MS MANUEL HERRADOR-COLMENERO (Orcid ID : 0000-0003-2145-4725)

Article type : Original Article

Longitudinal associations between weather, season, and mode of commuting to school amongst Spanish youths.

Herrador-Colmenero M[1*], Harrison F[2], Villa-González E[1], Rodríguez-López C[1], Ortega FB[1], Ruiz JR[1], Jones AP[2] and Chillón P[1].

[1] PROFITH "Promoting FITness and Health through physical activity" research group, Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain.

[2] UKCRC Centre for Diet and Activity Research (CEDAR) and Norwich Medical School, University of East Anglia, Norwich, UK.

* Corresponding author (Permanent address): Manuel Herrador-Colmenero, Department of Physical Education and Sport. Faculty of Sport Sciences, University of Granada. Ctra. Alfacar, s/n; Granada 18011

Spain Phone: +34 958 24 43 53

Fax: +34 958 24 43 69

Email address: mhc@ugr.es

Running Head: Weather, Season and Active Commuting in youth

Abstract

Aim. To study the associations of weather conditions with the travel mode choice for commuting to and from school. **Methods.** A total of 6,979 Spanish youths aged 7 to 18 years old (80% adolescents aged 12-18 years old, 51% male) completed a 5-day survey of mode of commuting to school in autumn, winter, and spring. Weather data from the nearest weather station to each school was registered. We used Google Maps™ to calculate the distance from home to school. Multilevel logistic regression models were used to estimate odds of active travel based on weather and season. **Results.** We analysed a total of 163,846 discrete journeys. In winter, children (aged 7 to 11 years old) were less likely to choose an active mode of commuting to school (OR: 0.72, 95% CI: 0.59-0.89, p=0.003). In spring, adolescents were more likely to choose an active mode of commuting to school (OR: 1.43, 95% CI: 1.19-1.73, p<0.001). With higher mean temperatures, adolescents were more likely to choose an active mode of commuting from school (OR: 1.02, 95% CI: 1.00-1.04, p=0.029).

Conclusion. Certain weather conditions seem to influence the travel mode choice for commuting to and from school in youth, including season and temperature.

Keywords. Transportation, Journey, Health Behavior, Student, Climate.

1. Introduction

Worldwide physical inactivity causes 9% of premature mortality (1) and around 80% of adolescents aged 13-15 years old do not meet the international physical activity recommendations (2). The World Health Organization described the domains in which physical activity might occur, including work, transport, domestic duties and leisure time activities (3). Children and adolescents commute to and from school each school day. Therefore commuting to and from school provides a good opportunity to be physically active (4, 5). Choosing active commuting to and from school (ACS) has several health benefits independent of the geographical context (6), including healthier body composition (7) and better cardiorespiratory fitness (4, 8).

The prevalence of ACS has declined in recent decades (9–11). Therefore, it is important to identify which factors facilitate and act as barriers to ACS. In terms of environmental barriers, distance between home and school is a key factor (12–14), but weather conditions have also been associated with travel mode choice (13, 15). Parental perception of the weather has been found to inhibit ACS (16) in US, and a study of Belgian adolescents reported a preference for motorised transport in wet weather (17). Findings from the few quantitative studies that have explored associations between weather conditions and ACS are equivocal (14, 16, 18–21). A longitudinal study showed that higher temperature was positively associated with ACS in 2,711 north American children (16), but a Canadian study found that weather conditions were not associated with walking to school (18). Other cross-sectional and longitudinal studies in New Zealand, Canada, Spain, and US did not find associations between weather and ACS (14, 19–21).

However these studies have been limited by restricted data collection periods (limiting variability in weather conditions), relatively small population samples sizes, cross-sectional design, and the use of usual mode of travel as a proxy for mode choice on a given day. Additionally, previous evidence has considered weather conditions in relation to ACS behaviour using measures from the full day, which might not be temporally specific enough to identify relationships between weather conditions and the choice of mode of commuting to and from school (14).

We build on the research evidence by using a large, repeated-measures data set of travel mode collected from almost 7,000 children and adolescents in southern Spain. Linking these data to time-specific weather variables, we aimed to study the associations of weather conditions with the travel mode choice for commuting to and from school in children and adolescents aged 7 to 18 years old.

