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Physical Activity and Pediatric Obesity: a Quantile Regression Analysis

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Abstract

Purpose: We aimed to determine if moderate-to-vigorous physical activity (MVPA) and sedentary behavior (SB) were independently associated with body mass index (BMI) and waist circumference (WC) in children and adolescents.

Methods: Data from the International Accelerometry Database (ICAD) were used to address our objectives (N=11,115; 6-18y; 51% female). We calculated age and gender specific body mass index (BMI) and waist circumference (WC) Z-scores and used accelerometry to estimate MVPA and total SB. Self-reported television viewing was used as a measure of leisure time SB. Quantile regression was the used to analyze the data.

Results: MVPA and total SB were associated with lower and higher BMI and WC Z-scores, respectively. These associations were strongest at the higher percentiles of the Z-score distributions. After including MVPA and total SB in the same model the MVPA associations remained, but the SB associations were no longer present. For example, each additional hour per day of MVPA was not associated BMI Z-score at the 10th percentile (b=-0.02, P=0.170), but was associated with lower BMI Z-score at the 50th (b=-0.19, P<0.001) and 90th percentiles (b=-0.41, P<0.001). More television viewing was associated with higher BMI and WC and the associations were strongest at the higher percentiles of the Z-score distributions, with adjustment for MVPA and total SB.

Conclusions: Our observation of stronger associations at the higher percentiles indicate that increasing MVPA and decreasing television viewing at the population-level could shift the upper tails of the BMI and WC frequency distributions to lower values, thereby lowering the number of children and adolescents classified as obese.

Key Words: adolescent, accelerometry, ICAD, BMI, television

Introduction

Over 34% of adults and 16% of children in the U.S. are obese (29). These levels are approximately 3-fold higher compared to the levels observed in the 1960s (16), and similar increases in obesity prevalence have been observed globally (28). Obesity increases the risk of the leading chronic diseases (38), tracks from childhood into adulthood (37), and obesity related metabolic co-morbidities are increasingly being diagnosed in childhood (30). It is therefore particularly important to determine contributors to child and adolescent obesity to address any related short and long term health problems.

While the data are not conclusive (15), there is evidence that secular declines in moderate-to-vigorous physical activity (MVPA), and increases in sedentary behavior (SB), coincided with the rise in childhood obesity levels (3). It has therefore been hypothesized that increasing MVPA and decreasing SB in childhood could help to reduce the prevalence of childhood obesity. However, the epidemiological evidence relies heavily on self-reported measures of MVPA and SB (22, 31), with fewer studies using accelerometry estimated MVPA and SB to study childhood obesity. Importantly, different accelerometer methodologies were used across these latter studies making it challenging to draw comparisons and conclusions (10, 17, 33). Furthermore, there is little-to-no evidence that accelerometry estimated total SB is independently associated with pediatric obesity (19, 23, 36); yet, television viewing, the most common leisure time SB has been robustly associated with pediatric obesity (5, 26, 35). Additional research is therefore needed to understand the complexity of physical activity energy expenditure, SB and pediatric obesity.

In addition, statistical methods that extend beyond the analysis of the mean of obesity-related phenotypes are needed to build upon past studies (14). The upper percentiles of the distribution for such phenotypes are of interest in the context of childhood obesity (e.g., 95th body mass index [BMI] percentile). Quantile regression is a statistical method that can model the median and any other percentile of a continuous variable, enabling investigators to test how predictors (e.g. MVPA and SB) affect the shape of obesity-related phenotype distributions (e.g. BMI and waist circumference [WC]) (4). Importantly, this method does not categorize participants into obese and non-obese groups (e.g. <95th percentile versus ≥95th percentile), which has the following drawbacks (1): i) assumes that all participants within a category are homogeneous (e.g., 10th percentile similar to 90th percentile), ii) assumes participants at category boundaries are very different rather than very similar (e.g. 94th percentile more similar to 10th percentile than the 95th percentile).

