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Are Spanish adolescents who actively commute to and from school more active in other domains? A spatiotemporal investigation

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ABSTRACT

We examined the association between mode of commuting to/from school (i.e., walking, multimodal, and motorized-vehicle) and movement behaviours in several space-time domains (i.e., total day, home, school, transport, and other locations). Walking to and/or from school was associated with higher MVPA in all space-time domains except home, where no associations were found. After subtracting commuting time to/from school from total day domain, the associations in favour of walking to/from school were maintained compared to those using other commuting modes, and in transport domain these associations dissipated. The study suggests the importance of promoting walking to/from school for increasing MVPA levels.

1. Introduction

Daily physical activity (PA) is related to several health benefits, such as physical, social, and psychological improvements in adolescence (Poitras et al., 2016; Rodriguez-Ayllon et al., 2019). Nevertheless, around two-thirds of the adolescents worldwide are not considered physically active (Aubert et al., 2022). To overcome this, several interventions for promoting PA have been carried out, but results indicated that they often only resulted in small changes in PA levels, when PA was assessed with device-based measures (Cushing et al., 2014; Metcalf et al., 2012). As Ortega et al. (2020) pointed out, one possible reason could be that these interventions were only focused on one space-time domain (e.g., school) without considering other space-time domains where adolescents spend their time (e.g., home, transport, or other locations).

In recent years, researchers have become increasingly interested in understanding how adolescents accumulate movement behaviours including sedentary time, light PA (LPA), and moderate-to-vigorous PA (MVPA), across different space-time domains (Kek et al., 2019; Lopes et al., 2022). Nevertheless, as Stewart et al. (2017) indicated, this relationship is difficult to explore since most studies are not able to determine where and for how long the different movement behaviours are taking place. Thus, studies such as those carried out by Stewart et al. (2017), Pizarro et al. (2017), and Remmers et al. (2020) using the combination of accelerometry, Global Positioning System (GPS) data, and Geographic Information Systems (GIS), were able to obtain information about the exposure of participants to different space-time domains such as home, school, transport, and other locations. One area of particular interest inside the transport domain in youth, is active commuting to/from school (Larouche et al., 2014; Martin et al., 2016).

It is well known that active commuting to/from school is associated with higher PA levels on school days (Kek et al., 2019; Pizarro et al., 2016) and more likely to meet the PA guidelines (Khan et al., 2021). Nevertheless, the relationship between the mode of commuting to and from school and movement behaviours in different space-time domains (e.g., home, school, transport, and other locations) remains unclear. This

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means that it is not known whether increasing PA levels during commuting to and from school may result in a reduction in PA across other space-time domains (compensation hypothesis [Ridgers et al., 2014]) or whether increase in PA levels in one space-time domain, is linked to increases in PA in other domains (activity synergy hypothesis [Butler et al., 2007]). Indeed, the scientific literature seems to indicate that exercise or PA in one domain does not alter overall levels of PA because of declines in other domains (Gomersall et al., 2013; Nooijen et al., 2018). Other studies support the activity synergy hypothesis (Goodman et al., 2011; Sahlqvist et al., 2013). This hypothesis would be supported by theories such as the Self-Determination Theory (SDT) (Deci and Ryan, 1985) and the Theory of Planned Behaviour (TPB) (Ajzen and Driver, 1991). SDT suggests that motivation for practicing PA can be influenced by both individual and interpersonal factors. In addition, the TPB recognises that if adolescents have a positive attitude towards a behaviour, perceives that others think they should engage in it, and feels they have control over it, they are more likely to intend to engage in the behaviour, and therefore more likely to do so.

To date, only one study analysed the association between modes of commuting to and from school and movement behaviours in different space-time domains by combining accelerometry, GPS, and GIS, which seems to confirm this hypothesis (Stewart et al., 2017). They showed that active commuting to/from school was associated with less sedentary time and higher MVPA, not only during transport, but also in other locations. However, this study was conducted in New Zealand adolescents, and given that the results in other countries may not be the same due to cultural or social factors (Stewart et al., 2017) and, furthermore, they did not differentiate the trip direction (i.e., home-school and school-home directions) in spite of the recent evidence indicating that the two types of trips may provide different PA benefits (Campos-Garzón et al., 2023a), making it necessary to go deeper into this topic. Thus, this study will extend the research on active commuting to and from school by deepening the understanding of how the mode of commuting to and from school may be associated with movement behaviours in different spatio-temporal domains. In fact, if Stewart et al. (2017) hypothesis is confirmed, it will further reinforce the importance of promoting active commuting to/from school.

Furthermore, it is not known whether adolescents who actively commute to and from school have higher daily PA because of the PA achieved on the active commute, or because they are generally more active throughout the day compared to passive commuters. For example, during weekends, it has been shown that the bidirectional association between being more physically active and active commuting to/from school disappears (Faulkner et al., 2009; Larouche et al., 2014). Given that commuting actively to school contributes to PA in the transport and total day domains, to examine the association between active commuting to/from school and movement behaviours outside of the school commute, it is necessary to subtract the PA achieved during the school commute from these space-time domains. In this way, it will be possible to analyse whether there is a tendency to compensate according to the mode of commuting or whether it is more synergistic. This means that if when subtracting the commuting time from the total day, the associations persist, this would confirm the hypothesis of activity synergy, since despite subtracting the time of a domain, there is still an association between active commuting to school and higher levels of PA. On the other hand, if there is an association in favour of those who did not walk, it would mean that there is a compensation of PA by those who actively commute, having less PA in the rest of the domains.

By understanding how commuting to and from school is related to movement behaviours across different space-time domains, policymakers and public health practitioners can develop targeted interventions to promote active commuting to/from school. Therefore, the aims of the current study were (1) to examine the association between modes of commuting to and/or from school (i.e., walking vs. multimodal vs. motorized-vehicle) for each movement behaviour (i.e., sedentary time, LPA, and MVPA), across different space-time domains (i.e., total day, home, school, transport, and other locations), and trip directions (i.e., home-school, school-home, and in both directions), and (2) to examine these associations in the transport and total day domains, after subtracting the PA achieved on the school commute.

2. Methods

This cross-sectional study was conducted under the PACO study framework (https://profith.ugr.es/paco) (Chillón et al., 2021). The main objective of PACO study was to promote cycling to and from school and increasing PA levels in adolescents from four different cities in Spain (i.e., Almería, Jaén, Granada, and Valencia). The data collection process took place from January 2019 to June 2021. The PACO study was approved by the Review Committee for Research Involving Human Subjects at the University of Granada (Reference: 162/CEIH/2016).