2. Methods

2.1.Study participants and design

A total of 6,979 young people including 1,409 children (49% males) aged 7 to 11 and 5,570 adolescents (51% males) aged 12 to 21 years old from 39 schools, invited by convenience, located in southern Spain (cities of Granada, Almería and Murcia), participated in the study. Longitudinal data collection was carried out during the 2012-2013 school year and included 3 seasonal measurement time points: autumn (2012 November 19th to 23rd and 26th to 30th), winter (2013 February 11th to 15th and 18th to 22nd and 2013 March 4th to 8th), and spring (2013 May 13th to 17th and 20th to 24th). Due to the proximity between the involved cities, all shared a specific climate (i.e. Semiarid and Mediterranean continental climates), characterized by an absence of extreme fluctuations during the year. The mean temperatures of the involved cities in each season were 12.6 C (54.7 F) in autumn, 10.1 C (50.2 F) in winter, and 17.3 C (63.2 F) in spring. Those who consented to participate were asked to complete the ‘Mode and Frequency of Commuting to and from School Questionnaire’ at the 3 seasonal measurement time points; participants wrote their name or code (depending on the school policy) in the questionnaires in order to link the information in the 3 measurement points. Weather data from the nearest weather station to each school were obtained from the Spanish Meteorological State Agency (AEMET). A total of 17 different weather stations were used to obtain weather data. The mean proximity between each weather station and school setting was 10523.59 ± 11834.42 m. Commuting distance from home to school for each participant was estimated as the shortest walking network path between the home and school using Google Maps^{TM} software.

The research Ethics Committee from the University of Granada (Granada, Spain) approved the study protocol (case no. 817). Every school involved in the study was informed about the study purpose, and they informed the students and parents about the study aims. Parents provided a signed informed consent.

2.2.Commuting to and from school

Students completed a valid self-reported questionnaire (22) with the help of the teacher; the use of such surveys has been proposed as the most appropriate and valid method for ascertaining mode of commuting to school (22, 23). In addition to personal data (date of birth, gender, postal address, school and grade) the questionnaire asked participants how they usually travelled to and from school, and also to record how they had travelled to and from school on every day over the previous week. The response options were: walk, cycle, motorcycle, car, bus and 'other' (in this case, the mode was requested). Modes to and from school were classed as *active transport* (walk and cycle) and *passive transport* (car, motorcycle and bus). The mode "other" was omitted as few journeys (n=130) recorded an alternative mode. Journeys in which participants selected at least one active mode and one passive mode (i.e. a multimodal trip) were also omitted as it was not possible to class them as either active or passive transport (n=90 journey observations). For a better journey observation characterisation, the direction of travel was also recorded.

From the question about how participants usually travelled to school a variable was created by the sum of the usual mode of commuting questions at each season (autumn, winter and spring), taking in account each way of commuting separately (i.e. to and from school). Those participants were coded as being *usually active* if they reported a usually active mode of commuting (walk or cycle) in at least half of the measurement time points they completed. Otherwise they were coded as being *usually passive.* The same procedure was developed to create a variable from the question about how participants usually travelled from school.

2.3. *Weather variables*

Weather data were obtained from the nearest weather station to each school from the Spanish Meteorological State Agency. Data on day length, direct sunlight (hours of sunlight with an intensity ≥80%), temperature, wind speed and precipitation were obtained from the Spanish Meteorological State Agency for each hour of the day. For daylight and direct sunlight variables, the total of hours were calculated, while for temperature, wind speed, and total precipitation variables, means during 7:00 a.m. to 3:00 p.m. were calculated.

2.4. Inclusion criteria

Participants were included in the analysis if all personal data (i.e. age, gender, address) were reported. All individual journeys for included participants were then included as long as a single travel mode had been reported. Multimodal trips were excluded as they could not be categorised as active or passive.

2.5. Statistical analyses

Descriptive analysis was undertaken in order to characterise participants and journey observations, summarised as mean and standard deviation for continuous variables, and percentages for categorical variables. Students t-tests were performed for continuous variables and χ^2 tests were performed for categorical variables to test if there were differences in outcomes between seasons (i.e. *autumn, winter* and *spring*) and between the modes of commuting reported in each journey (i.e. a*ctive transport and passive transport*).

As the sampling frame of journey observations was based on participants and schools, adjusted relationships between weather variables and each mode of commuting outcome were assessed using logistic multilevel modelling, using the binary mode of commuting mode as the outcome (active vs passive) and Markov Chain Monte Carlo (MCMC) estimation. The hieratical nature of the sample of journeys within participants within schools, is taken into account in the model. First, the association between each exposure variable and each outcome measure was assessed. Individual factors with a p-value of <0.1 were included in multiple models. Due to the strong relationship between season and day length, we included only season in subsequent analyses. Multilevel logistic regression models were fitted stratified by direction of travel (to vs. from school), and age (children vs. adolescents). Furthermore, multilevel logistic regression models were undertaken stratified by the usual mode of commuting to school (i.e. usually active and usually passive), and age (children vs adolescents). Descriptive and logistic regression analysis were undertaken using STATA v.11 (24) and multilevel logistic regression models were constructed using MLwiN v.2.34 (25).