To address the research gaps related to physical activity energy expenditure, SB, and pediatric obesity, and the focus on modeling the mean of obesity phenotypes, we analyzed standardized data from the International Children's Accelerometry Database (ICAD), using quantile regression. We specifically aimed to determine if time spent in MVPA and SB (total and leisure time) were independently associated with BMI and WC Z-score frequency distributions in children and adolescents.

Methods

Study Design and Data Source

The ICAD consortium pooled raw accelerometry data from international studies involving children and adolescents, and used standardized methods to derive estimates of MVPA and SB (33). Specifically, accelerometry data from 21 studies that used an ActiGraph accelerometer (models: AM7164 and GT1M) were pooled, along with anthropometric and demographic data when available. These studies were conducted between 1998 to 2009 in Europe, the U.S., Brazil and Australia. For the purpose of our study, we included 6 to 18 year olds with complete accelerometry, anthropometric and covariate data in the ICAD database (N=11,115). These participants were originally enrolled in the following 8 studies: Avon Longitudinal Study of Parents and Children (ALSPAC, Children's of the 90s Cohort, N=4,281) (8), Denmark European Youth Heart Study (EYHS, N=1,108), Estonia EYHS (N=437), National Health and Nutrition Examination Survey (NHANES) 2003-2004 (N=1,915), NHANES 2005-2006 (N=2,097), Norway EYHS (N=286), Personal and Environmental Associations with Children's Health (PEACH, N=640) and Portugal EYHS (N=351). All partners contributing data completed data-sharing agreements and institutional review boards at each contributor's institution approved the sharing of the data (33).

Accelerometer Estimated MVPA and SB

The majority of waking hours are spent in SB (20, 25). SB includes any waking behavior characterized by low energy expenditure (1.0-1.5 metabolic equivalents [METs]), while in a sitting or reclining posture (32). In contrast, a small proportion of waking hours are spent in MVPA (39). In children, MVPA includes any physical activity that requires an energy expenditure that is 4 times greater than the energy expended at rest (≥4 METs) (31). Accelerometry can be used to provide estimates of free-living MVPA and SB. In our study, standardized methods were used to derive estimates of MVPA and SB from the raw accelerometer files, using commercially available software: KineSoft, version 3.3.20 (KineSoft, Saskatchewan, Canada; www.kinesoft.org). All data files were integrated to a 1-minute epoch and 60 minutes of consecutive zero counts were considered non-wear time (allowing for 2 minutes of non-zero interruptions). Participants providing at least 1 day of count data, for 10 to 20 hours, were included. Time spent in total SB was the average minutes per day <100cpm and time spent in MVPA was the average minutes per day ≥2,296 (40). These SB and MVPA cutpoints have been shown to have high sensitivity and specificity (40).

Anthropometrics

BMI correlates highly with total fat mass and WC correlates highly with visceral fat mass (2). In our study, height and weight were measured by trained research staff, which allowed for the calculation of BMI's (kg/m^2). WC (cm) was measured using metal anthropometric tapes, mid-way between the lower rib margin and the iliac crest, at the end of a gentle expiration (in the NHANES sample, the metal tape was placed just above the iliac crest at the midaxillary line). Since BMI and WC increase with normal growth and physical development, age and sex specific Z-scores were calculated, using the sample means and standard deviations from 8 ICAD studies, and the Z-scores were included as outcomes in our study. We excluded those with BMI <12 kg/m^2, >50 kg/m^2 and BMI Z-scores >3.5. Similarly, we excluded those with WC <40 cm or >120 cm, and WC Z-scores >3.5.

Covariates

As children age, MVPA declines, SB increases and the likelihood of being obese increases (25, 27); we therefore included age in years as a covariate. Also, males tend to accumulate more MVPA, less SB and are less likely to obese compared to females (20, 27); we therefore included sex as a covariate. Similarly, white children engage in more MVPA, less SB and are less likely to be obese compared to their non-white counterparts (20); we therefore included race (white or non-white) as a covariate. Children belonging to lower income households spend less time in MVPA, more time in SB and are more likely to be obese compared to children belonging to higher income households (20, 29); we therefore included household income quartile as a covariate. Finally, we included study year as a covariate to control for any secular changes in the outcomes and predictors from 1998 to 2009, and study as a covariate to control for any cultural differences across the international studies.