Briefly, the 10 eligible secondary schools that participated in the PACO study and collected accelerometry and GPS data (two from Almería, three from Granada, three from Jaén, and two from Valencia) were included in the present study. The 10 participating schools were all public schools within the cities, and two 3rd grade classes per school were invited to participate. To be eligible, the schools had to meet certain criteria: having two 3rd grade classes with at least 15 students per class, students not having participated in any other activity promoting active commuting to/from school during the last year, and the school not offering school transport to students. The participants were recruited by the research team after obtaining parental consent.

2.1. Participants

From the PACO study, 181 adolescents aged 14–15 years old presented accelerometry and GPS data, with at least one home-school or school-home trip. In order to focus on daily movement behaviours, the inclusion criterion was as follows: presenting a day in which a trip to and/or from school was detected, with a minimum duration of 8 h. After the application of this inclusion criterion, the final sample of the present study was 99 adolescents, thus 82 participants were excluded because they did not present a minimum duration of 8 h on the day in which a trip to and/or from school was detected by accelerometry and GPS. Finally, following the inclusion criteria, a total of 275 trips to and/or from school were analysed.

2.2. Procedure

Data collection took place from January 2019 to June 2021, aligning with the school calendar and excluding July and August. Once the school agreed to participate and met the inclusion criteria, the participants returned the informed consent form signed by their parents or legal guardians, the research team visited the school. During the first visit, a belt with an accelerometer and a GPS device was given to each participant. Participants wore an accelerometer and a GPS device on their hip during data collection, removing them for water activities, showers, and sleep. Initially, participants were asked for seven days of wear for both devices with overnight charging of the GPS (January 2019 to January 2020). However, due to COVID-19, this was changed to a 40-h wear (battery life) protocol that recorded two home-school and school-home trips (January 2020 to June 2021), because the health restriction period in Spain (i.e., school schedule changes and participant attendance variations necessitated this adjustment). The accelerometer protocol remained consistent at seven days throughout the study. Seven days after the first visit, the research team returned to the school to collect the devices and the participants completed a paper-based questionnaire.

2.3. Outcomes

2.3.1. Demographic and socioeconomic data

Through a student questionnaire (https://profith.ugr.es/paco), participants self-reported their demographic data (e.g., gender and age). This questionnaire is composed of different valid and reliable scales, which was used in the PACO study (Chillón et al., 2021). In addition, participants reported their own socioeconomic status (SES) using an adaptation of the Family Affluence Scale II (FAS II) (Currie et al., 2008). Although this scale is composed of 4 questions which consists of self-reported number of computers and cars in the home, having one's own bedroom, and holidays, the PACO study questionnaire proposed an adaptation of this scale. Participants were asked two questions about how many computers and 4-wheeled motorized-vehicles their family had. The options for the number of computers were: (0) no; (1) one; (2) two; (3) two or more. The options for the number of 4-wheels motorized-vehicles were (0) no; (1) Yes, one; (2) Yes, two or more. A variable was created by combining the answers to both questions, ranging from 0 (i.e., no computer and no 4-wheels motorized-vehicles, considering a low family socio-economic level) to 4 (i.e., two or more computers and 4-wheels motorized-vehicle, considering a high family socio-economic level).

2.3.2. School neighbourhood built environment

For the evaluation of the school neighbourhood built environment, the walkability-index was used (Molina-García et al., 2017). Using ArcGIS 10.3 (ESRI, Redlands, CA, USA), the variables net residential density, land use of mix, and intersection density were analysed. A threshold distance of 1350 m (Rodriguez-Lopez et al., 2017) for adolescent walking was used to create a street-network buffer around the schools to delineate the school neighbourhood. Net residential density was computed by dividing the number of residential units in a given area by the total land area designated for residential use. Land use mix, which ranged from 0 to 1, represented the distribution of various land use types (e.g., residential, office, recreational, and retail) within the neighbourhoods surrounding the schools. Intersection density was determined by dividing the number of street intersections in a block group by the total land area, excluding freeways and inaccessible roads (Frank et al., 2005). Additionally, road intersections were defined as points where three or more segments intersected. Finally, the school neighbourhood walkability index was the sum of the z-score of each of these variables of the built environment.

2.3.3. Location data

The different locations of the participants were obtained with the GPS QStarz BT-Q1000XT (Qstarz. Taipei, Taiwan). This device shows a good median dynamic error of 0.5–3.9 m (Schipperijn et al., 2014). For the initialization and downloading of GPS data the software QTravel was used. Every GPS device was set up with an epoch of 15 s and was configured to record date, time, longitude, latitude, elevation, speed, and distance.

2.3.4. Sedentary time and PA levels data

Sedentary time and PA levels were assessed with the ActiGraph GT3X + accelerometer (ActiGraph, Pensacola, FL). For the initialization and downloading of accelerometer data the Actilife software (v.6) was used. Following the recommendations of Migueles et al. (2017) and Burchartz et al. (2020) a frequency of 30 Hz was chosen and an epoch of 15 s was set to align with the GPS sampling frequency.

2.3.5. Data processing

The processing of accelerometry and GPS data, and the creation of the space-time domains, was performed in two steps. For the first step, the HABITUS software (https://www.sdu.dk/en/habitus) was used, which applied cut-off points for sedentary time and PA levels (in this case, those cut-off points proposed by Evenson (2008) were used), as well identified non-wear time, defined as 60 consecutive minutes of zero values (Cain et al., 2018). As for the GPS data, invalid points were corrected by eliminating possible signal errors such as: (1) extreme speed changes higher than 130 km/h, (2) extreme elevation changes higher than 100 m, and (3) extreme distance changes higher than 1000 m. Once these points were removed, they were replaced with the last valid GPS data within 600 s. In addition, the trip identification and the mode of commuting categorization were carried out in this step. For the trip identification, a trip was defined as: (1) a continuous period of movement longer than 120 s where a distance of at least 100 m or more is travelled, (2) a pause during the journey of a maximum of 120 s was allowed, (3) pauses longer than 180 s were considered as the end point of the trip (Klinker et al., 2014; Pizarro et al., 2016; Stewart et al., 2017; Villa-Gonzalez et al., 2019). Regarding the mode of commuting, a trip was categorized as walking if the speed of the trip was $\geq$1 km/h <10 km/h and as motorized-vehicle if the speed of the trip was $\geq$10 km/h. This speed thresholds were previously used in different studies (Pizarro et al., 2016; Villa-Gonzalez et al., 2019) and they were validated using a SenseCam (Carlson et al., 2015). Finally, the accelerometry and GPS data were combined by matching the timestamp of each device.