3. Results

A total of 6,979 students participated in the study, from which 7 participants were excluded because they did not report age or gender. A final sample of 6,972 participants were therefore included in the study and 209,160 journey observations (i.e. 30 journey observations per participant) were recorded. A total of 45,314 journey observations (22%) did not meet the inclusion criteria. The final sample size was 163,846 journey observations (see Figure 1).

Table 1 describes the characteristics of the participants, mode of commuting and weather variables within each season. There were significant differences in age, gender, usual mode of commuting to school, usual mode of commuting from school and daylight between autumn, winter and spring (all, p<0.001).

Table 2 shows descriptive characteristics of the journey observations. There was a difference in average distance from home to school between active and passive journeys (763±1,015 vs. 5,277±6,295m, p<0.001). Direct sunlight, temperature and wind speed were all on average higher on active journeys, and precipitation was slightly lower. There were differences in age, gender, direction of travel and season between *active transport* and *passive transport modes* (all, p<0.001).

Age, gender, direction of travel, daylight, direct sunlight, mean temperature, mean wind, total precipitation, and season showed statistically significant (p<0.05) associations with mode of commuting (i.e. *Active transport* and *Passive transport*) in multivariable models (data not shown). Table 3 shows the results of multilevel models stratified by direction of commuting (i.e. to school or back). With higher total precipitation, children were slightly more likely to commute actively to school (OR: 1.01, 95% CI: 1.00-1.02, p=0.047), and in winter, children were less likely to choose an active mode of commuting to school (OR: 0.72, 95% CI: 0.59-0.89, p=0.003). In spring, adolescents were more likely to choose an active mode of commuting to school (OR: 1.43, 95% CI: 1.19-1.73, p<0.001), and with higher mean temperature, adolescents were slightly more likely to choose an active mode of commuting for returning from school (OR: 1.02, 95% CI: 1.00-1.04, p=0.029).

Table 4 shows the results of multilevel binary logistic regression models between mode of commuting in each journey (i.e. *active transport* and *passive transport*) with direction of travel and weather variables stratified by usual mode of commuting. Although some variations were found by age in the association between the mode commuting with weather conditions, analysing all the sample together, the results remain constant in the association between the mode commuting with direction of travel; youths were more likely to choose an active mode of commuting (all, p<0.001) on the journey home from school, regardless of whether they reported being usually active travellers or usually passive travellers.

Moreover, for usually active commuters, youths were more likely to choose an active mode of commuting with higher mean wind (OR: 1.02, 95% CI: 1.01-1.02, p<0.001) and in spring (OR: 1.10, 95% CI: 1.04-1.17, p=0.002). Moreover, with more time with direct sunlight, (OR: 0.99, 95% CI: 0.98-0.99, p=0.004), with a higher mean temperature (OR: 0.99, 95% CI: 0.98-0.99, p<0.001), and with higher total precipitations (OR: 0.99, 95% CI: 0.99-0.99, p=0.002), youths were less likely to choose an active mode of commuting. For usually passive commuters, with higher mean temperature (OR: 1.04, 95% CI: 1.02-1.05, p<0.001), higher mean wind speed (OR: 1.05, 95% CI: 1.03-1.07, p<0.001) and with higher total precipitations (OR: 1.01, 95% CI: 1.00-1.01, p=0.021), youths were more likely to choose an active mode of commuting. Additionally, in winter, youths were less likely to choose an active mode of commuting (OR: 0.81, 95% CI: 0.70-0.93, p=0.002).

4. Discussion

We explored the associations between weather conditions and mode of commuting to and from school in Spanish children and adolescents. Although mode of commuting to school was not consistently associated with weather conditions, we observed that some changes in the weather might modify the usual mode of commuting to and from school of the children and adolescents.

In general, in the current study small size effects of the weather conditions on active commuting were detected. For example, higher mean temperatures were associated with ACS in adolescents, but only on the direction of travel from school. A previous study reported similar associations between higher temperatures and ACS (16) in children. Higher total precipitation was slightly associated with ACS choice in children, a different finding given the associations previously seen between rainfall and physical activity in general (26–30). Moreover, in a qualitative study, older adolescents reported to prefer the use of motorized transportation in rainfall conditions (17), but we found no association in the current study. This difference might be explained by the methodology used, with the qualitative study reporting the intention of the adolescents for commuting given different rainfall conditions, while our study follow a quantitative methodology which showed how the adolescents actually commuted regardless of their preferences. Additionally, due to the cross-sectional analysis performed in this study, the results obtained with the precipitation variable could be dismissed as a punctual and unusual result compared with previous researches.

