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Relationship between TV watching during childhood and adolescence and fitness in adulthood in the Raine Study cohort

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Running Head: Impact of early-age TV watching on adult fitness

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ABSTRACT

To investigate: 1) whether TV watching habits throughout childhood and adolescence, a proxy of sedentary behavior, impacted cardiorespiratory fitness (CRF) in adulthood, and 2) whether any potential impact of TV watching in childhood and adolescence on CRF in adulthood was changed by adult physical activity (PA) levels.

A longitudinal study with questionnaire data available regarding TV watching collected at ages 5, 8, 10, 14, 17 and 20yrs, allowed trajectories of TV watching to be developed. At age 28yrs, participants completed a VO₂peak test and the International Physical Activity Questionnaire. General linear models tested for differences in CRF (time to exhaustion TTE and VO₂peak mL·kg⁻¹·min⁻¹) between TV watching trajectories. Secondary analysis tested the potential effect current PA levels has on the relationship between TV trajectory and fitness.

449 participants [male n=255 (56.8%), 28.3±0.5yrs; female n=194 (43.2%), 28.2±0.4yrs] were included in the study. Three distinct trajectories of TV watching were identified: High TV, Increasing TV and Low TV. CRF was lowest in the High TV watching trajectory and increased progressively from High to Increasing TV and Increasing to Low TV (all P<0.05). Within each of the TV trajectories, those engaging in high levels of current PA had greater CRF than those engaging in low and moderate PA.

TV watching in childhood and adolescence negatively impacts upon adult fitness at the age of 28 years. However, this negative impact of historical TV watching on CRF can largely be attenuated by engaging in higher levels of PA in adulthood.
Highlights

- High levels of TV watching during childhood and adolescence have negative downstream impacts on cardiorespiratory fitness in adulthood.

- Taking part in high levels of physical activity in adulthood partially reverses the negative impact of historical TV watching on adult fitness.

- Engaging in low levels of TV watching throughout childhood and adolescence does not protect individuals from the detrimental impact of low current physical activity levels.

- Our findings support important public health messages with relevance to parents, schools and government; to target low levels of sedentary time throughout the developmental years of life, whilst encouraging the adoption of regular physical activity across the lifespan including young adulthood.

**Keywords:** CARDIORESPIRATORY FITNESS, SEDENTARY BEHAVIOUR, PHYSICAL ACTIVITY, EXERCISE
1. Introduction

Extended periods of sedentary behavior (SB), characterized by lying or sitting and defined as <1.5 times resting energy expenditure, is highly prevalent in developed countries.\textsuperscript{1,2} This has been attributed to an increase in sedentary occupations, widespread presence of TV and screens in households and reduction in active travel.\textsuperscript{3,4} Evidence suggests that children and adolescents indulge in considerable screen time, and TV watching has been a valid proxy for overall SB.\textsuperscript{5} SB is now recognized as an independent risk factor for a variety of negative health outcomes.\textsuperscript{3,6-8} Recognizing the importance of reducing SB for health,\textsuperscript{9} contemporary physical activity (PA) guidelines place a strong emphasis on reducing overall sitting time throughout the day in children, adolescents and adults.\textsuperscript{10-12}

Cross-sectional studies suggest that, during childhood and adolescence, daily SB is inversely associated with fitness.\textsuperscript{13-15} This may have health implications, as the duration of TV watching throughout youth impacts indices of adult health, including body mass index, cholesterol and inflammatory profile.\textsuperscript{16,17} However, as TV watching may change over the course of the developmental years, it is currently unknown whether patterns of TV watching behavior characterized throughout childhood and adolescence impact cardiorespiratory fitness (CRF) in adulthood. It is also unclear whether any detrimental impacts of SB in childhood and adolescence on adult fitness can be modulated by engaging in PA as an adult.