The second step was carried out using the PALMSplusR R package (https://thets.github.io/palmsplusr/index.htm). In this step, home was determined as the GPS coordinate recorded by the GPS at 3:00 a.m., and a buffer of 50 m was applied to this point. School was determined as the entire area it occupied by digitizing the school boundary in ArcGIS. Using PALMSplusR, multimodal trips, which meet specific spatial and temporal criteria, were identified. For this purpose, the start of the next trip must be within 200 m of the end point of the previous trip, and the start of the next trip must not be more than 10 min from the end point of the previous trip. If a trip contains multiple segments but only one mode of commuting (walking or by motorized-vehicle), it was considered a single-mode trip. However, if a trip contained at least two different modes of commuting (e.g., walking trip and motorized-vehicle), it was classified as multimodal (Stewart et al., 2017). Moreover, the trips from home to school and school to home, as well as the different space-time domains were identified in this step. For the space-time domain identification, each of the combined GPS-accelerometry points could only belong to one of the established domains. Five different space-time domains were identified: (1) the total sedentary time and PA levels recorded during the day were considered as *total day*; (2) all data points within the home buffer were considered as *home domain;* (3) all data points within the geolocated area of the school were considered as *school domain*; (4) transport: all data points categorized by HABITUS as trips were considered as *transport domain*; and (5) all data points not assigned to any of the other four domains were considered as *other locations domain.* Next, for the creation of (6) *total day without home-school and school-home trips* and (7) *transport without home-school and school-home trips time* domains, the sedentary time and PA levels identified during the commuting to and/or from school were subtracted from the *total day* and *transport* domains. The output of this process were two databases: (1) with data from each identified trip providing information on date, start and end time, mode of travel, duration, length, speed, time spent at each movement behavior, and trip direction; (2) with data from each of the days the participant wore the accelerometer and GPS providing information for each space time domain on date, duration, wear time, and time spent at each movement behavior. Therefore, the databases present the total minutes of each movement behaviors by space-time domain recorded per day. A visual summary of the complete process is shown in Fig. 1, as well as below is a further explanation of the criteria for trip identification, categorizing the mode of commuting, and the space-time domain identification.

Furthermore, given that a participant could commute in different modes in home-school and school-home directions, trips were classified as: walking if any of their trips were performed walking; motorized-vehicle if multimodal and motorized-vehicle were combined or both trips were performed by motorized-vehicle; and multimodal if both trips

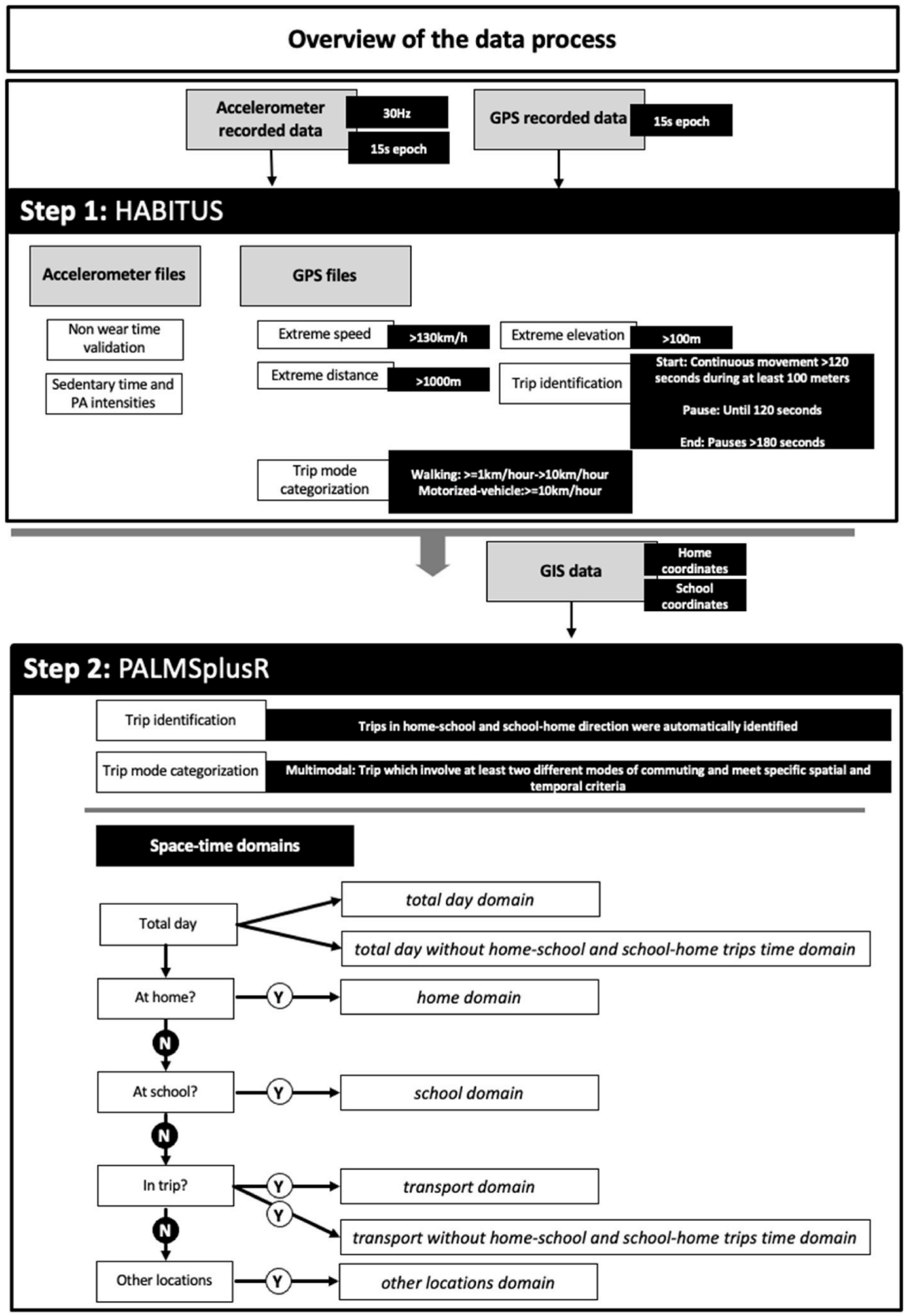

Fig. 1. Overview of the data process split into HABITUS step and PALMSplusR step. **Hz** = hertz; **s** = seconds; **GPS** = global positioning system; **km** = kilometre; **h** = hour; **m** = meter; **GIS** = geographical information system; **Y** = yes; **N** = No.

direction were performed in this mode.