Some studies from the last decade support the idea that weather conditions do not have any impact on the mode of commuting to school (14, 19–21). The lack of a consistent impact and the slight effect of the current study might be explained by the specific climate of the schools' location (i.e. Semiarid and Mediterranean continental climates), a climate without extreme fluctuations during the year, which allows the development of a strong routine behaviour. Furthermore, the weather characteristics in the chosen weeks were quite mild and stable with no heavy rainfall. Moreover, the average active journey length was relatively short at 763m (SD 1,015) for active travellers, compared to 5,277m (SD 6,295) for passive journeys, which may be a reason to maintain the active or passive behaviour irrespective from weather conditions in each group. We may speculate, following the results of Mitra and Faulkner (18) in Canadian children, and Robertson-Wilson et al. (19) in Canadian adolescents, that specific weather conditions should not be an actual barrier to ACS in children and adolescents from the south of Spain.

Concerning seasonal associations with ACS, children were less likely to choose an active mode of commuting for going to school in winter while adolescents were more likely to choose an active mode of commuting for going to school in spring. Nevertheless, there was no association for the mode of commuting from school, which could indicate that seasons might have an effect on the choice of the mode of commuting to school, but not for commuting from school. The seasonal variations in the choice of mode of commuting to school are consistent with previous findings; children and adolescents were more sensitive to seasonality, with higher percentages of active commuting in warm seasons (31–33). However, other studies supported the idea that seasonal climate did not appear influencing on the choice of mode of commuting from school (18, 19). In the current study, ACS was associated with more pleasant seasons such as autumn and spring compared to winter time. However, seasonality shows different characteristics in every geographical context, and there are inconclusive results in the scientific literature regarding the influence of the season on the mode of commuting to school in youths.

Regarding the effect of weather conditions and season on the usual mode of commuting to school, our results suggest some deviation from usual behaviour as previous studies showed (13, 33). Children who reported being usually passive were more likely to become active commuters in spring. On the other hand, adolescents who reported being usually passive were more likely to become active commuters with higher mean temperature, higher mean wind speed and in autumn, compared with winter. These results suggest that among those who are usually passive, warmer weather conditions may produce a change from passive behavior to ACS. Faulkner et al. (2010) found that parents of children who are usually active choose a passive mode when they perceived worse weather and those who are usually passive choose an active mode when they perceived better weather (34). These results, which are similar to those found in the current study, highlight the importance of working with both parents and young people through intervention programs to reduce the impact of the weather conditions by helping active commuters to stay active in worse weathers, and encouraging those who are usually passive to be active in better weather conditions.

The most conclusive result observed was that all participants (i.e. usually active and usually passive commuters, children and adolescents) were more likely to use active modes of commuting on the direction of travel back from school than on the direction of travel to school. Parents' convenience might be the main factor associated with changes in the mode of commuting to and coming from school (35). Additionally, differences between weather conditions during the afternoon compared to the morning might prompt children and adolescents change to choose an active mode of commuting when coming back from school. These observations are important when planning interventions to promote active commuting to school.

The associations between weather and season and ACS were more evident in adolescents than in children. These differences might be explained because children have less say on their mode of commuting than adolescents (9, 34). Children's mode of commuting to and from school is usually a parental decision, and parents' perceptions are a strong determinant on their children's mode of commuting (13, 36). Other determinants such as distance (12), safety (37) or neighbourhood attributes (38) might be more important than weather conditions in that choice. Independence in the decision on mode of commuting increases in adolescents because independent mobility increases with age (37, 39). Adolescents make a decision about their mode of commuting to school taking into account the distance, safety or weather factors. Accordingly, Simons et al. (2013) concluded that weather (as well as travel time, autonomy and social support among others) is a determinant in the decision on mode of commuting in older adolescents (17).

4.1.Study strengths and limitations

The main strengths of the work are the inclusion of a large sample of journeys, measured at three seasonal time points in the same school year with individually linked data on personal characteristics and travel mode to and from school over three five-day periods, that allowed us to examine in detail the associations between mode of commuting and weather variables via multilevel analyses. Our data was recorded at the journey level allowing us to explore changes in behaviour within individuals. We were able to study weather conditions during school hours which are a more temporally specific measure of exposure than is usual in this type of study. Furthermore, weather data were objectively collected by the Spanish Meteorological State Agency while in some other studies it was parents or research assistants who collected these data (40), being less objective, although weather conditions recorded at the meteorological station may not be those actually experienced by the participants.

In terms of weaknesses, the weather variation within the sample is somewhat limited, since participants come from a similar and proximal geographical area, so our results may not be generalizable to settings with different weather conditions. Although our repeated measures study design is stronger than the cross-sectional methods often used, we cannot determine causality in the associations we observed and the large number of tests undertaken means that some associations observed may be due to chance. Although we were able to consider distance from home to school, a key determinant on travel mode choice, we did not have information on parental mode of commuting, which may be important for children's commuting behaviour.