A longitudinal study in Western Australia (The Raine Study) collected information related to TV watching over a 15 year period throughout childhood and adolescence; and sophisticated trajectories were recently developed from these repeated data to determine specific patterns of TV watching.\textsuperscript{18,19} The TV trajectories have been used in the past to identify an inverse relationship between TV watching between the ages of 5-20 years and bone mineral content.\textsuperscript{18} High TV watching was also related to poorer body composition at age 20yrs.\textsuperscript{19} The aims of this investigation were to: 1) test whether trajectories of TV watching throughout childhood and adolescence are associated with objectively measured CRF in adulthood; and 2) test whether any potential impact of TV watching in childhood and adolescence on adult fitness is changed by adult PA levels.
2. Material and methods

Participants were Generation 2 (Gen2) of the Raine Study, whose pregnant mothers were recruited between May 1989 and November 1991. The 2,868 babies entered into the study subsequently attended follow-ups throughout childhood and adolescence. Questionnaire data regarding time spent watching TV at 6 follow-ups has previously been used by our group to develop trajectories of TV watching in this cohort. This study utilized these trajectories, in combination with newly acquired measures of maximal CRF and PA to address our aims.

2.1. TV watching trajectories – historical data

When Gen2 participants were aged 5, 8 and 10 years, parents completed a questionnaire related to the length of time their child spent watching TV. At ages 14, 17 and 20 years, Gen2 participants completed their own questionnaire related to TV watching. A comprehensive description of the protocol used to develop these trajectories is available elsewhere. In brief, using TV watching at 5, 8, 10, 14, 17 and 20 years, a latent class analysis was conducted using an ordinal logit model including 200 random starts and 100 iterations (LatentGold Version 4.5, Statistical Innovations Inc, Belmont MA USA) to estimate trajectories of TV watching. Data from 2,411 participants was included in the trajectories and sex was a covariate in the models. This resulted in three distinct trajectory groups based on levels of TV watching: High TV (>14 hrs/wk), Low TV (<14 hrs/wk) and Increasing TV (change from Low to High TV during adolescence), see Supplementary Figure 1.

2.2. Graded exercise test in adulthood

At age 28 years (between March 2018 and December 2019; see Figure 1), 1,997 participants were contacted (in order of birth oldest – youngest) with an invitation to attend a follow-up appointment. Participants accepting the invitation attended the laboratory and had CRF measured by performing a graded exercise test (GXT) on a treadmill (ExciteMed, Technogym, Cesena, Italy) using a continuous, incremental protocol consisting of 3 minute stages. No specific warm-up was performed, as the protocol commenced with 4 walking stages with speed and gradient increasing every 3 minutes. The speed was then set to 8.0km/hr and increased 1.0km/hr every 3 minutes (with a fixed gradient of 10%) until volitional exhaustion. Oxygen consumption (\(\text{VO}_2\)) was measured breath-by-breath throughout using indirect calorimetry and averaged in 30sec epochs (ParvoMedics-TrueOne2400, Salt Lake City, UT, USA). Heart rate was monitored using a Polar H10 monitor (PolarElectro Oy, Kempele, Finland). For CRF data
to be included in the analysis, an observed plateau of heart rate despite increased work rate had to be met\textsuperscript{,21} with the highest 30sec \( \dot{VO}_2 \) value used as \( \dot{VO}_2 \text{peak} \) \textsuperscript{22}. The dependent variables used for analysis were \( \dot{VO}_2 \text{peak} \) (mL·kg\(^{-1}\)·min\(^{-1}\)) and physical performance in time to exhaustion (TTE).

### 2.3. Physical activity levels in adulthood

At the GXT appointment, participants were asked to complete the International Physical Activity Questionnaire (IPAQ). This was used to generate an overall PA category, using an established protocol\textsuperscript{,23} In brief, participants were asked the number of hours on a typical day they engaged in vigorous PA, moderate intensity PA, and walking, and the number of days per week this occurred. These data were used to group participants into PA categories: High PA (vigorous intensity PA on at least 3 days per week achieving 1,500 MET·mins\(^{-1}\) or weekly combination of walking, moderate and vigorous PA achieving more than 3,000 MET·mins·wk\(^{-1}\)); Moderate PA (achieving at least 30 minutes of vigorous PA on 3 or more days per week or walking 30 minutes per day 5 days a week achieving ~600 MET·mins·wk\(^{-1}\)); and Low PA (a score below that of the moderate PA category). Basic anthropometric measurements (height and weight) were also collected and these were used to calculate body mass index (BMI).