2.3.6. Statistical analysis

The statistical analyses were conducted using R software. The descriptive results were presented as means and standard deviation (SD) for continuous variables, and as percentage for categorical variables. For the purposes of this study, the unit of analysis were trips (i.e., to identify the modes of commuting in each day) and valid days (i.e., to identify the movement behaviour in each domain), rather than by participants. To analyse how each movement behaviour (sedentary, LPA, MVPA) varied across different space-time domains (total day, home, school, transport, total day without the school commute, transport without the school commute), and whether these relationships varied by mode of commuting (walking, motorized-vehicle, multimodal) and trip direction (home-school, school-home, both directions), a series of linear mixed models were used (one model for each movement behaviour). Sedentary time, LPA, and MVPA were considered as dependent variables (separately), while the mode of commuting and trip direction were included as fixed effects. A separate model was run for each space-time domain. For all models, a nested random effect was specified (participant (ICC: 0.720) nested within school (ICC:0.118)), as the likelihood ratio test indicated this nested structure performed better than a random intercept with just the participant (ICC:0.721). Total time in each space-time domain, FAS, school walkability index, and gender were included as covariates in all models. Moreover, analyses between participants included in the analysis and those not included can be found in the Supplementary Material (Table S1), as well as participants who had the 7-day GPS protocol and the 40-h protocol can be found in supplementary material (Tables S2, S3, S4, and S5). The *lme4* package was used to fit all mixed models. If a participant had a valid trip to and/or from school but lacked valid data in any of the domains analysed, this participant would be excluded from the analysis of the domain with no data. However, the participant would be included in the rest of the analyses of the other domains if any data were presented.

3. Results

Participant characteristics and descriptive sedentary time and PA levels per space-time domain can be found in Table 1. In total, 99 adolescents (48.5% girls) met the inclusion criterion. These participants presented 199 valid days in which they performed 275 trips to/from school. These trips were mainly walked in the home-school direction (53.4%) and in school-home direction (42.5%), although boys showed the same percentage of trips walking and by motorized-vehicle (37.4%) in the school-home direction. Sedentary time and PA levels in each space-time domain by mode of commuting and trip direction can be found in Table 2 and Table 3. In all space-time domains, regardless of the mode of commuting, most of the time was spent sedentary, followed by light-intensity activities, and finally moderate-vigorous activities.

Table 4 shows the association between mode of commuting and movement behaviours, for each space-time domain, stratified by trip direction. In the total day domain, performing multimodal trips in home-school direction and motorized-vehicles trips in school-home direction presented higher sedentary time than walking (B: 36.0; 95% Confidence Interval [CI]: 7.4 to 65.0; 49.0; 95% CI: 23.0 to 75.0, respectively). On the other hand, motorized-vehicles trips in school-home direction showed less LPA minutes than walking trips (B: −26.0; 95% CI: −46.0 to −6.5), and multimodal and motorized-vehicles trips in home-school, school-home, and in both directions presented fewer MVPA minutes than walking (all $p < 0.05$). In school domain, having used motorized-vehicles in school-home direction presented more sedentary time (B: 20.0, 95% CI: 8.0 to 31.0), and lower LPA (B: −11.0, 95% CI: −22.0 to −1.0) and MVPA (B: −6.4, 95% CI: −10.0 to −2.8) levels than walking. In addition, the used of motorized-vehicle in both directions was associated with fewer MVPA minutes in the school domain compared to perform walking trips (B: −5.5; 95% CI: −10.0 to −0.9). Regarding the transport domain, walking in home-school, school-home, or in both directions, showed less sedentary time compared to use multimodal modes (all, $p < 0.05$). Moreover, having used multimodal modes and motorized-vehicles in home-school, school-home, or in both directions was associated with fewer MVPA minutes than walking (all, $p < 0.05$, except walking vs motorized-vehicle, $p = 0.12$). In the other locations domain, commuting by multimodal modes in home-school direction and motorized-vehicle in school-home direction was associated with more sedentary time than walking (B: 12.0, 95% CI: 0.2 to 24.0; B: 17.0, 95% CI: 2.4 to 31.0, respectively). In addition, multimodal modes and motorized-vehicles was associated with fewer LPA minutes than walking in school-home direction (B: −11.0, 95% CI: −20.0 to −1.4; B: −12.0, 95% CI: −22.0 to −2.4, respectively). Finally, having used multimodal modes in home-school direction showed fewer MVPA minutes than walking (B: −8.9, 95% CI: −15.0 to −3.1).

Table 5 shows the association between the mode of commuting and movement behaviours, for the total day and transport domains where the school commute has been removed. During the total day, the use of motorized-vehicle modes in the school-home direction accumulated significantly more sedentary time across the whole day (B: 37.0, 95% CI: 11.0 to 62.0), and lower LPA (B: −26.0, 95% CI: −46.0 to −6.5) and MVPA (B: −11.0, 95% CI: −22.0 to −0.8) than walking. Performing multimodal trips in home-school direction and in both directions presented significantly fewer MVPA minutes than walking (B: −19.0, 95% CI: −29.0 to −7.7; B: −18.0, 95% CI: −33.0 to −2.2, respectively). No significant associations were found in transport domain after removing the PA and sedentary time accumulated on the school commute.

Table 1
Descriptive data of the participants.

	All (n = 99)	Boys (n = 51)	Girls (n = 48)
Participant characteristics (mean ± SD)			
Age (years)	14.4 ± 0.6	14.4 ± 0.7	14.4 ± 0.6
BMI (kg/m^2)	22.3 ± 3.9	21.9 ± 4.1	22.7 ± 3.8
FAS	3.4 ± 0.8	3.5 ± 0.7	3.2 ± 0.9
Valid days per participant (days)	2.0 ± 1.4	1.9 ± 1.3	2.1 ± 1.6
Valid days 7-days GPS protocol (days)	2.5 ± 1.8	2.5 ± 1.7	2.5 ± 1.9
Valid days 40-h GPS protocol (days)	1.5 ± 0.7	1.5 ± 0.6	1.4 ± 0.5
Trips per participant (number)	2.7 ± 2.1	2.6 ± 1.8	2.9 ± 2.3
Trips per participant 7-day GPS protocol (number)	3.6 ± 2.5	3.7 ± 2.3	3.5 ± 2.7
Trips per participant 40-h GPS protocol (number)	1.9 ± 0.8	1.9 ± 0.8	1.8 ± 0.7
Space-time domain data (%)[a]			
Total day	100.0	100.0	100.0
Home	73.8	66.3	81.6
School	86.9	86.1	87.8
Transport	100.0	100.0	100.0
Other locations	100.0	100.0	100.0
Home-school mode of commuting (%)			
Walking	53.4	57.7	50.0
Multimodal	29.3	26.9	31.3
Motorized-Vehicle	17.3	15.4	18.7
School-home mode of commuting (%)			
Walking	42.5	37.2	48.6
Multimodal	25.0	25.6	24.3
Motorized-Vehicle	32.5	37.2	27.1

SD= Standard deviation; **BMI** = body mass index; **kg** = kilogram; **m** = meter; **FAS** = family affluence scale.
GPS = global positioning system; **h** = hour.
[a] Percentage of days with data in each domain.

