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Association of change in the school travel mode with changes in different physical activity intensities and sedentary time: A International Children's Accelerometry Database Study

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ABSTRACT

Our aim was to assess the association between changes in active travel to school and changes in different intensities of physical activity (i.e. moderate - MPA and vigorous - VPA) and time spent sedentary (SED) among adolescents and assess the moderating effect of children's sex, age and weight status. Data from six cohort studies in the International Children's Accelerometry Database were used (4108 adolescents aged 10–13y at baseline, with 1.9±0.7y of follow-up). Participants self-reported travel mode to school at baseline and follow-up. Mutually exclusive categories of change were created using passive (e.g. by car) or active (cycling or walking) forms of transport (active/active, passive/active, active/passive, passive/passive). Multilevel linear regression analyses assessed associations with change in accelerometer-assessed time spent MPA, VPA and SED, adjusting for potential confounders. The moderation of sex, age and weight status was tested though the inclusion of interaction terms in the regression models. Relative to those remaining in active travel (active/active), participants classified as passive/active increased VPA (*B*: 2.23 min/d; 95%CI: 0.97–3.48), while active/passive (MPA: −5.38min/d; −6.77 to −3.98; VPA: −2.92min/d; −4.06 to −1.78) and passive/passive (MPA: −4.53min/d; −5.55 to −3.50; VPA: −2.84min/d; −3.68 to −2.01) decreased MPA and VPA. There were no associations with SED. An interaction was observed, age group moderated the association with change in VPA: among 12–13y-olds a greater increase in VPA was observed for the passive/active group compared to active/active. Promoting active travel to school can be a strategy to attenuate the decline in physical activity through adolescence.

1. Introduction

High levels of physical activity and low sedentary behavior are protective factors for several negative health outcomes during adolescence, including cardiovascular risk factors (Júdice et al., 2020; Renninger et al., 2020; Werneck et al., 2020) and mental health-related outcomes (Rodriguez-Ayllon et al., 2019). Specifically, the association between physical activity and health outcomes changes according to the intensity of physical activity, with higher intensities as moderate and, especially, vigorous presenting stronger associations with

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cardiovascular health (Aadland et al., 2020; Werneck et al., 2020). However, the prevalence of physical inactivity (insufficient levels of moderate-to-vigorous physical activity) and elevated sedentary time is high worldwide, with approximately 80% of adolescents being classified as inactive and more than 30% spending in excess of 3h/day of sitting time (Cooper et al., 2015; Guthold et al., 2020; Vancampfort et al., 2018). In addition, physical activity levels decline throughout adolescence, while sedentary behavior increases (Cooper et al., 2015).

Most previous intervention studies to promote physical activity in young people have focused on leisure-time physical activity or in school settings. These interventions have had limited effect on physical activity behaviour and faced implementation challenges (Dobbins et al., 2013; Love et al., 2019). Active travel to school may have the potential to increase overall physical activity to recommended levels and could be a complementary strategy (Aparicio-Ugarriza et al., 2020; Chillón et al., 2012; Salway et al., 2019; Smith et al., 2012; van Sluijs et al., 2009). Beyond the potential impact on habitual physical activity levels, active travel to school is also aligned to strategies aiming to decrease the use of motorized transport, contributing to reductions of greenhouse gas emissions and also different health outcomes due to the consequential reductions in air pollution (Bearman and Singleton, 2014).

Previous research investigating the association between active travel to school and device-measured physical activity and sedentary behavior has been mostly cross-sectional (Aparicio-Ugarriza et al., 2020; Barranco-Ruiz et al., 2018; Cooper et al., 2005; Kek et al., 2019; van Sluijs et al., 2009). Prospective studies investigating the association between change in school travel mode and device-measured physical activity and sedentary behavior have found a change of passive to active travel to school was positively associated with change in MVPA (Dalene et al., 2018; Larouche et al., 2014; Smith et al., 2012) and inversely associated with after-school sedentary time (SED) (Atkin et al., 2016). However, the association between change in school travel mode and different intensities of physical activity is still lacking, especially in multi-country studies, considering that travel mode to school varies by country (Kleszczewska et al., 2020). The investigation of the association between changes in active travel to school and intensities of physical activity can help the comprehension of how changes in active transportation could change the dynamics of physical activity as a whole, having in mind that there may be compensatory effects in other domains (Panter et al., 2011).