### 2.4. Ethical approval

This study conformed to the Declaration of Helsinki, was granted approval by The University of Western Australia Human Research Ethics Committee (approval #RA/4/20/1038) and all participants provided written, informed consent prior to participation. This paper adheres to the STROBE guidelines for reporting observational studies. The study size equates to the number of participants accepting the invitation to attend the 28 year follow-up appointment between March 2018 and December 2019. Participants without both TV trajectory and GXT data were removed from the analysis, and we have no reason to believe selection bias will be an issue in our study design. Raine Study participants have an active involvement in the planning of new projects, providing input regarding participant burden and participate on various Raine Study committees (e.g. Community Advisory Committee). Each participant was provided with their individual \( \dot{VO}_2 \text{peak} \) score and agreed to have their de-identified data collated with other participants' to be disseminated in scientific conferences and journal manuscripts.
2.5. Statistics

Statistics were completed using SPSS (Version 27, IBM Corp., Armonk, NY, USA) (with the exception of linear regression which was performed in Stata Version 15 (Stata Corp, College Station, TX, USA)) and significance was set at $P<0.05$.

Model 1: To determine the impact of SB throughout childhood and adolescence on adult fitness, a General Linear Model compared dependent variables from the GXT (TTE and $\dot{V}O_2$peak mL·kg$^{-1}$·min$^{-1}$) between trajectories of TV watching (weighted for probability of membership)$^{24,25}$ As differences in fitness between male and female participants are well-established$^{26}$ our model accounted for the effects of sex. Pairwise comparisons determined between group differences in CRF. Although sex was accounted for in our primary statistical model, we also performed a two-way ANOVA to test for TV trajectory*sex interaction effects, to determine whether the relationship between TV trajectory and fitness was different based on sex. In Model 1 and Model 2 analyses, BMI was included as a covariate when TTE was the dependent variable, but was not a covariate for $\dot{V}O_2$peak mL·kg$^{-1}$·min$^{-1}$ analyses, as weight was already accounted for in this outcome variable.

Model 2: To investigate whether the impact of childhood and adolescent TV trajectories on adult fitness were influenced by current (i.e. adult) PA, a linear regression was performed to test for TV trajectory*IPAQ category interaction effects. This included adjustment for the effects of sex. To further examine the potential influence of current PA on adult fitness, one-way ANOVA tests with Bonferroni adjustment were used to test for differences in fitness between IPAQ categories for each TV trajectory; and for differences in fitness between TV trajectories for each IPAQ category.

3. Results

Of the 1,997 participants that were contacted with an invitation to attend the follow-up appointment, 467 participants attended the laboratory to undergo a GXT. Data from 18 of these participants was removed from analysis, due to participants not meeting the criteria for a valid peak exercise test (i.e. sub-maximal). Therefore, 449 participants were suitable for inclusion in Model 1. Information detailing the number of participants at each stage of the study can be found in Figure 1. Descriptive data of participants included in Model 1 and Model 2 can be found in Table 1.
3.1. Model 1

Of the 449 participants in Model 1, trajectories comprised: High TV (M n=128, F n=83); Increasing TV (M n=96, F n=65) and Low TV (M n=31, F n=46), see Figure 1 and Table 1. There was a step-wise increase in CRF (TTE) from High TV to Low TV trajectories (High TV vs Increasing TV \( \Delta 0.8 \pm 0.3 \text{ min}^{-1}, P=0.020 \); Increasing TV vs Low TV \( \Delta 0.9 \pm 0.4 \text{ min}^{-1}, P=0.042 \); High TV vs Low TV \( \Delta 1.6 \pm 0.4 \text{ min}^{-1}, P<0.001 \), see Figure 2A). The trend for step-wise increases in CRF between trajectories were similar for \( \dot{V}O_2 \text{peak} \) (mL·kg\(^{-1}\)·min\(^{-1}\)), although not all between-group differences were statistically significant (High TV vs Increasing TV \( \Delta 1.8 \pm 0.9 \text{ mL·kg}^{-1} \cdot \text{min}^{-1}, P=0.057 \); Increasing TV vs Low TV \( \Delta 2.6 \pm 1.2 \text{ mL·kg}^{-1} \cdot \text{min}^{-1}, P=0.038 \); High TV vs Low TV \( \Delta 4.4 \pm 1.2 \text{ mL·kg}^{-1} \cdot \text{min}^{-1}, P<0.001 \), see Figure 2B).