4. Discussion

The present study aimed (1) to examine the association between modes of commuting (i.e., walking, multimodal, and motorized-vehicle) for each movement behaviour (i.e., sedentary time, LPA, and MVPA), across different space-time domains (i.e., total time, home, school, transport, and other locations), and trip directions (i.e., home-school, school-home, and in both directions), and (2) to examine these associations in the transport and total day domains, after subtracting the PA achieved on the school commute. These results suggest that the reduction in sedentary time and increase in PA from walking to/from school may extend beyond the actual time spent commuting and may be associated with other aspects of daily life. Future research should explore the underlying mechanisms of these associations to better understand how mode of commuting influences movement behaviours in different space-time domains.

The results obtained reinforce the idea that walking to and/or from school is associated with higher levels of PA at school, transport, and other locations, in short, during the total day. This confirms the activity synergy hypothesis. In fact, although there is no consensus in the scientific literature between compensation and activity synergy theories (Melanson, 2017; Sugiyama et al., 2010), the findings of the current study are supported by the review of reviews carried out by Prince et al. (2022). In the current study, walking to and/or from school was associated with less sedentary time and higher minutes of PA in total day domain compared to commute using multimodal or motorized-vehicles modes. This is consistent with previous studies that have shown that active commuting to/from school was associated with less sedentary time and more PA among adolescents (Gale et al., 2021; Peralta et al., 2020). In fact, the meta-analysis by Campos-Garzón et al. (2023b) indicated that active commuting to/from school may account for up to 48% of the WHO PA recommendations in young people. In line with these results, Khan et al. (2021) showed that those adolescents who

Table 2
Descriptive data of movement behaviours by mode of commuting and trip direction.

Space-time domains	Home-school direction (number of trips = 128)			School-home direction (number of trips = 147)			Both directions (number of trips = 76)		
	Walking (mean ± SD)	Multimodal (mean ± SD)	Motorized-vehicle (mean ± SD)	Walking (mean ± SD)	Multimodal (mean ± SD)	Motorized-vehicle (mean ± SD)	Walking (mean ± SD)	Multimodal (mean ± SD)	Motorized-vehicle (mean ± SD)
Total day (n = 199)									
Sedentary time (min/day)	433.5 ± 144.4	546.7 ± 117.2	492.0 ± 137.9	420.6 ± 114.0	473.0 ± 158.9	487.8 ± 96.1	445.7 ± 149.5	417.4 ± 23.3	509.5 ± 108.1
LPA (min/day)	118.9 ± 53.9	123.7 ± 53.9	117.0 ± 65.1	117.9 ± 44.5	108.9 ± 61.1	103.7 ± 46.1	120.1 ± 36.2	73.4 ± 17.6	98.0 ± 46.8
MVPA (min/day)	52.4 ± 32.9	25.9 ± 14.9	16.5 ± 7.9	56.6 ± 30.4	34.4 ± 21.9	22.2 ± 21.3	57.2 ± 34.9	22.8 ± 17.4	16.3 ± 9.2
Home (n = 147)									
Sedentary time (min/day)	135.7 ± 132.4	200.5 ± 166.5	125.5 ± 76.1	102.6 ± 84.8	137.5 ± 118.1	149.8 ± 116.2	113.9 ± 96.6	152.6 ± 146.6	164.2 ± 145.6
LPA (min/day)	29.1 ± 25.4	42.8 ± 42.6	18.5 ± 23.4	22.9 ± 19.6	27.8 ± 39.2	23.8 ± 22.9	24.5 ± 17.9	20.6 ± 24.4	23.2 ± 17.7
MVPA (min/day)	5.7 ± 8.5	8.1 ± 12.8	3.2 ± 1.8	6.1 ± 9.6	3.5 ± 4.6	2.1 ± 2.0	5.3 ± 9.5	3.5 ± 3.0	3.1 ± 2.5
School (n = 173)									
Sedentary time (min/day)	134.3 ± 111.6	169.8 ± 105.8	190.7 ± 99.6	133.1 ± 100.1	143.8 ± 92.7	204.3 ± 71.8	149.1 ± 108.3	119.5 ± 134.6	194.9 ± 76.1
LPA (min/day)	45.6 ± 40.3	51.1 ± 32.3	67.4 ± 38.9	36.9 ± 28.3	30.3 ± 22.1	46.1 ± 27.1	40.1 ± 31.4	14.3 ± 8.3	40.6 ± 25.4
MVPA (min/day)	8.8 ± 8.9	7.8 ± 6.3	8.3 ± 4.8	10.1 ± 8.1	8.0 ± 8.8	7.1 ± 4.5	9.9 ± 9.3	1.5 ± 1.8	7.3 ± 4.6
Transport (n = 199)									
Sedentary time (min/day)	65.2 ± 50.3	73.5 ± 50.9	39.3 ± 2.5	68.9 ± 45.3	81.2 ± 68.3	39.3 ± 24.1	78.9 ± 50.6	110.8 ± 81.6	36.8 ± 9.8
LPA (min/day)	17.8 ± 12.7	22.4 ± 16.8	11.8 ± 6.8	20.8 ± 15.9	23.3 ± 24.6	11.9 ± 9.5	20.9 ± 12.8	29.3 ± 20.8	11.9 ± 4.6
MVPA (min/day)	28.0 ± 24.7	7.9 ± 7.5	1.7 ± 1.7	29.7 ± 23.4	12.7 ± 11.8	5.3 ± 7.7	32.9 ± 25.7	15.6 ± 9.6	3.8 ± 3.9
Commuting to/from school (n = 199)									
Sedentary time (min/day)	2.7 ± 2.2	12.3 ± 4.9	9.0 ± 7.5	2.8 ± 3.3	8.9 ± 3.1	10.9 ± 9.1	6.8 ± 6.3	22.5 ± 9.3	17.3 ± 9.5
LPA (min/day)	2.9 ± 2.5	5.6 ± 3.1	2.6 ± 1.3	6.1 ± 4.7	5.6 ± 3.3	3.8 ± 2.3	9.5 ± 6.9	10.6 ± 5.0	7.7 ± 2.9
MVPA (min/day)	10.4 ± 6.5	4.2 ± 2.9	0.5 ± 0.8	11.9 ± 7.8	4.6 ± 4.0	0.7 ± 0.8	21.3 ± 14.8	10.3 ± 3.4	3.3 ± 2.8
Other locations (n = 199)									
Sedentary time (min/day)	98.3 ± 85.7	102.8 ± 84.9	136.6 ± 76.9	115.9 ± 87.7	110.5 ± 78.6	94.4 ± 60.6	103.7 ± 80.3	34.5 ± 24.5	113.7 ± 68.9
LPA (min/day)	31.7 ± 30.2	22.6 ± 20.2	32.0 ± 17.9	37.1 ± 29.1	27.6 ± 27.9	21.8 ± 20.8	34.6 ± 30.8	9.3 ± 5.3	22.3 ± 16.6
MVPA (min/day)	9.8 ± 14.9	2.5 ± 2.8	3.5 ± 3.0	10.6 ± 13.6	10.2 ± 19.0	7.7 ± 16.9	9.0 ± 14.2	2.3 ± 3.7	2.2 ± 2.2