Sex, age, and weight status are cross-sectionally and prospectively associated with device-measured physical activity (Cooper et al., 2015; Jago et al., 2020). Consequently, it is possible that changes in active travel to school could have a greater contribution to changes in device-measured physical activity in the specific groups with lower physical activity practice, as among girls, older adolescents and adolescents with overweight/obesity (Cooper et al., 2015; Jago et al., 2020). Therefore, we aimed to:

1) Analyze the association between changes in active travel to school with changes in different intensities of physical activity and SED among adolescents;
2) Analyze the moderation effect of sex, age and weight status in this association;
3) Assess the probability of reaching 60 min/d of MVPA during the follow-up by change in travel to school.

2. Methods

2.1. Design and sample

The International Children's Accelerometry Database (ICAD) (http://www.mrc-epid.cam.ac.uk/research/studies/icad) has the aim of pooling data from studies with accelerometer-assessed physical activity conducted among children and adolescents worldwide. More information about the study process has been previously described (Sherar et al., 2011). Briefly, the dataset has pooled objectively measured ActiGraph accelerometer data (ActiGraph, LLC, Pensacola, Florida). When available, data of sociodemographic, anthropometric, and cardiometabolic factors were also harmonised. Participant ages ranged from 3 to 18 years, from 20 studies worldwide, including cross-sectional, longitudinal and interventional studies. For the present study, we used data from ICAD 2.0 from six longitudinal studies from four countries: Sport, Physical Activity and Eating Behaviour: Environmental Determinants in Young people - SPEEDY (England), Personal and Environmental Associations with Children's Health - PEACH (England), Avon Longitudinal Study of Parents and Children - ALSPAC (England), Children Living in Active Neighbourhoods - CLAN (Australia) Denmark European Youth Heart Study - EYHS Denmark (Denmark), Kinder-Sportstudie Study - KISS (Switzerland).

Due to the greater declines in physical activity occurring after 10 years of age (Cooper et al., 2015), we only considered children aged between 10 and 17 years. Also, we only included participants with valid accelerometer data and data on active travel to school at two time points. The analysis sample comprised 4108 adolescents (2289 girls, 56%) between 10 and 13 years during the baseline: SPEEDY (n = 485), PEACH (n = 416), ALSPAC (n = 2704), CLAN (n = 283), EYHS Denmark (n = 48), KISS (n = 172).

2.2. Active travel to school

Active travel to school was assessed in different studies through questions asking about mode and duration of travel to school. To harmonize different studies, in the studies that allowed the participants to select more than one travel mode (mixed transportation), we considered the reported predominant travel mode and classified travel to school as either active (walking or cycling) or passive (e.g. by bus, car, public transport or motorcycle depending of the survey) in both waves of each study (Jago et al., 2020; Yang et al., 2014). For our final indicator of active travel to school patterns over time, we classified individuals into four mutually exclusive patterns: 1) consistent active travel (active/active), 2) changed from passive to active travel (passive/active), 3) changed from active to passive travel (active/passive), 4) consistent passive travel (passive/passive). Further details on the harmonization process are presented in the Supplementary Text 1.

2.3. Device-measured physical activity and sedentary time

To harmonize data processing ICAD reanalyzed accelerometer data using 60 second epochs during daytime (6 am–11 pm). Non-wear time was considered as 60 min of consecutive zeros with tolerance of 2 min of non-zero epochs (Sherar et al., 2011). Also, aiming to minimize missing data, we adopted the cutoff point of 500 minutes per day as a valid day of measurement and a minimum of one valid weekday per week (Migueles et al., 2017). We conducted a sensitivity analysis only including participants with at least three valid accelerometer days, including at least one weekend day at both time points, aiming to test if the inclusion of participants with less valid days changed the results. To classify intensities of physical activity, we used the cutoff points suggested by Evenson et al. (Evenson et al., 2008). A detailed description of how physical activity measures were pooled has been described previously (Sherar et al., 2011). We used the difference between baseline and follow-up (in min/day) of SED, moderate (MPA), vigorous (VPA) and MVPA as our indicators. We also categorized MVPA using the cutoff point of an average of 60 min/d over the valid days (World Health Organization, 2020).