5. Perspective

Weather conditions showed few consistent associations with active commuting to school. Educational and policy programs focused on increasing physical activity levels through this behavior among children and adolescent should potentially emphasize the reduction of barriers such as distance (12–14) or parental perceptions about active commuting to school behavior (16). However, we found that daily weather conditions modified the usual mode of commuting to and from school. So that, usually passive commuters were more likely to take an active mode in the spring (this association was seen for children only). Policies aimed at encouraging a change in behavior from passive to active commuting may therefore be best targeted in the Spring when children may be more amenable to change, while programs in autumn and winter may be more successfully aimed at behavior maintenance.

6. Conclusion

Few associations were observed between weather conditions and mode of commuting to and from school. We found that specific weather conditions such as higher mean temperatures and warmer seasons had positive association with the daily ACS. Additionally, some deviations from the usual mode were associated with weather conditions, specifically increased odds of active travel among usually passive travelling adolescents in warmer weather, and among passively travelling children in spring. It may therefore be beneficial to explore the promotion of active travel options to usually passive commuters in good weather, allowing them to have good experiences which may lead a behaviour change throughout the year.

Acknowledgement

We acknowledge the effort and collaboration of the schools, their teachers, students and parents for their unconditional participation in this study without which this project would not have been possible. We also thank everyone who helped with the data collection, especially to Borja Martínez and José Manuel Segura. This study is part of a Ph.D. Thesis conducted in the Biomedicine Doctoral Studies of the University of Granada, Spain.

Funding

This study was supported by the Spanish Ministry of Economy, Industry and Competitiveness and the European Regional Development Fund [DEP2016-75598-R (MINECO/FEDER, UE)] and, also, it was supported by a grant from the Spanish Ministry of Education and Science [FPU13/01088]. This study takes place thanks to the additional funding from the University of Granada, Plan Propio de Investigación 2016, Excellence actions: Units of Excellence; Unit of Excellence on Exercise and Health (UCEES). The work of Flo Harrison was supported, wholly or in part, by the Centre for Diet and Activity Research (CEDAR), a UKCRC Public Health Research Centre of Excellence (RES-590-28-0002). Funding from the British Heart Foundation, Department of Health, Economic and Social Research Council, Medical Research Council, and the Wellcome Trust, under the auspices of the UK Clinical Research Collaboration, is gratefully acknowledged. Financial contribution to this project by the Spanish National Meteorological Agency (AEMET), in terms of providing each and every one of the meteorological data in this study.

References

1. Lee I-M, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Impact of Physical Inactivity on the World's Major Non-Communicable Diseases. *Lancet* 2012;380(9838):219–29.
2. Hallal PC, Andersen LB, Bull FC, et al. Global physical activity levels: Surveillance progress, pitfalls, and prospects. *Lancet* 2012;380(9838):247–57.
3. World Health Organisation. *Global health risks: mortality and burden of disease attributable to selected major risks*. Geneva: World Health Organization; 2009.1-62
4. Larouche R, Saunders TJ, Faulkner GEJ, Colley R, Tremblay M. Associations between active school transport and physical activity, body composition, and cardiovascular fitness: a systematic review of 68 studies. [Internet]. *J Phys Act Health* 2014;11:206–27.
5. Van Dijk ML, De Groot RH, Van Acker F, Savelberg HH, Kirschner P a. Active commuting to school, cognitive performance, and academic achievement: an observational study in Dutch adolescents using accelerometers. [Internet]. *BMC Public Health* 2014;14:799.
6. Mueller N, Rojas-Rueda D, Cole-Hunter T, et al. Health impact assessment of active transportation: A systematic review [Internet]. *Prev Med (Baltim)* 2015;76:103–14. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0091743515001164
7. Lubans DR, Boreham C a, Kelly P, Foster CE. The relationship between active travel to school and health-related fitness in children and adolescents: a systematic review. [Internet]. *Int J Behav Nutr Phys Act* 2011;8(1):5.
8. Chillón P, Ortega FB, Ruiz JR, et al. Active commuting to school in children and adolescents: an opportunity to increase physical activity and fitness. [Internet]. *Scand J Public Health* 2010;38(8):873–9.
9. Buliung RN, Mitra R, Faulkner G. Active school transportation in the Greater Toronto Area, Canada: an exploration of trends in space and time (1986-2006). [Internet]. *Prev Med (Baltim)* 2009;48(6):507–12.
10. McDonald NC. Active transportation to school: trends among U.S. schoolchildren, 1969-2001. [Internet]. *Am J Prev Med* 2007;32(6):509–16.
11. Van der Ploeg HP, Merom D, Corpuz G, Bauman AE. Trends in Australian children traveling to school 1971–2003: Burning petrol or carbohydrates? [Internet]. *Prev Med (Baltim)* 2008;46(1):60–2.
12. Chillón P, Panter J, Corder K, Jones AP, Sluijs EMF Van. A longitudinal study of the

distance that young people walk to school. *Health Place* 2014;5(July 2007):1–5.