SD= Standard deviation; **min** = minutes; **LPA** = light physical activity; **MVPA** = moderate-to-vigorous physical activity; **n** = number of valid days analysed.

actively commuted in the home-school and school-home directions had 22% less daily sedentary time, as well as double the chance of meeting PA recommendations than those adolescents who used passive modes of commuting. Therefore, these results support the impact that active commuting to/from school can have on adolescents' daily PA levels and highlight the importance of implementing interventions that promote active commuting to/from school instead of multimodal or motorized-vehicle modes.

The literature consistency shows that young people who used active commuting to/from school accumulate less sedentary time and more PA across the total day. However, less was known how active commuting to/from school may impact other daily space-time domains. Regarding home domain, no association were found between the mode of commuting to and/or from school and movement behaviours, similarly to Stewart et al. (2017). It is possible that PA performed at home is characterized by less social structure and interaction compared to PA performed elsewhere (Carlson et al., 2017). Consequently, individual factors may have a greater influence on physical activity performed at home, such as involvement in household chores and may be of lower intensity (Butte et al., 2018). On the other hand, commuting by motorized-vehicles from school was associated with more sedentary time and less MVPA time than walking in the school domain. Given that school domain includes a recess or Physical Education classes, where MVPA levels can be reached (Grao-Cruces et al., 2020), according to the activity synergy hypothesis adolescents who walk from school may tend to have a more active predisposition during the school day (Abbott et al., 2009). Nevertheless, to clarify this result, future studies may add these space-time subdomains to examine this in more detail (Klinker et al., 2014). Similarly, our results indicated that having use multimodal and motorized-vehicles modes of commuting to and/or from school was associated with more sedentary time, and fewer LPA and MVPA minutes in the other locations domain compared to walking. Stewart et al. (2017) obtained results like those of the present study, where adolescents who engaged in active commuting to/from school accumulating less

Table 3
Descriptive data of movement behaviours by mode of commuting and trip direction, of the space time domains without home-school and school-home trip times.

Space-time omains	Home-school direction (number of trips = 128)			School-home direction (number of trips = 147)			Both directions (number of trips = 76)		
	Walking (mean ± SD)	Multimodal (mean ± SD)	Motorized-vehicle (mean ± SD)	Walking (mean ± SD)	Multimodal (mean ± SD)	Motorized-vehicle (mean ± SD)	Walking (mean ± SD)	Multimodal (mean ± SD)	Motorized-vehicle (mean ± SD)
Total day without home-school and school-home trip times (n = 199)									
Sedentary time (min/ day)	430.8 ± 144.7	534.4 ± 118.0	482.9 ± 145.5	417.8 ± 115.6	464.1 ± 158.0	476.9 ± 100.6	438.9 ± 150.7	394.9 ± 14.0	492.2 ± 116.6
LPA (min/ day)	116.0 ± 44.4	118.1 ± 53.1	114.4 ± 65.9	111.8 ± 43.8	103.3 ± 60.1	99.8 ± 45.1	110.5 ± 35.2	62.8 ± 21.7	90.3 ± 47.9
MVPA (min/ day)	41.9 ± 29.3	21.8 ± 14.1	16.0 ± 8.3	44.6 ± 27.6	29.8 ± 21.6	21.5 ± 21.5	35.9 ± 26.4	12.5 ± 17.3	13.1 ± 8.9
Transport without home-school and school-home trip times (n = 199)									
Sedentary time (min/ day)	62.5 ± 49.9	61.2 ± 49.7	30.2 ± 10.0	66.2 ± 44.3	72.3 ± 67.4	28.3 ± 18.8	72.2 ± 48.5	88.3 ± 79.9	19.4 ± 13.4
LPA (min/ day)	14.8 ± 12.2	16.8 ± 17.4	9.3 ± 7.1	14.7 ± 15.0	17.6 ± 24.4	8.1 ± 8.2	11.4 ± 12.4	18.7 ± 19.9	4.2 ± 4.6
MVPA (min/ day)	17.6 ± 21.4	3.7 ± 4.9	1.1 ± 1.0	17.8 ± 20.8	8.1 ± 10.9	4.6 ± 7.8	11.7 ± 19.8	5.3 ± 9.1	0.5 ± 1.2

SD= Standard deviation; **min** = minutes; **LPA** = light physical activity; **MVPA** = moderate-to-vigorous physical activity.); **n** = number of valid days analysed.

Table 4
Associations between the mode of commuting to and from school and movement behaviours, for each space-time domain and trip direction[a],[b].