There were no TV trajectory*sex interaction effects for TTE \( (P=0.146) \) or \( \dot{V}O_2 \text{peak} \) mL·kg\(^{-1}\)·min\(^{-1}\) \( (P=0.373) \) and visual inspection of male and female data separately indicated that the step-wise increase in fitness for each TV trajectory was similar for both sexes (data not shown).

3.2. Model 2

Of the 405 participants in Model 2, trajectories comprised: High TV (M n=116, F n=75); Increasing TV (M n=83, F n=58) and Low TV (M n=29, F n=44), see Figure 1 and Table 1. Linear regression indicated there were no significant interaction effects for TV trajectory*IPAQ category \( (F=2.76, P=0.064) \), indicating the way CRF was impacted by current PA was not different based on TV trajectory membership (see Figure 3).

When each TV trajectory was sub-divided by current PA, the proportion of participants within each IPAQ category (i.e. Low, Moderate and High PA) were similar across the 3 TV trajectories (see Fig 1).

Within the High TV trajectory, those engaging in High PA had greater CRF than those engaging in Low PA (TTE \( \Delta 2.6 \pm 0.5 \text{ min}^{-1}, \dot{V}O_2 \text{peak} \Delta 6.8 \pm 1.6 \text{ mL·kg}^{-1} \cdot \text{min}^{-1}, \) both \( P<0.001 \)) and Moderate PA (TTE \( \Delta 1.9 \pm 0.5 \text{ min}^{-1}, \dot{V}O_2 \text{peak} \Delta 6.0 \pm 1.5 \text{ mL·kg}^{-1} \cdot \text{min}^{-1}, \) both \( P<0.001 \), see Fig 3).

Within the Increasing TV trajectory, those engaging in High PA had greater CRF than Low PA (TTE \( \Delta 3.2 \pm 1.0 \text{ min}^{-1}, P=0.036; \dot{V}O_2 \text{peak} \Delta 8.7 \pm 2.9 \text{ mL·kg}^{-1} \cdot \text{min}^{-1}, P=0.017 \) and greater
TTE than Moderate PA (TTE $\Delta 1.4 \pm 0.9$ min$^{-1}$, $P=0.038$; $\dot{V}O_2$peak $\Delta 4.2 \pm 2.5$ mL$\cdot$kg$^{-1}$$\cdot$min$^{-1}$, $P=0.142$), see Fig 3.

Within the Low TV trajectory, those engaging in High PA had greater CRF than Low PA (TTE $\Delta 2.5 \pm 1.0$ min$^{-1}$, $P=0.033$; $\dot{V}O_2$peak $\Delta 6.9 \pm 2.6$ mL$\cdot$kg$^{-1}$$\cdot$min$^{-1}$, $P=0.028$). There were no significant differences between High PA and Moderate PA (TTE $P=0.455$; $\dot{V}O_2$peak $P=0.286$), or between Moderate PA and Low PA (TTE $P=0.763$; $\dot{V}O_2$peak $P=0.983$) see Fig 3. Within each IPAQ category, there were no significant differences in CRF between the three TV trajectories (all $P>0.050$).

4. Discussion

We provide novel evidence suggesting the extent to which individuals watch TV throughout childhood and adolescence predicts CRF, an independent predictor of mortality, in adulthood. Our data suggests the impact of TV watching during childhood and adolescence on adult CRF is largely negated by current PA levels in adulthood. The negative impact of high SB in childhood and adolescence was not present in those engaging in higher PA levels as an adult, whilst the legacy impact of low TV viewing does not protect individuals from the detrimental impact of low current PA levels.