13. Chillón P, Hales D, Vaughn A, Gizlice Z, Ni A, Ward DS. A cross-sectional study of demographic, environmental and parental barriers to active school travel among children in the United States. [Internet]. *Int J Behav Nutr Phys Act* 2014;11:61.
14. Oliver M, Badland H, Mavoa S, et al. Environmental and socio-demographic associates of children's active transport to school: a cross-sectional investigation from the URBAN Study [Internet]. *Int J Behav Nutr Phys Act* 2014;11(1):70.
15. Silva KS, Vasques DG, Martins CDO, Williams LA, Lopes AS. Active commuting: prevalence, barriers, and associated variables. [Internet]. *J Phys Act Health* 2011;8(6):750–7.
16. Mendoza JA, Cowan D, Liu Y. Predictors of Children's Active Commuting to School: an Observational Evaluation in Five US Communities. *J Phys Act Heal* 2014;11(4):729–33.
17. Simons D, Clarys P, De Bourdeaudhuij I, de Geus B, Vandelanotte C, Deforche B. Factors influencing mode of transport in older adolescents: A qualitative study [Internet]. *BMC Public Health* 2013;13:323.
18. Mitra R, Faulkner G. There's No Such Thing as Bad Weather, Just the Wrong Clothing: Climate, Weather and Active School Transportation in Toronto, Canada. *Can J public Heal* 2012;103(Suppl. 3):S35–41.
19. Robertson-Wilson JE, Leatherdale ST, Wong SL. Social-ecological correlates of active commuting to school among high school students [Internet]. *J Adolesc Heal* 2008;42(5):486–95.
20. Segura-Díaz JM, Herrador-Colmenero M, Martínez-Téllez B, Chillón P. Effect of precipitation and seasonal period on the patterns of commuting to school in children and adolescents from Granada. *Nutr Hosp* 2015;31(3):1264–72.
21. Sirard JR, Ainsworth BE, McIver KL, Pate RR. Prevalence of active commuting at urban and suburban elementary schools in Columbia, SC. *Am J Public Health* 2005;95(2):236–7.
22. Chillón P, Herrador-Colmenero M, Migueles JH, et al. Convergent validation of a questionnaire to assess the mode and frequency of commuting to and from school. *Scand J Public Health* 2017;45:612–20.
23. Herrador-Colmenero M, Pérez-García M, Ruiz J, Chillón P. Assessing Modes and Frequency of Commuting to School in Youngsters: A Systematic Review. [Internet]. *Pediatr Exerc Sci* 2014;26(3):291–341.
24. StataCorp: 110th editionCollege Station, TX: StataCorp LP; 2009[date unknown].
25. Rasbash J, Browne W, Healy M, Cameron B, Charlton C. *MLwiN Version 2.35*. Bristol: Centre for Multilevel Modelling, University of Bristol; 2012.
26. Chan CB, Ryan D a. Assessing the Effects of Weather Conditions on Physical Activity Participation Using Objective Measures [Internet]. *Int J Environ Res Public Health* 2009;6(10):2639–54.
27. Harrison F, van Sluijs EM, Corder K, Ekelund U, Jones A. The changing relationship between rainfall and children's physical activity in spring and summer: a longitudinal study [Internet]. *Int J Behav Nutr Phys Act* 2015;12(1):41.
28. Harrison F, Jones AP, Bentham G, van Sluijs EM, Cassidy A, Griffin SJ. The impact

of rainfall and school break time policies on physical activity in 9-10 year old British children: a repeated measures study [Internet]. *Int J Behav Nutr Phys Act* 2011;8(1):47.

29. Staiano A, Broyles S, Katzmarzyk P. School Term vs. School Holiday: Associations with Children's Physical Activity, Screen-Time, Diet and Sleep [Internet]. *Int J Environ Res Public Health* 2015;12(8):8861–70.

30. Bélanger M, Gray-Donald K, O'loughlin J, Paradis G, Hanley J. Influence of Weather Conditions and Season on Physical Activity in Adolescents. *Ann Epidemiol* 2009;19(3):180–6.

31. Yang Y, Diez Roux A V, Bingham CR. Variability and seasonality of active transportation in USA: evidence from the 2001 NHTS. [Internet]. *Int J Behav Nutr Phys Act* 2011;8(1):96.