		Home-school direction		School-home direction		Both trip directions	
		Walking vs. multimodal	Walking vs. Motorized-vehicle	Walking vs. multimodal	Walking vs. Motorized-vehicle	Walking vs. multimodal	Walking vs. Motorized-vehicle
Space-time Domains		B 95% CI	B 95% CI	B 95% CI	B 95% CI	B 95% CI	B 95% CI
Total day (n = 199)	*Sedentary time (min)*	**36.0 (7.4 to 65.0)**	20.0 (−14.0 to 54.0)	24.0 (−1.1 to 49.0)	**49.0 (23.0 to 75.0)**	33.0 (−8.2 to 74.0)	35.0 (−2.9 to 73.0)
	LPA (min)	−4.5 (−27.0 to 17.0)	4.7 (−21.0 to 30.0)	−7.0 (−26.0 to 12.0)	**−26.0 (−46.0 to −6.5)**	−0.5 (−32.0 to 31.0)	−14.0 (−43.0 to 15.0)
	MVPA (min)	**−31.0 (−44.0 to −18.0)**	**−22.0 (−37.0 to −6.4)**	**−17.0 (−28.0 to −6.2)**	**−24.0 (−36.0 to −12.0)**	**−32.0 (−50.0 to −14.0)**	**−23.0 (−40.0 to −5.5)**
Home (n = 147)	*Sedentary time (min)*	2.5 (−9.2 to 14.0)	0.0 (−16.0 to 16.0)	−0.3 (−10.0 to 9.7)	11.0 (−1.5 to 23)	−5.6 (−22.0 to 11.0)	14.0 (−3.2 to 30.0)
	LPA (min)	−2.3 (−12.0 to 7.1)	4.1 (−8.7 to 17.0)	1.0 (−7.5 to 9.6)	−5.1 (−15.0 to 5.1)	2.5 (−11.0 to 17.0)	−9.1 (−22.0 to 4.2)
	MVPA (min)	1.2 (−3.4 to 5.7)	−3.9 (−10.0 to 2.5)	0.2 (−3.4 to 3.7)	−4.1 (−8.5 to 0.4)	2.6 (−4.7 to 9.8)	−5.7 (−13.0 to 1.7)
School (n = 173)	*Sedentary time (min)*	4.3 (−8.8 to 17.0)	8.6 (−7.4 to 25.0)	1.8 (−9.2 to 13.0)	**20.0 (8.0 to 31.0)**	1.0 (−17.0 to 18.0)	13.0 (−4.0 to 29.0)
	LPA (min)	−2.5 (−14.0 to 9.2)	−4.0 (−18.0 to 10.0)	0.0 (−9.7 to 9.7)	**−11.0 (−22.0 to −1.0)**	4.1 (−11.0 to 19.0)	−7.0 (−22.0 to 7.8)
	MVPA (min)	−2.3 (−6.2 to 1.6)	−4.1 (−8.9 to 0.7)	−1.9 (−5.3 to 1.5)	**−6.4 (−10.0 to −2.8)**	−5.0 (−9.9 to 0.0)	−5.5 (-10.0 to -0.9)
Transport (n = 199)	*Sedentary time (min)*	**14.0 (4.7 to 23.0)**	7.0 (−3.5 to 17.0)	8.3 (0.6 to16.0)	6.7 (−1.4 to 15.0)	**15.0 (1.2 to 28.0)**	2.8 (−9.3 to 15.0)
	LPA (min)	4.4 (−3.4 to 9.3)	5.0 (−0.7 to 11.0)	3.6 (−1.1 to 8.3)	4.0 (−0.8 to 8.9)	3.4 (−4.1 to 11.0)	5.3 (−1.4 to 12.0)
	MVPA (min)	**−18.0 (−25.0 to −10.0)**	**−12.0 (−21.0 to −3.7)**	**−12.0 (−18.0 to −5.8)**	**−11.0 (−17.0 to −4.7)**	**−18.0 (−29.0 to −6.8)**	−8.2 (−18.0 to 2.0)
Other locations (n = 199)	*Sedentary time (min)*	**12.0 (0.2 to 24.0)**	11.0 (−3.7 to 26.0)	13.0 (−0.6 to 26)	**17.0 (2.4 to 31.0)**	10.0 (−7.9 to 28.0)	17.0 (−1.0 to 36.0)
	LPA (min)	−3.5 (−13.0 to 6.3)	−8.2 (−20.0 to 3.9)	**−11.0 (−20.0 to −1.4)**	**−12.0 (−22.0 to −2.4)**	−2.3 (−16.0 to 12.0)	−11.0 (−25.0 to 2.6)
	MVPA (min)	**−8.9 (−15.0 to −3.1)**	−2.7 (−9.6 to 4.3)	−1.7 (−8.6 to 5.2)	−4.2 (−11.0 to 2.8)	−6.2 (−16.0 to 3.6)	−4.3 (−14.0 to 5.1)

B = beta; **CI** = confidence interval; **LPA** = light physical activity; **min** = minutes; **MVPA** = moderate-to-vigorous physical activity. **n** = number of valid days analysed. Adjusted by duration in each space-time domain, FAS, school walkability index, and gender..
[a] Walking was the reference mode of commuting.
[b] Bold values mean significant results.

sedentary time and more PA time. Regarding the association between modes of commuting to and/or from school with sedentary time and PA levels in this study, as Stewart et al. (2017) explained, other locations and transportation domains are related. In fact, active modes of commuting have been associated with recreational places in the neighbourhood (Grow et al., 2008) and visiting open spaces can increase daily PA time (Van Hecke et al., 2018). Moreover, walking to and/or from school was associated with more MVPA time in the transport

Table 5
Associations between the mode of commuting to and from school and movement behaviours, for each space-time domain without home-school and school-home trips time, and trip direction[a],[b].

		Home-school direction		School-home direction		Both directions	
		Walking vs. multimodal	Walking vs. Motorized-vehicle	Walking vs. multimodal	Walking vs. Motorized-vehicle	Walking vs. multimodal	Walking vs. Motorized-vehicle
Space-time domains		B 95% CI	B 95% CI	B 95% CI	B 95% CI	B 95% CI	B 95% CI
Total day without home-school and school-home trips time (n = 199)	*Sedentary time (min)*	23.0 (−4.5 to 51)	5.7 (−27.0 to 39.0)	11.0 (−13.0 to 35.0)	37.0 (11.0 to 62.0)	18.0 (−22.0 to 57.0)	19.0 (−17.0 to 56.0)
	LPA (min)	−4.6 (−26.0 to 17)	4.4 (−21.0 to 30-0)	−6.2 (−25.0 to 13.0)	**−26.0 (−46.0 to −6.5)**	0.7 (−30.0 to 32.0)	−14.0 (−43.0 to 15.0)
	MVPA (min)	**−19.0 (−29.0 to −7.7)**	−7.9 (−21.0 to 5.0)	−5.4 (−15.0 to 4.6)	**−11.0 (−22.0 to −0.8)**	**−18.0 (−33.0 to −2.2)**	−7.3 (−22.0 to 7.5)
Transport without home-school and school-home trips time (n = 199)	*Sedentary time*	1.6 (−7.2 to 10.0)	−6.7 (−17.0 to 3.7)	−3.5 (−11.0 to 4.0)	−5.0 (−13.0 to 2.9)	0.8 (−12.0 to 14.0)	−12.0 (−23.0 to 0.0)
	LPA (min)	4.2 (−0.6 to 8.9)	4.5 (−1.1 to 10.0)	4.2 (−0.4 to 8.9)	4.1 (−0.7 to 8.9)	4.2 (−3.4 to 12.0)	5.0 (−1.8 to 12.0)
	MVPA (min)	−5.8 (−12.0 to 0.7)	0.9 (−6.9 to 8.6)	−0.6 (−5.4 to 4.2)	1.0 (−4.1 to 6.2)	−3.4 (−13.0 to 5.8)	6.1 (−2.3 to 14.0)

B = beta; **CI** = confidence interval; **LPA** = light physical activity; **min** = minutes; **MVPA** = moderate-to-vigorous physical activity; **n** = number of valid days analysed. Adjusted by duration in each space-time domain, FAS, school socioeconomic status, and gender..
[a] Walking was the reference mode of commuting.
[b] Bold values mean significant results.

domain (that includes all transportation during the day) than commuting by multimodal or motorized-vehicles. These results are widely supported by the scientific literature, but they only focused on the period of commuting to and/or from school and not on the rest of daily trips (Frazer et al., 2015; Villa-Gonzalez et al., 2019; Voss et al., 2015). Other studies that have focused on transportation in general have indicated that higher daily minutes of MVPA can be attributed to this domain when commuting is actively performed (Klinker et al., 2014; Pizarro et al., 2017; Stewart et al., 2017). All these findings suggest that promoting active commuting to/from school is important for reducing sedentary time and increasing PA time among adolescents, in part due to the positively impact that it has in other daily activities occurring in other times and spaces along the day. Nevertheless, further studies using accelerometry and GPS in other countries and with a larger number of participants are needed to confirm these findings.