Subsample with screen-based SB

Television viewing is the most common leisure-time SB (6), so we additionally tested for association between this particular SB and BMI Z-score and WC Z-score. The participants were categorized into the following groups based on their reported television viewing: <1 h/d, 1-2 h/d, 3-4 h/d or >4 h/d. Only a subsample of the participants included in our study had television viewing data (N=6,712), from the following studies: Denmark European Youth Heart Study (EYHS, N=1,091), Estonia EYHS (N=431), National Health and Nutrition Examination Survey (NHANES) 2003-2004 (N=1,914), NHANES 2005-2006 (N=2,096), Norway EYHS (N=272), Personal and Environmental Associations with Children's Health (PEACH, N=637) and Portugal EYHS (N=271).

Statistical Analysis

To describe our sample, we presented means and standard deviations for the continuous variables and frequencies and percentages for the categorical variables. We used the International Obesity Task Force age- and gender-specific cutoffs to describe the proportion of normal, overweight and obese participants (11). To address the aims of our study we used quantile regression, modeling BMI Z-score and WC Z-score as the dependent variables. This statistical method models the median of outcome variables (rather than the mean) and any other percentile across the frequency distribution without the need to categorize participants. We first tested if MVPA (hour per day, hr/d) was associated with BMI Z-score and WC Z-score, adjusting for the covariates (model 1a). We then tested if total SB (hr/d) was associated with BMI Z score and WC Z-score, adjusting for the covariates (model 1b). Thereafter, we included both MVPA and total SB in the same model (model 2) to determine if the MVPA and total SB associations were independent of one another. We tested for associations at the following BMI Z-score and WC Z-score percentiles, to capture the lower, mid and upper parts of the frequency distributions: 5^{th}, 10^{th}, 15^{th}, …, 85^{th}, 90^{th}, and 95^{th} percentiles. We repeated model 2 with the addition of television viewing as the main predictor for the sub-sample. All statistical analyses were completed using Stata 12.1 (StataCorp LP, College Station, TX) using the *sqreg* command with 100 bootstrap samples to calculate standard errors. The *grqreg* command was used to graph key findings. We also performed sensitivity analyses using UK and US population reference data to calculate BMI Z-scores (12, 18); and stratified the analyses by sex, race and household income categories. We also performed sensitivity analyses to re-examine the WC Z-score association with the NHANES data removed, given the different WC measurement approached used in these studies.

Results

Our primary analytical sample included 11,115 participants aged 6 to 18 years; 51% were female, 71% were white and 6% were obese (Table 1). The sample included approximately equal proportions of children belonging to low, middle and high-income households. The average time spent in MVPA was 55 minutes per day and the average time spent in total SB was 6.4 hours per day. The percent of participants providing 3 or more days of accelerometry data was 91%. The characteristics of the sub-sample (N=6,712) with television viewing data were similar to the full sample; however, a large majority of those with missing television viewing data were white. The participants most commonly reported watching television for 3-4 hours per day.

MVPA and BMI/WC Z-scores

More time spent in MVPA was associated with lower BMI and WC Z-scores, and these associations were strongest at the upper percentiles of the Z-score distributions (Table 2). For example, at the 10^{th} percentiles each additional hour of MVPA was associated with a 0.01 (P=0.248) lower BMI Z-score and with a 0.04 (P=0.018) lower WC Z-score (Table 2, models 1a); whereas, at the 90^{th} percentiles each additional hour of MVPA was associated with a 0.35 (P<0.001) lower BMI Z-score and with a 0.36 (P<0.001) lower WC Z-score (Table 2, models 1a). These associations remained after adjustment for total SB for BMI Z-score (10^{th} percentile beta=-0.02, P=0.167; 90^{th} percentile beta=-0.41, P<0.001) and WC Z-score (10^{th} percentile beta=-0.02, P=0.329; 90^{th} percentile beta=-0.36, P<0.001) (Table 2, models 2). The 90^{th} percentile beta coefficients were stronger that the 10^{th} percentile coefficients for BMI Z-score (beta difference: 0.39; 95% confidence interval (CI): 0.31-0.48; P-value: <0.001) and WC Z-score (beta difference: 0.34; 95% CI: 0.24-0.45; *P*-value: <0.001). Visual representation of the MVPA association with WC Z-score is presented in Figure 1, and the linear regression coefficients for MVPA and the mean WC Z-score (model 1a: β=-0.27, *P*<0.001 and model 2: β=-0.26, *P*<0.001) are plotted for comparison.