32. Børrestad LA, Andersen LB, Bere E. Seasonal and socio-demographic determinants of school commuting. [Internet]. *Prev Med (Baltim)* 2011;52(2):133–5.

33. Fyhri A, Hjorthol R. Children's independent mobility to school, friends and leisure activities [Internet]. *J Transp Geogr* 2009;17(5):377–84.

34. Faulkner GE, Richichi V, Buliung RN, Fusco C, Moola F. What's "quickest and easiest?": parental decision making about school trip mode. *Int J Behav Nutr Phys Act* 2010;7(62):1–11.

35. Panter J, Corder K, Griffin SJ, Jones AP, van Sluijs EM. Individual, socio-cultural and environmental predictors of uptake and maintenance of active commuting in children: longitudinal results from the SPEEDY study. [Internet]. *Int J Behav Nutr Phys Act* 2013;10:83.

36. Timperio A, Ball K, Salmon J, et al. Personal, family, social, and environmental correlates of active commuting to school. [Internet]. *Am J Prev Med* 2006;30(1):45–51.

37. Janssen I, Ferrao T, King N. Individual, family, and neighborhood correlates of independent mobility among 7 to 12-year-olds [Internet]. *Prev Med Reports* 2016;3:98–102.

38. De Meester F, Van Dyck D, De Bourdeaudhuij I, Cardon G. Parental perceived neighborhood attributes: associations with active transport and physical activity among 10-12 year old children and the mediating role of independent mobility. [Internet]. *BMC Public Health* 2014;14(1):631.

39. Herrador-Colmenero M, Villa-González E, Chillón P. Children who commute to school unaccompanied have greater autonomy and perceptions of safety [Internet]. *Acta Paediatr* 2017;1–6.

40. Bungum TJ, Clark S, Aguilar B. The Effect of an Active Transport to School Intervention at a Suburban Elementary School. [Internet]. Am J Heal Educ 2014;45(4):205–9.

Figure 1. Flow chart of sample journey observation

Table 1. Descriptive characteristics of the study participants and weather stations.

	Autumn n=6,003 Mean±SD	Winter n=5,333 Mean±SD	Spring n=5,159 Mean±SD
Age (years)	13.4±2.2 [a,b]	13.5±2.2 [a,c]	13.7±2.2 [b,c]
Gender (Male %/Female %)	50.2/49.8 [a,b]	51.1/48.9 [a,c]	50.8/49.2 [b,c]
Usual mode of commuting to school (%)*	55.6/0.3/25.8/0.4/17.7/0.1/0.1 [a,b]	54.8/0.2/26.3/0.4/18.1/0.1/0.1 [a,c]	55.0/0.4/26.3/0.4/17.7/0.1/0.1 [b,c]
Usual mode of commuting from school (%)*	58.7/0.3/22.1/0.4/18.4/0.0/0.1 [a,b]	57.7/0.2/22.4/0.5/19.0/0.1/0.1 [a,c]	57.5/0.4/23.0/0.5/18.4/0.1/0.1 [b,c]
Walk distance (m)•	2,672.7±4,770.6	2,726.8±4,730.1	2,713.6±4,820.9
Daylight (h/day)‡	9.8±0.2 [a,b]	10.6±0.4 [a,c]	14.1±0.1 [b,c]
Direct sunlight (h/day) ‡	6.2±1.8	6.6±3.6	7.0±2.9
Mean temperature: 7-15 h (ºC) ‡	12.7±2.9 [b]	11.0±4.5 [c]	17.0±4.4 [b,c]
Mean wind: 7-15 h (m/s) ‡	1.4±1.4 [a,c]	2.7±2.4 [a]	3.5±2.2 [c]
Number of days raining (%)‡ #	79.0/21.0/0/0/0 [a,c]	30.0/40.0/15.0/5.0/10.0 [a]	16.7/44.4/33.3/5.6/0 [c]
Total precipitation: 7-15 h (L/m^2) ‡ †	0/0/0/16	0/0/1/18	0/0/0/88

* “Mode of commuting to/from school” correspond to walk/cycle/car/motorcycle/bus/other/multimodal.

• Sample size for walk distance is as follow: autumn, n=5,768; winter, n=5,178; and spring, n=5,014.

‡ Sample size for weather variables correspond to weather stations of which data were collected. Sample size is as follow: autumn, n=15; winter, n=13; and spring, n=15.

“Number of days raining” correspond to 0/1/2/3/4 days raining, out of a maximum of 5 weekdays.

[†] "Total precipitation: 7-15 h" correspond to p25/p50/p75/max. L/m^2 = Litres divided by square meters

SD: Standard deviation.

[a] Differences between autumn and winter $p<0.001$

[b] Differences between autumn and spring $p<0.001$

[c] Differences between winter and spring $p<0.001$

Table 2. Descriptive characteristics of the journeys which combines the observations from the 3 seasons studied.