2.4. Covariates

Age at baseline assessment (10–11 and 12–13 years), study (when appropriate), country, change in the accelerometer wear time, baseline body mass index z-score, follow-up duration (individual-based time in years between the baseline and follow-up) and mother's academic achievement were used as confounders. Body mass index (BMI) was estimated from measured height (in meters) and body mass (in kilograms) in all studies. For continuous analysis, BMI was transformed into age and gender specific z-scores according to the calculation proposed by Cole et al. (1995), using the charts from the World Health Organization (de Onis, 2007). For the categorial analyses, BMI was classified (creating weight status) according to standardized cut-off points, which consider the classification according to the distribution of the population according to age and gender, classifying the participants as with normal weight, overweight or obesity (Cole, 2000). Mother's academic achievement was classified as any post-compulsory education including vocational training up to and including completion of compulsory education. Further details of the harmonization of mother's academic achievement are presented in Supplementary Text 2.

2.5. Statistics

All analyzes were conducted in Stata 15.1. Characteristics of the sample were described using frequencies and proportions or means and standard deviations as appropriate. The outcomes were tested for normality and presented normal distribution. Multivariate analysis of covariance through the Wilks' lambda test was used to compare shift in the differences of physical activity intensities and SED over time according to travel to school patterns overtime. Multilevel linear regression models (study and individual level), including random effects, were created to analyze the association between change in travel to school patterns overtime and change in different intensities of physical activity and SED, adjusting for the baseline of the outcome (e.g. SED at baseline for Δ SED analysis), change in the wear time in model 1 and additionally for sex, age, weight status, mother's education, country and follow-up length in model 2. Interaction terms for sex, age group (10–11 or 12–13 years) and weight status were included subsequently in model 2 to estimate a potential moderating effect.

We conducted five sensitivity analyzes. The first, analysed the associations by cohort using linear regression models to explore whether the associations are different in the different studies. The second was including only participants with passive travel to school at baseline, comparing those maintaining passive travel to school with those taking up active travel over time. This analysis contributes to explore how taking up passive active transport can affect device-measured physical activity. The third was only including participants with at least three valid accelerometer days, including at least one weekend day at both time points, which is the traditional inclusion criteria for accelerometer studies (Migueles et al., 2017). The fourth was not including adolescents reporting cycling to school, considering that cycling is not fully registered by accelerometers placed at hip (Slootmaker et al., 2009). The fifth was stratifying the sample according to follow-up length ($<$ 2 years of follow-up or $\geq$ 2 years of follow-up), aiming to explore possible long-term associations.

Lastly, we used multilevel logistic regression to estimate the probability of reaching the recommendations (60 min of MVPA per day), according to the change in transport modes being active/active, passive/active, active/passive or passive/passive.

3. Results

Table 1 presents the characteristics of the analysis sample. Compared with participants who were excluded (n = 2185), the proportion of girls (Included: 55.7% vs. Excluded: 50.9%) and participants aged 10–11 years (Included: 62.4% vs. Excluded: 58.7%) were slightly higher (Supplementary Table 1). The proportion of mothers with post-compulsory education was similar (included: 71.7%; excluded: 72.0%; n = 951). At baseline, participants with consistent passive travel (SED: 367.7±74.2; MPA:35.3±15.1; VPA:14.0±11.3; MVPA:49.3±23.9) presented similar SED, but lower MPA, VPA and MVPA than the consistent active travel (SED: 391.3±128.1; MPA:42.7±16.9; VPA:17.0±12.8; MVPA:59.6±26.8), taking up active travel (SED: 352.2±77.6; MPA: 37.6±15.6; VPA:14.8±11.9; MVPA:52.4±24.8) and taking up passive travel groups (SED: 361.0±78.4; MPA:39.4±15.8; VPA:16.1±12.4; MVPA:55.5±25.8). Overall, over the 1.9 (SD: 0.7) years of follow-up time spent in SED increased while time spent MPA and MVPA decreased, no change was observed for VPA (Table 1).