Total SB and BMI/WC Z-scores

More time spent in total SB was associated with higher BMI and WC Z-scores, and these associations were strongest at the upper percentiles of the Z-score distributions (Table 2). For example, at the 50th percentiles each additional hour of SB was associated with a 0.03 (*P*<0.001) higher BMI Z-score and with a 0.04 (*P*<0.001) higher WC Z-score (Table 2, models 1b); whereas, at the 90th percentiles each additional hour of SB was associated with a 0.05 (*P*= *P*=0.003) higher BMI Z-score and with a 0.08 (*P*<0.001) higher WC Z-score (Table 2, models 1b). However, these associations did not hold after adjustment for MVPA (Table 2, models 2). Visual representation of the total SB association with WC Z-score is presented in Figure 1, and the linear regression coefficients for total SB and the mean WC Z-score (model 1b: β=0.06, *P*<0.001; model 2: beta=0.01, *P*=0.504) are plotted for comparison.

Television Viewing and BMI/WC Z-scores

In the subsample with complete television viewing data, more time spent watching television was associated with higher BMI and WC Z-scores, and these associations were strongest at the upper percentiles of the Z-score distributions, and remained after adjustment for total SB and for MVPA (Figure 2 and Supplementary Table 1). For example, at the 10th percentiles, relative to <1 hour per day of television viewing, 3-4 hours per day was associated with a 0.08 (*P*=0.005) higher BMI Z-score and with a 0.08 ($P=0.022$) higher WC Z-score; whereas, at the 90th percentiles, relative to <1 hour per day of television viewing, 3-4 hours per day was associated with a 0.34 ($P<0.001$) higher BMI Z-score and with a 0.35 ($P<0.001$) higher WC Z-score.

Sensitivity Analyses

We repeated our analysis of accelerometry estimated MVPA and total SB using BMI Z-scores calculated using reference population data from the UK and the US. The MVPA and total SB associations remained similar to our findings that used internal means and standard deviations to calculate BMI Z-scores (Supplementary Table 2). We also repeated our analysis by sex, race and household income categories. The MVPA and total SB associations with BMI and WC Z-scores remained similar within each group (Supplementary Table 3). The WC Z-score associations remained similar with the NHANES data removed (Supplementary Table 4).

Discussion

This is the largest study to date to use standardized accelerometry methods and quantile regression to study the association between physical activity energy expenditure and childhood obesity. We found that more time spent in MVPA was independently associated with lower BMI and WC. In contrast, total SB was not independently associated with BMI or WC in our sample of children and adolescents. However, time spent in a specific leisure time SB, television viewing, was independently associated with higher BMI and WC. Interestingly, our quantile regression analysis revealed that the associations between MVPA, television viewing and BMI/WC Z-scores were non-linear; these exposures were most influential at the upper percentiles of the BMI and WC frequency distributions. These non-linear associations indicate that if more children were to meet the physical activity guidelines, and limit their television viewing hours, then the prevalence of childhood obesity could be reduced by specifically shifting the upper percentiles of the BMI and WC frequency distributions to lower values.