Cross-sectional studies in young participants have demonstrated a link between TV watching, health and CRF. This includes correlations between TV viewing time and the presence of inflammatory markers$^{13}$ and higher metabolic risk profiles,$^{28}$ and inverse relationships between TV watching time and exercise performance.$^{13,14}$ We present evidence that patterns of TV watching in childhood and adolescence may also extend to impact upon CRF in adulthood. Few previous longitudinal studies have investigated the impact of legacy behaviors on adult CRF. Two previous publications,$^{16,29}$ derived from a cohort study in New Zealand, measured TV viewing by questionnaire between the ages of 5 and 15 years and calculated a composite TV viewing time in hours per week throughout that period.$^{16}$ They reported that, at age 26yrs and 32yrs, fitness estimated from a submaximal cycle test was greater in those reporting less than 2hrs of TV per day compared to more than 3hrs. These findings are in line with our own, but they did not report CRF levels with reference to TV viewing time. Other strengths of our study are that we exercised participants to volitional exhaustion and directly measured $\dot{V}O_2$peak, and our trajectory analysis allowed groups to be identified based on patterns of TV
watching over time. We also report the impact of adult PA levels on the relationship between historical SB and adult levels of fitness. Taken together, these data are consistent in suggesting a deleterious impact of high levels of screen time in childhood and adolescence on CRF in adulthood.

To investigate the potential influence current PA levels may have on CRF, we sub-divided TV trajectories according to current PA levels (i.e. PA category derived from IPAQ). This approach (see Figure 3) consistently illustrated that, regardless of TV trajectory membership, participating in high levels of PA had positive impacts on CRF compared to engaging in low or moderate levels of PA. This indicates that the apparent detrimental effect of legacy SB on CRF can be at least partly mitigated by participating in high levels of PA in adulthood. CRF is a physiological capacity, partly determined by genetic predisposition, but it is also impacted by environmental factors and it is therefore unsurprising that participating in high levels of PA was associated with greater CRF across all groups. Our data suggests: i) the proportion of participants in each PA category was similar between the TV trajectories, indicating that high levels of SB throughout childhood and adolescence does not infer low levels of PA in adulthood; or vice versa, and ii) the negative impact of legacy SB on adult CRF was still apparent, despite the relative number of participants within each PA category being similar for each TV trajectory. This second point suggests that current PA was unable to fully negate the impact of SB in childhood and adolescence on adult CRF; otherwise we would not have observed differences in CRF between TV trajectories (model 1). In any case, our findings provide a positive message for individuals who may have engaged in high levels of SB earlier in life; that the adoption of PA in adulthood results in significant benefits in terms of CRF, and by extension health. Indeed, previous research suggests that high levels of PA can mitigate the negative influence of SB on all-cause mortality. Our study included relatively young participants and was not designed to address clinical end-points, but we provide novel evidence that engaging in high levels of PA in adulthood can partly mitigate the negative impact that high levels of SB in youth has on CRF.

The predominantly Caucasian participants in our study had CRF similar to those in the U.S. and Canada. As in other cohorts, the proportion of consistently high SB throughout childhood and adolescence in the Raine Study (i.e. High TV trajectory) accounted for nearly 50% of the sample, with only 17% in the Low TV trajectory. Collectively, this suggests that our population and findings are likely to be broadly applicable to other Western countries. This
highlights the need for a two-pronged approach to optimizing health, by reducing the high prevalence of SB, whilst encouraging the uptake and maintenance of higher levels of PA in adulthood and across the lifespan.

A strength of this study is the repeated follow-up data gathered over a 15 year period in childhood and adolescence, in combination with the objectively measured peak CRF in adulthood. Although we provide evidence of the relationships between SB, TV watching, and CRF in adulthood, there are limitations. Firstly, of the 2,411 participants originally included in the TV trajectories, only 449 participants were included in this study. However, we have no reason to believe this resulted in selection bias in our sample or results; as the percentage of participants in each TV trajectory were similar to those in the entire cohort.\textsuperscript{18} Likewise, when TV trajectories were sub-divided based on current PA levels, the proportion in each IPAQ category was similar between TV trajectories. Secondly, a questionnaire was used to measure current PA levels and this may be less robust than objective devices to measure PA. However, the consistency of our findings around the moderating effect of current PA on CRF indicates the IPAQ was an adequate tool to test our hypotheses. Finally, whilst this study provides insight suggesting a link between TV watching in childhood and adolescence and adult CRF, it is an observational study and conclusions related to causality must be treated cautiously. The TV trajectory\textsuperscript{18,19} and CRF data included in this study provide baseline data that can be used in future to determine whether early life SB, and CRF in early adulthood, are predictive of health outcomes in later life.

