age, and the examination of different types of screens including tablets and smartphones at early childhood. However, limitations have to be considered. Firstly, total and device-specific SVT was reported by parents/caregivers, rather than objectively measured. However, a structured interview questionnaire used and it was administered by trained interviewers at two-time points, which should have mitigated the reporting errors. Secondly, unmeasured residual confounding factors, such as changes in SVT and time spent in outdoor playing/exercising activities between ages 3 and 4.5 years, moderate and vigorous physical activity, eating while viewing screen devices and frequency of eating unhealthy snacks and sweetened beverages, cannot be discounted. Further follow-up of this cohort, including measurement of the above confounders, could help clarify the link between SVT and abdominal adiposity. Finally, our study is limited to a subgroup of the GUSTO cohort, and children with and without MRI measurements differed in ethnicity, sex and SVT, which might affect the generalizability of our results. Nevertheless, our findings make a novel contribution to the literature and may influence the design of future studies, including the testing of intervention strategies to reduce childhood abdominal adiposity and their cardio-metabolic consequences later in life.

In conclusion, our study provides evidence that greater total SVT at age 2-3 years is associated with higher abdominal SSAT, DSAT and VAT, at age 4.5 years in boys. Associations appeared stronger in Malay than in Chinese and Indian children. The associations between SVT, particularly handheld device, and abdominal adiposity lend credence to the role of early-life screen-viewing in detrimental health outcomes by increasing DSAT and VAT in children. Given the increase in handheld screen device usage, this study highlights the importance of limiting handheld device time to promote health. Future studies with larger sample size and context-specific screen-viewing data are warranted to confirm our observations. In light of increasing screen-viewing in children, our findings support the need for the development of evidence-based health promotion strategies to limit childhood SVT and prevent abdominal adiposity and its adverse cardiometabolic health consequences.

Abbreviations: GUSTO, The Growing Up in Singapore Towards healthy Outcomes; BMI, body mass index; SSAT, superficial subcutaneous adipose tissue; DSAT, deep subcutaneous adipose tissue; VAT, visceral adipose tissue.

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Availability of data and materials: The dataset supporting the conclusions of this article can be made available upon request and after approval by the GUSTO Executive Committee.

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Figure 1: Study flowchart

Table 1: Comparison of children with and without magnetic resonance imaging (MRI) abdominal adiposity data in the GUSTO cohort

Table 2: Screen-viewing time at age 2-3 years and MRI-based abdominal adiposity at age 4.5 years, according to sex and ethnicity of children in the GUSTO cohort

Table 3: Associations of SVT at age 2-3 years with abdominal adiposity at ages 4.5 years in the GUSTO cohort