We have shown in previous U.S. based studies that lower accelerometry estimated MVPA and higher television viewing are associated with greater increases in BMI over time during childhood, and that these associations were strongest at the upper BMI percentiles (24, 26). These findings are consistent with our present results and together support that increasing MVPA and lowering television viewing could help to prevent childhood obesity, potentially by increasing energy expenditure and correcting energy imbalance. However, there are contrasting data suggesting that increases in weight status lead to lower MVPA and higher SB (21). We cannot rule out reverse-causality in our cross-sectional study. We also cannot rule out that a cyclical (bi-directional) relationship exists between physical activity energy expenditure and weight status. Indeed, the stronger association between MVPA and television viewing at the upper percentiles of the BMI/WC distributions could reflect such a cyclical relationship.

Alternatively, the stronger associations at the upper percentiles could be explained by gene-environment interactions. It is well known that BMI and WC are heritable traits and a large number of genetic loci are associated with higher BMI and WC (9). Specifically, individuals at the upper percentiles of the BMI and WC distributions are more likely to be genetically predisposed to obesity (26). If these individuals are exposed to lower MVPA or higher television viewing, then greater increases in their BMI/WC could be due to their genetic susceptibility to obesity, compared to those who are less likely to be genetically predisposed to higher BMI/WC at the lower percentiles of the distribution.

It has been proposed that SB, independent of time spent in MVPA, is an obesity risk factor. Studies that have estimated total SB using accelerometry have observed associations with measures of childhood obesity (10, 17, 19, 23, 24, 36), but such associations have tended not to hold after adjustment for MVPA (17, 19, 23, 36). We observed the same pattern in our study, suggesting that total SB is not an independent risk factor for childhood obesity. In contrast, there is convincing evidence that television viewing is associated with childhood obesity, independent of MVPA (13, 26, 35). Television viewing is the most common leisure time SB, but it is also a behavior associated with snacking and exposure to food advertisements (34). Therefore, the television viewing associations may not be fully explained by the SB-energy expenditure paradigm and could be partly explained by increases in energy intake. In addition, television viewing is the most common activity before going to bed (7), and our television viewing associations could be partly explained by reductions in total sleep time (26).

The strengths of our study include the large sample size and the standardized methods to estimate MVPA and total SB using accelerometry. Given the large sample size, we were able to perform sensitivity analyses and replicated our findings in key sub-groups. We used quantile regression and the advantages of this analytical approach are increasingly being recognized for investigating continuous variables in epidemiological studies (4). By using this method we observed stronger associations between MVPA, total SB (not independent of MVPA) and television viewing at the upper percentiles of the BMI and WC Z-score distributions; these patterns of association across the percentiles would have been missed had we modeled the mean Z-scores using linear regression. We used both BMI and WC as primary outcomes to make inferences on overall fat mass and visceral fat mass, and the latter is of particular clinical importance (2). Our study does have limitations. We adjusted for key confounders, but the ICAD database does not have dietary or sleep data to include as covariates. Also, given the populations of origin for this study a dichotomous race variable was used; it will be important to replicate our findings in more diverse populations. The majority (91%) of participants provide 3 or more days of valid accelerometry data. We included participants who provided 1 and 2 valid days accelerometry data and the MVPA and total SB estimates may not be representative of habitual patterns among these participants. We used a cross-sectional design and so were not able to establish the temporality between our exposures and Z-score outcomes.

Preventing childhood obesity has the greatest potential to counter the short and long-term health problems associated with obesity. We conclude that increasing MVPA and decreasing television viewing in childhood could help to prevent obesity in early life. By using quantile regression we showed that increasing the time children spend in MVPA and decreasing the time they spend watching television could help to lower BMI's and WC's, especially for children in the population with the higher BMIs and WCs for their age.