The distributions of the change of SED and physical activity intensity according to mode of travel to school over time are presented in Table 2. The distribution pattern of physical activity intensities changed according to the travel to school patterns (Wilks' lambda = 0.963, p < 0.001). Participants with consistent active travel (change SED: 36.09±101.29 min/d; MPA: −3.32±17.97; VPA: 0.16±13.86) and those taking up active travel (SED: 48.74±82.07; MPA: −0.57±16.97; VPA: 4.15±15.24) to school had a lower increase in SED, lower declines or

Table 1
Characteristics of the sample (n = 4108).

Variables	Mean/n (%/SD)
Country, %	
UK	3605 (87.8)
Australia	283 (6.9)
Denmark	48 (1.2)
Switzerland	172 (4.2)
Age (baseline), y	11.5 (0.6)
Age-group (10–11), %	2565 (62.4)
Follow-up length, y	1.9 (0.7)
Sex (girls)	2289 (55.7)
Body mass index, z-score	0.4 (1.2)
Weight status, %	
Normal	3274 (79.7)
Overweight	687 (16.7)
Obesity	147 (3.6)
Mother's academic achievement (any post-compulsory education), %	2945 (71.7)
Active travel to school patterns (Baseline/follow-up), %	
Active/Active	1524 (37.1)
Passive/Active	409 (10.0)
Active/Passive	552 (13.4)
Passive/Passive	1623 (39.5)
Sedentary time at baseline, min/day	374.0 (99.4)
Moderate physical activity at baseline, min/day	38.8 (16.3)
Vigorous physical activity at baseline, min/day	15.5 (12.2)
Moderate-to-vigorous physical activity at baseline, min/day	54.3 (25.8)
At least 60min/d of moderate-to-vigorous physical activity at baseline, %	1466 (35.7)
Δ Wear time, min/day	−1.9 (100.7)
Δ Sedentary time, min/day	44.5 (93.8)
Δ Moderate physical activity, min/day	−4.0 (16.8)
Δ Vigorous physical activity, min/day	0.2 (13.5)
Δ Moderate-to-vigorous physical activity, min/day	−3.8 (26.2)

Note. Values are described using absolute and relative frequencies or means and standard deviation.

Table 2
Distribution of the change in physical activity intensities and sedentary time according to active travel to school patterns across the waves 1 and 2 (n = 4108).

Active travel to school patterns (Baseline/follow-up)	Δ Sedentary time Mean ±	Δ Moderate PA Mean ±	Δ Vigorous PA Mean ±
Active/Active	36.09 ± 101.29	−3.32 ± 17.97	0.16 ± 13.86
Passive/Active	48.74 ± 82.07	−0.57 ± 16.97	4.15 ± 15.24
Active/Passive	51.36 ± 93.16	−7.04 ± 16.67	−1.65 ± 12.96
Passive/Passive	48.93 ± 88.73	−4.51 ± 15.51	−0.16 ± 12.72

Note. Values of change in physical activity intensities and sedentary time represents min/day. Wilks' lambda = 0.963, p < 0.001. The multivariate analysis of covariance included sex, age, weight status, mother's academic achievement, country, study, follow-up length, change in wear time and baseline values of sedentary time, moderate physical activity and vigorous physical activity. PA, physical activity.

even increases in MPA as well as a slight increase in VPA. Participants taking up passive travel (SED: 51.36±93.16; MPA: −7.04±16.67; VPA: −1.65±12.96), and those with consistent passive travel to school (SED: 48.93±88.73; MPA: −4.51±15.51; VPA: −0.16±12.72) presented greater increases in the SED and higher declines in MPA and VPA.