5. Conclusion

This study provides evidence that SB in youth has legacy impacts on CRF, at age 28 years. Participation in PA as an adult is also important, as we found a clear effect of higher levels of PA on CRF across each of the TV trajectories. As CRF is a strong independent predictor of all-cause and cardiovascular mortality in adults,\textsuperscript{27} our data support recommendations to limit sedentary time (such as screen time) in youth and to achieve and maintain a physically active lifestyle in adulthood.\textsuperscript{10,11}
Acknowledgements

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Authors’ contributions
DJG, PRE, LS, TAM and LB secured funding for the data collected at age 28yrs. AH led the collection of adult follow-up data. LS and JM led the development of TV watching trajectories. AH, JM, and DJG led the analysis and interpretation of the data and initial development of the manuscript and LL provided additional statistical support. All authors guided the design of the study, including reviewing, editing and approving the final version of the paper.

Disclosure statement
The authors declare that they have no competing interests.

Data availability statement
The data that supports the findings of this study are held on the Raine Study database and enquiries related to access can be made by email: rainestudyscience@uwa.edu.au

References


Figure Legend

**Figure 1.** Diagram detailing the number of participants included at each stage of the study.
ORIGINAL COHORT MEMBERS

Total: (n = 2,868)

n = 457 excluded due to no TV trajectory data.

PARTICIPANTS INCLUDED IN TV TRAJECTORIES

Total: (n = 2,411)
High TV (n = 1,142, 47.4 %)
Increasing TV (n = 913, 37.9 %)
Low TV (n = 356, 14.7 %)

n = 414 not contacted.

PARTICIPANTS INVITED TO ATTEND FOLLOW-UP

Total: (n = 1,997)
Participants Accepting (n = 467, 23.4 %)
Participants Declining (n = 1,530, 76.6 %)

n = 18 of participants accepting invitation were excluded due to not reaching maximal effort on GXT.

n = 1,530 declined invitation.

INCLUDED IN MODEL 1

Total: (n = 449)
High TV (n = 211, 47.0 %)
Increasing TV (n = 161, 35.9 %)
Low TV (n = 77, 17.1 %)

n = 44 excluded as did not complete IPAQ.

INCLUDED IN MODEL 2

Total: (n = 405)

High TV (n = 191, 47.2 %)
Increasing TV (n = 141, 34.8 %)
Low TV (n = 73, 18.0 %)

Low PA
(n = 46, 24.1 %)
Mod PA
(n = 60, 31.4 %)
High PA
(n = 85, 44.5 %)

Low PA
(n = 27, 19.1 %)
Mod PA
(n = 52, 36.9 %)
High PA
(n = 62, 44.0 %)

Low PA
(n = 21, 28.8 %)
Mod PA
(n = 23, 31.5 %)
High PA
(n = 29, 39.7 %)
Figure 2. Peak exercise test results (time to exhaustion (panel A) and volume of oxygen per minute (\(\dot{V}O_2\)) relative to bodyweight (panel B) of participants according to TV watching trajectories. Analysis adjusted for the effects of gender and data are estimated means \(\pm\) SEM derived from general linear model with pairwise comparison results indicating differences in fitness between TV trajectories. * denotes significance at \(P<0.050\) and ** denotes significance at or below \(P=0.001\).

![Graph showing time and \(\dot{V}O_2\) for different TV watching trajectories.]

Figure 3. Peak exercise test results (time to exhaustion (panel A) and volume of oxygen per minute (\(\dot{V}O_2\)) relative to bodyweight (panel B) of participants according to Physical Activity (PA) levels for each TV trajectory. Results are differences in fitness between PA categories within each TV trajectory, derived from one-way ANOVA tests with Bonferroni correction. *
denotes significance at \( P<0.050 \) and ** denotes significance at or below \( P=0.001 \). Mod PA is Moderate PA.

**Supplementary Figure 1.** Trajectory classes derived from latent class analysis, illustrating patterns of TV watching (mean duration hrs/wk) measured at 6 follow-ups over a 15 year period.
Table 1. Participant Descriptive Data

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<th>Model 1</th>
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<th>Model 2</th>
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<td>High TV</td>
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General descriptive data (Body Mass Index BMI) of participants included in Model 1 and Model 2. Participants are grouped by trajectories of TV watching during childhood and adolescence.