Furthermore, our results suggested that the contribution of walking to and/or from school is so substantial that when excluding this behaviour from the transport domain, significant associations between modes of commuting and MVPA in the transport domain no longer exist. The high relevance of active commuting to/from school may be explained by the fact that most of the daily transportation is commuting to and/or from school; in fact, in the current study, walking to and from school accounted for almost the 65% of the MVPA in the transport domain and 40% across the total day. On the other hand, even if the PA of commuting to and/or from school is subtracted from the total day's PA, there are still positive associations with active commuting leading to higher levels of daily PA than multimodal or passive modes. Our hypothesis is that despite subtracting this PA levels from the total day, adolescents who actively commute to and/or from school continue to show higher levels of PA in other domains, which leads to this association being maintained. Thus, this fact seems to indicate that the "activity synergy hypothesis", increasing PA levels in one domain (active commuting to and/or from school) leads to increase more PA levels in other domains (e.g., school or other locations) is confirmed (Carlson et al., 2017). This emphasizes the importance on researching and developing strategies to encourage commuting to and from school among young people.

The fact that increased PA in one domain (commuting to and/or from school) leads to increased PA levels in the other domains could be explained by different theories. On the one hand, at the psychological level, the SDT proposes that an adolescent's perception of social support for active commuting to/from school from people such as parents, teachers, and peers may affect the adolescent's satisfaction of basic psychological needs (e.g., autonomy, competence, and relationship satisfaction in active commuting to/from school). This, in turn, may affect the adolescent's autonomous motivation and health-related behaviours, so that the adolescent may be more active in other contexts because he or she perceives it to be good for his or her health (Zhang and Solmon, 2013). Complementing this hypothesis, the TPB suggests that if adolescents perceive that when they active commute to and/or from school, others think that they should do so, and they feel control over it, it is likely active commuting to/from school may lead to being active in other contexts. On the other hand, the built environment may also affect PA levels. Depending on the characteristics of the micro- or macro-level built environment, participants might be more likely to increase their PA activity levels or spend more time sedentary (Timperio et al., 2017). For example, there is evidence that youth were less sedentary when living in neighbourhoods with parks and green spaces compared to children living in neighbourhoods with higher residential density and less built-up land (Norman et al., 2010). Therefore, future studies may distinguish between individual and built environment factors to understand the drivers of these associations.

5. Strengths, limitations, and future directions

This study had significant strengths: accelerometer and GPS data were used to identify the mode of commuting, trip direction, space-time domains, and sedentary time and PA levels in each space-time domain. Additionally, the study was able to capture multimodal trips by utilizing the PALMSplusR, which allowed for identification of trips that involved multiple modes of commuting. Moreover, we considered the walkability index (based on three built environment features) of school neighbourhoods as built environment confounder.

It is important to note that this study has several limitations. First, despite these positive results, we must highlight that we cannot establish a definitive causal direction between active commuting to and/or from school and PA in other space-time domains. It is possible that adolescents who are physically active in other space-time domains choose walking to and/or from school as an extension of their active behaviour. Furthermore, it is plausible that walking to and/or from school promotes PA in other domains by providing a regular opportunity for PA. Thus, more studies are necessaries in order to answer this bidirectionality. Second, the study was conducted in a specific geographic location and the findings may not be generalizable to other populations with different urban design and transportation infrastructure. Third, while GPS is a useful device to record locations, it has some limitations to keep in mind. There may be errors in the spatial data due to poor satellite signal quality. Traffic congestion could cause some motorized-vehicle modes to be categorized as multimodal modes. Fourth, if a participant remained stationary for more than 10 min before arriving at school or home, some trips may have been missed. There is also the possibility that some GPS points may have been mistakenly classified into other space-time domains. Fifth, although there is no established measurement wear protocol for the combination of GPS and accelerometry (Kepper et al., 2022), in the current, study due to health restrictions by the COVID in Spain (e.g., students did not have to attend school every day), the GPS protocol was reduced from 7 days to 40 h, which may imply a reduction of the representativeness of movement behaviours across the days recorded. It is worth mentioning that the data collection during the COVID pandemic partially affected the results as the sensitivity analysis pointed out. Finally, it is important to note that there may be a large range of variables that may explain the associations observed between the mode of commuting to and/or from school and movement behaviours in different spatio-temporal domains. Future studies should explore other individual, social, and environmental variables in order to provide a broader explanation. Moreover, future research is needed to examine the relationship between mode of commuting to and/or from school and movement behaviours in different regions and populations to better understand the broader impact of walking in home-school and school-home, and in both trip directions, on sedentary time and minutes of PA, as well as they should try to record as many days as possible, in order to obtain more information on the variability of movement behaviour across the days.

6. Conclusions

Walking to and/or from school was associated with more MVPA minutes and less sedentary time compared to use multimodal or motorized-vehicle modes of commuting in all space-time domains studied except at home. Moreover, the contribution of walking to and/or from school can transfer to increase the PA into other domains, even when removing the commuting time to/from school. It supports the activity synergy hypothesis by indicating that active commuting to and/or from school was still associated with higher levels of PA in other domains compared to multimodal or passive modes used to commute to and/or from school. Future strategies to reduce daily sedentary time and increase PA time should consider active commuting to and from school, because of its potential benefits on PA in other space-time domains.

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CRediT authorship contribution statement

P. Campos-Garzón: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **T. Stewart:** Writing – review & editing, Visualization, Methodology, Formal analysis, Conceptualization. **X. Palma-Leal:** Writing – review & editing, Investigation. **J. Molina-García:** Writing – review & editing, Investigation. **M. Herrador-Colmenero:** Writing – review & editing, Investigation. **J. Schipperijn:** Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization. **P. Chillón:** Writing – review & editing, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Barranco-Ruiz:** Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors have no conflicts of interest to declare.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2024.103211.

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