Table 3 shows the association between change in travel mode to school with device-measured SED and physical activity intensities. Fully adjusted models showed that taking up active travel was associated with an increase of 2.23 min/day in VPA (*B*: 2.23; 95%CI: 0.97–3.48) when compared with consistent active travel. On the other hand, participants taking up passive travel and participants with consistent passive travel to school reduced both their MPA and VPA. The findings of the greater reductions of MPA and VPA among participants with consistent passive travel or taking up passive travel were consistent across the cohorts, with small variations (Supplementary Table 2 for analyses by cohort). Considering only participants with passive travel to school during the baseline, taking up active travel was associated with increases in both MPA (*B*: 5.05; 95%CI: 3.60–6.50), VPA (*B*:4.85; 95%CI: 3.61–6.08) and MVPA (*B*: 9.85; 95%CI: 7.55–12.14) (Supplementary Table 3). Sensitivity analyses restricting participants to those with at least three valid accelerometer days, including one weekend day at both time points, and excluding participants reporting cycling gave similar results (Supplementary Tables 4 and 5, respectively). Also, the associations were consistent across shorter and longer follow-up lengths (Supplementary Table 6).

The interactions between sex, age group and weight status and active travel to school patterns associated with changes in device-measured SED and physical activity intensities are presented in Table 4. There was no evidence of effect modification by sex or weight status. However, in older participants taking up active travel was associated with increases in VPA when compared with younger participants, with consistent active travel (*B*: 3.06; 95%CI: 0.46–5.65). Stratified analyses revealed that both younger and older participants taking up passive travel (10–11y: *B:* −2.92; 95%CI: -−4.30 to −1.54. 12–13y: *B:* −2.92; 95%CI: −4.91 to −0.92) as well as with consistent passive travel (10–11y: *B:* −2.81; 95%CI: −3.84 to −1.78. 12–13y: *B:* −2.67; 95%CI: −4.08 to −1.27) decreased VPA compared with those remaining active travelers. However, taking up active travel was associated with a greater increase in VPA only among older adolescents (10–11y: *B:* 1.17; 95%CI: −0.34–2.69. 12–13y: *B:* 4.11; 95%CI: 1.92–6.29).

Fig. 1 presents the association between change in travel mode to school and meeting the recommendations of MVPA at follow-up. Compared with the consistently active group, those taking up passive travel (OR: 0.48; 95%CI: 0.37, 0.61) and participants with consistent

Table 3
Multilevel linear regression of the association between active travel to school patterns across waves and different intensities of physical activity and sedentary time (n = 4108).

Active travel to school patterns (Baseline/follow-up)	Δ Sedentary time *B* (95%CI)	Δ Moderate PA *B* (95%CI)	Δ Vigorous PA *B* (95%CI)	Δ Moderate-to-vigorous PA *B* (95%CI)
Model 1				
Active/Active	REF	REF	REF	REF
Passive/Active	−3.64 (−11.85 to 4.56)	0.91 (−0.64 to 2.46)	2.29 (1.02 to 3.56)	3.34 (0.90 to 5.78)
Active/Passive	3.52 (−3.98 to 11.02)	−5.28 (−6.70 to −3.87)	−2.91 (−4.07 to −1.75)	−8.12 (−10.35 to −5.90)
Passive/Passive	4.84 (−0.60 to 10.28)	−4.37 (−5.42 to −3.33)	−2.92 (−3.77 to −2.08)	−7.08 (−8.72 to −5.45)
Model 2				
Active/Active	REF	REF	REF	REF
Passive/Active	−4.07 (−12.16 to 4.02)	0.63 (−0.90 to 2.15)	2.23 (0.97 to 3.48)	2.95 (0.56 to 5.34)
Active/Passive	2.95 (−4.44 to 10.34)	−5.38 (−6.77 to −3.98)	−2.92 (−4.06 to −1.78)	−8.26 (−10.44 to −6.08)
Passive/Passive	3.32 (−2.04 to 8.69)	−4.53 (−5.55 to −3.50)	−2.84 (−3.68 to −2.01)	−7.26 (−8.87 to −5.66)

Note. Model 1 is adjusted for change in wear time and baseline values of the outcome (e.g. sedentary time during baseline for Δ Sedentary time analysis). Model 2: Model 1 + sex, age, weight status, mother's academic achievement, country (all during the baseline) and follow-up length. PA, physical activity. *B*, unstandardized coefficient. CI, confidence interval.