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Conflicts of Interest

The results of the present study do not constitute endorsement by ACSM

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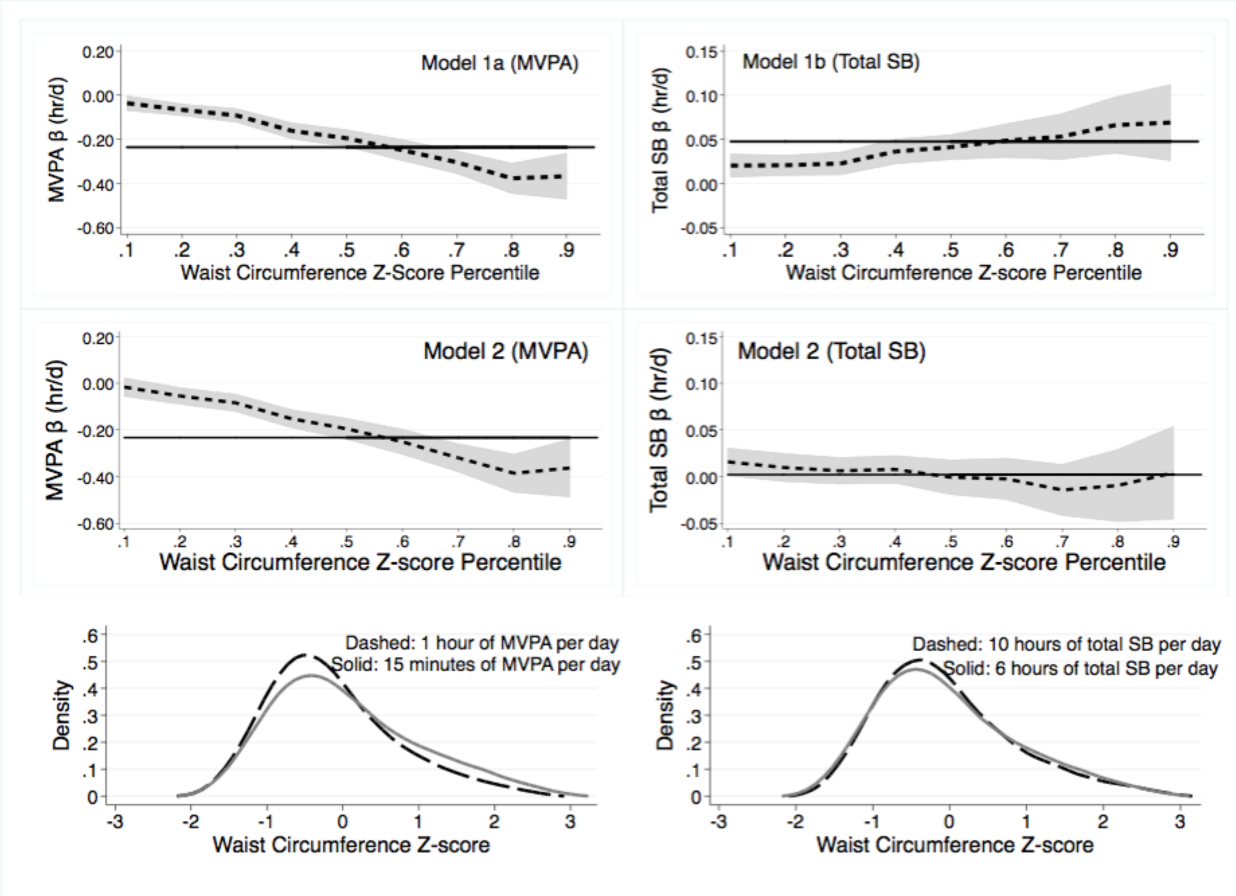

Figure 1. Illustration of the quantile regression associations between moderate-to-vigorous physical activity (MVPA, left column), total sedentary behavior (SB, right column) and waist circumference (WC) Z-scores. The quantile regression findings from model 1a and model 1b are presented in the top row; whereas the quantile regression findings from model 2 are present in the second row. MVPA is the primary predictor in model 1a and total SB is the primary predictor in model 1b; both models are adjusted for age, race, household income and accelerometer wear time. In model 2, MVPA and total SB are included as predictors in the same model along with age, race, household income and accelerometer wear time. For comparison, the horizontal black lines represent the linear regression coefficients for the change in mean WC Z-score per additional hour per day of MVPA or total SB. The distribution plots in the bottom row are derived from model 2.