Table 4
Beta coefficients of the interactions between active travel to school patterns across waves and covariates (sex, age group and weight status) with different intensities of physical activity and sedentary time (n = 4108).

	Δ Sedentary time *B* (95%CI)	Δ Moderate PA *B* (95%CI)	Δ Vigorous PA *B* (95%CI)	Δ Moderate-to-vigorous PA *B* (95%CI)
Active travel to school patterns * sex interaction (active/active and boys as reference)				
Passive/Active + Girl	−6.37 (−22.37 to 9.64)	−0.16 (−3.17 to 2.85)	0.80 (−1.67 to 3.28)	0.61 (−4.11 to 5.33)
Active/Passive + Girl	5.83 (−8.45 to 20.12)	0.19 (−2.50 to 2.88)	−0.49 (−2.70 to 1.72)	−0.36 (−4.57 to 3.86)
Passive/Passive + Girl	2.95 (−7.38 to 13.27)	−0.27 (−2.21 to 1.67)	−0.55 (−2.14 to 1.05)	−0.83 (−3.88 to 2.21)
Active travel to school patterns * age group interaction (active/active and 10-11 as reference)				
Passive/Active + 12-13	5.56 (−11.21 to 22.33)	0.13 (−3.03 to 3.29)	3.06 (0.46 to 5.65)	2.96 (−1.99 to 7.91)
Active/Passive + 12-13	3.96 (−11.02 to 18.93)	1.88 (−0.93 to 4.69)	0.44 (−1.88 to 2.75)	2.41 (−2.01 to 6.82)
Passive/Passive + 12-13	−4.53 (−15.34 to 6.27)	1.71 (−0.31 to 3.73)	0.27 (−1.40 to 1.94)	2.05 (−1.13 to 5.24)
Active travel to school patterns * weight status interaction (active/active and normal weight as reference)				
Passive/Active + overweight/obese	2.01 (−17.33 to 21.36)	0.50 (−3.14 to 4.14)	−2.80 (−5.79 to 0.19)	−2.29 (−8.00 to 3.41)
Active/Passive + overweight/obese	1.80 (−16.31 to 19.91)	1.20 (−2.20 to 4.61)	0.91 (−1.89 to 3.71)	2.13 (−3.20 to 7.47)
Passive/Passive + overweight/obese	4.96 (−7.83 to 17.75)	0.21 (−2.19 to 2.62)	−0.89 (−2.87 to 1.09)	−0.68 (−4.45 to 3.09)

Note. Adjusted for sex, age, weight status, mother's education, country, follow-up length, change in wear time and baseline values of the outcome (e.g. sedentary time during baseline for Δ Sedentary time analysis). Active/active: active travel to school at both time-points. Inactive/active: active travel to school at follow-up, but not baseline. Active/inactive: active travel to school at baseline, but not follow-up. Inactive/inactive: active travel to school at baseline, but not follow-up. PA, physical activity. *B*, unstandardized coefficient. CI, confidence interval.

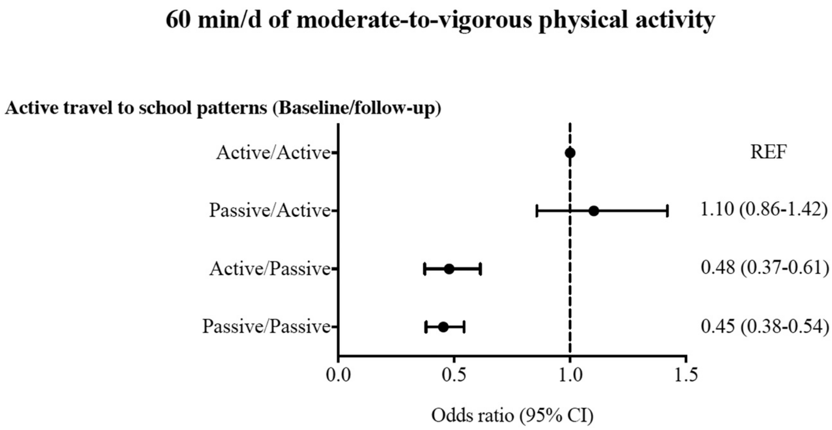

Fig. 1. Association of the association between active travel to school patterns across waves and meeting the recommendations of moderate-to-vigorous physical activity at follow-up. Note. Adjusted for sex, age, weight status, mother's education, country, follow-up length, change in wear time and baseline values of moderate-to-vigorous physical activity. CI, confidence interval. Proportion of meeting the recommendations of moderate-to-vigorous physical activity at follow-up: Active/Active: 41.1%; Passive/Active: 38.4%; Active/Passive: 26.3%; Passive/Passive: 21.5%.

passive travel (OR: 0.45; 95%CI: 0.38–0.54) were less likely to achieve recommended levels of physical activity.

4. Discussion

This large multi-country study shows that compared to consistent active commuters, adolescents taking up passive travel to school and those consistently travelling passively showed greater decrease in MPA, VPA, and MVPA and were less likely to achieve the recommended levels of physical activity. On the other hand, adolescents taking up active travel to school showed less of a decrease in MPA, VPA and MVPA relative to those with consistent active travel. Changes in school travel mode were not associated with changes in SED.

Our findings advance previous cross-sectional and prospective studies that have shown that active travel to school is associated with higher levels of physical activity (Aparicio-Ugarriza et al., 2020; Kek et al., 2019; van Sluijs et al., 2009). Our results suggest that changes in active travel to school over time are associated with different intensities of physical activity. Therefore, our findings highlight the importance of active travel to school for physical activity maintenance in both MPA and VPA intensities during early adolescence. The importance of active travel to school is reinforced considering that the expected declines in MPA and VPA throughout the adolescence occurred among the groups with maintenance of passive travel to school and among those taking up passive travel overtime (Cooper et al., 2015; Corder et al., 2016).

Also, the slightly different results for MPA and VPA, with taking up active travel to school associated with an increase in VPA, but only maintenance of MPA, advances studies that only considered MVPA. We highlight that our findings were consistent across the different cohorts, from different countries and the only cohort without associations between changes in active travel to school and changes in different intensities of physical activity was the EYHS Denmark, which can be due to the reduced sample size. Unlike a previous prospective study (Atkin et al., 2016), active travel to school patterns over time were not associated with SED changes, showing that sedentary behavior should have independent paths of promotion, outside of school travel mode.

We also found that taking up active travel to school is associated with a maintenance of MPA and increases in VPA. We also highlight that the sensitivity analyzes stratifying by follow-up length showed a persistent effect of active travel to school on MPA and VPA, which suggests an important potential window for possible interventions. The practice of active commuting accounts for MPA and/or VPA, with cycling presenting a slightly higher energy expenditure than walking (Brandes et al., 2012), which can be associated to further health benefits as increasing cardiorespiratory fitness (Chillón et al., 2012). However, accelerometers fail to capture part of the cycling intensity (Slootmaker et al., 2009). Therefore, walking for transportation can partly explain the higher impact of commuting mode on MPA. Another possibility is that the increase in active transportation to school is a marker of change in overall physical activity behavior, which was confirmed by our analyzes, considering that participants with consistent passive transport or taking up passive transport to school overtime presented lower odds for achieve recommended levels of physical activity. Active transportation to school can also be related to a greater independent mobility, which could also contribute to more options for after school physical activity (Page et al., 2010).

The potential of active travel to school was also highlighted among older adolescents in our study. A possible explanation for our findings regarding this interaction is that MVPA declines throughout adolescence (Corder et al., 2016; Farooq et al., 2020; Kwon et al., 2012) and active transport to school can possibly have a higher contribution to total MVPA according to age as it increases while MVPA declines (Carver et al., 2011). In addition, it is possible that older adolescents went through the transition between primary and secondary school during the study period, which could increase transport physical activity (Remmers et al., 2020). However, we found that there was a trend for a slightly decrease of MPA among participants with consistent active travel to school, which do not support the increase of transport physical activity and further studies analyzing specifically this transition are warranted. On the other hand, sex and weight status did not moderate the association.