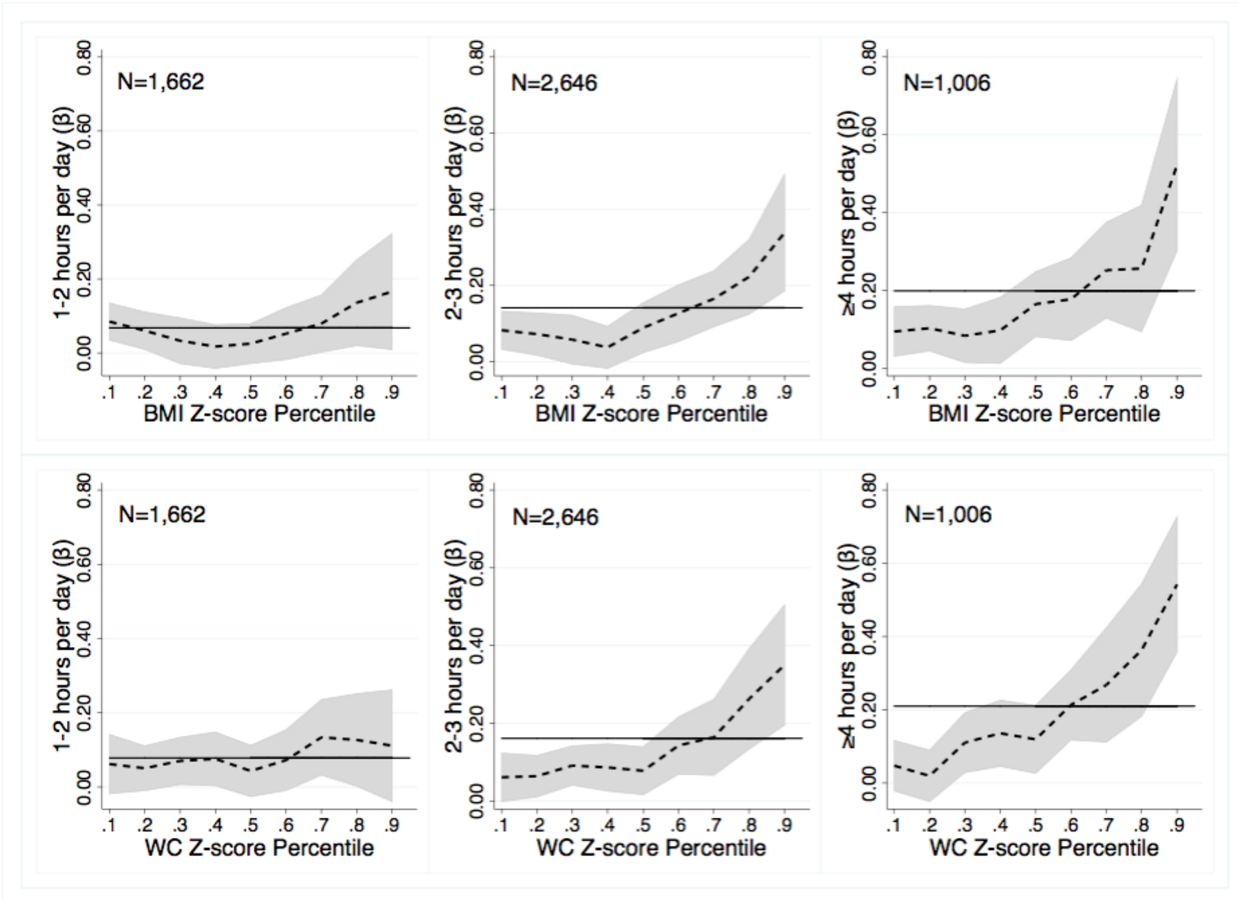

Figure 2. Television viewing associations with body mass index (BMI) Z-scores and waist circumference (WC) Z-scores using quantile regression. The <1 hour per day television viewing category is the referent group. The quantile regression models are adjusted for age, race, household income, moderate-to-vigorous physical activity, total sedentary behavior and accelerometer wear time. The horizontal black lines represent the linear regression coefficients for the change in mean BMI Z-scores and WC Z-scores for each television viewing category.

Supplemental Digital Content

Supplementary Table 1

Supplementary Table 2

Supplementary Table 3