Although we found that participants taking up and maintaining active travel to school showed less of a decrease in MPA and VPA when compared to their peers, active travel changes were not associated with changes in SED, which leads to an inference that it is possible that the increase in MPA and VPA probably occurred in detriment to the reduction of light physical activity among participants with active travel to school. Even though the substitution of SED with MPA and VPA may present more consistent health benefits (Grgic et al., 2018), the substitution of LPA with higher intensities can also promote benefits for health outcomes as adiposity and insulin (Moore et al., 2017). In addition, the differences in change in terms of time in VPA and MPA were modest, which could indicate a possible compensation of increasing active travel to school by reducing other domains (Panter et al., 2011).

These results suggest that interventions to promote active travel to school should be evaluated with the aim of attenuating the decrease in physical activity levels through adolescence. Interventions could incorporate promoting active travel to school or maintaining the behavior, which is crucial as approximately 14% of the adolescents took up passive travel to school over time, a larger amount than the proportion of participants taking up active travel to school over time (10%). Most of the previous interventions have focused on primary school-aged children and failed to provide high-quality intervention protocols and presented a low effect size (Villa-González et al., 2018). Therefore, further research on promoting active travel to school among adolescents is still warranted to guide public policies. Despite the role of active travel to school in the promotion of physical activity, more studies investigating determinants of active travel to school are needed and the determinants (e.g. distance to school, safety, presence of cycle paths) should be taken into account in the formulation of intervention strategies (Marzi et al., 2018; Panter et al., 2008). Concomitant to interventions focusing active travel to school, actions are also warranted in other physical activity domains, especially during leisure-time to avoid the compensation effect (i.e. increasing physical activity during transportation, while reducing physical activity in other domains).

Our study has a large sample size with prospective data on device-measured physical activity across different countries as a strength. However, our findings should be interpreted in light of potential limitations. First, due to different protocols in different studies, we used a minimum criterion of 1 day (weekday) of valid wear time, which can be biased as it does not necessarily represent habitual physical activity. However, sensitivity analysis restricting the sample to participants with at least three valid accelerometer days, including at least one weekend day at both time points showed similar results. Also, school travel mode was reported by the adolescents in the SPEEDY, PEACH, ALSPAC (wave 2), and EYHS Denmark, in ALSPAC (wave 1), CLAN and KISS only parental report of school travel mode was available. Even it is plausible to exist some degree of disagreement between participants and parental report of travel mode, a previous study found that the rates of active transport did not change (Koning et al., 2018). The different cohorts also included waves in adolescents with different age, consequently, the school levels were different across the cohorts. Second, there was considerable missing data due to attrition, but the characteristics of excluded participants were similar to the characteristics of the included participants, with only slight differences for sex and age. Third, data about distance to school and mixed types of transportation (e.g. public transport and active transport) were not available. Therefore, it is possible that participants that classified as passive travel, especially the public transport users (Voss et al., 2015), may also have included active travel in some part of the route but reported passive transport as it was the predominant travel mode, which can possibly underestimate the effect of active travel. Fourth, there are possible confounders that were not adjusted because data was not available, including if the participant changed the school and the (change in) distance to the school (Remmers et al., 2020; van Sluijs et al., 2009). Fifth, accelerometer-based physical activity assessment underestimate the intensity of physical activity by cycling (Slootmaker et al., 2009). Consequently, it is possible that the effect of changes in active transport to school on device-based physical activity intensities is underestimated in our study. Sixth, UK cohorts, especially the ALSPAC, were overrepresented in the sample. However, we found similar results across the surveys in the sensitivity analyzes, suggesting the potential to generalize these findings outside of the UK context.

In conclusion, adolescents maintaining active travel to school and those taking up active travel show a lower decrease in MPA and an increase in VPA. On the other hand, adolescents with consistent passive travel and those taking up passive travel to school show greater declines in MPA and VPA. No association were observed with changes in SED. Therefore, an increase in active travel to school can be a strategy to attenuate the decline in physical activity practice through adolescence. Future studies should include more waves of data collection to estimate behavior dynamics over the years, also including the accelerometer in other sites, such as the thigh, to better capture physical activity during cycling, aiming to produce more accurate estimates of how active travel to school can affect habitual physical activity over the years.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

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