	Total n=163,846 Mean±SD	Active transport n=92,792 Mean±SD	Passive transport n=71,054 Mean±SD	p
Age (years)	13.5±2.2	13.5±2.2	13.57±2.14	**<0.001**
Gender (Male %/Female %)	50.4/49.5	51.5/48.5	49.3/50.7	**<0.001**
Way (Go/Back, %)	50.0/50.0	48.9/51.1	51.5/48.5	**<0.001**
Walk distance (m)*	2,708.5±4,781.4	736.2±1,015.3	5,277.6±6,295.3	**<0.001**
Daylight (h/day)	11.4±1.9	11.4±1.9	11.4±1.9	0.111
Direct sunlight (h/day)	7.0±2.9	7.1±2.9	6.9±2.8	**<0.001**
Mean temperature: 7-15 h (ºC)	13.8±4.5	14.1±4.4	13.5±4.7	**<0.001**
Mean wind: 7-15 h (m/s)	3.0±2.8	3.3±2.9	2.7±2.6	**<0.001**
Total precipitation: 7-15 h (L/m^2)	2.3±10.3	2.2±9.8	2.4±10.9	**<0.001**
Season: autumn/winter/spring (%)	36.5/32.4/31.1	36.9/32.1/31.0	36.0/32.8/31.2	**<0.001**

* Sample size for walk distance is as follow: total, n=158,544 (96.8%); Active transport, n=89,690 (96.7%) and Passive transport, n=68,854 (96.9%).

SD: Standard deviation.

Table 3. Odds ratios of active commuting with weather variables analysed with a multilevel logistic regression model (clustered by direction of travel).

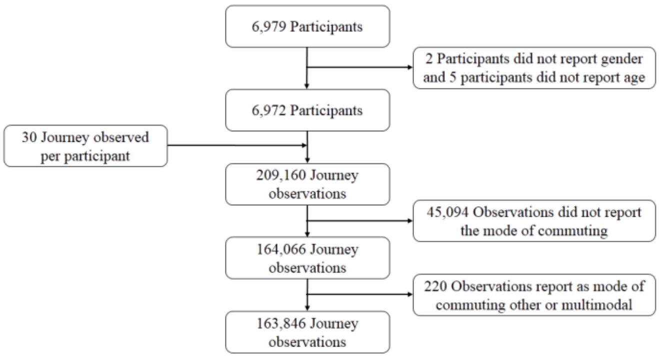
	Go to school				Come back from school			
All sample	OR	95% CI		P	OR	95% CI		P
Direct sunlight (hours)	0.99	0.97	1.01	0.156	0.99	0.97	1.01	0.212
Mean temperature: 7-15 h (ºC)	1.01	0.99	1.03	0.231	1.02	1.01	1.04	**0.009**
Mean wind: 7-15 h (m/s)	1.01	0.98	1.03	0.537	0.99	0.97	1.01	0.312
Total precipitation: 7-15 h (L/m^2)	1.00	1.00	1.01	0.708	1.00	1.00	1.01	0.554
Season								
Winter	0.96	0.85	1.08	0.460	0.97	0.87	1.09	0.652
Spring	1.33	1.15	1.54	**<0.001**	1.08	0.94	1.23	0.275
Children	OR	95% CI		P	OR	95% CI		P
Direct sunlight (hours)	1.01	0.97	1.04	0.766	0.98	0.95	1.01	0.140
Mean temperature: 7-15 h (ºC)	1.02	0.99	1.05	0.294	1.02	1.00	1.06	0.122
Mean wind: 7-15 h (m/s)	0.99	0.96	1.03	0.723	1.00	0.96	1.03	0.793
Total precipitation: 7-15 h (L/m^2)	1.01	1.00	1.02	**0.047**	1.00	0.99	1.01	0.688
Season								
Winter	0.72	0.59	0.89	**0.003**	0.89	0.73	1.09	0.252
Spring	1.22	0.97	1.54	0.095	1.10	0.88	1.37	0.414
Adolescents	OR	95% CI		P	OR	95% CI		P
Direct sunlight (hours)	0.98	0.96	1.00	0.062	1.00	0.98	1.02	0.713
Mean temperature: 7-15 h (ºC)	1.00	0.99	1.02	0.718	1.02	1.00	1.04	**0.029**
Mean wind: 7-15 h (m/s)	1.01	0.98	1.04	0.652	0.98	0.96	1.01	0.231
Total precipitation: 7-15 h (L/m^2)	1.00	0.99	1.00	0.440	1.00	1.00	1.01	0.297
Season								
Winter	1.10	0.95	1.28	0.217	1.05	0.91	1.20	0.542
Spring	1.43	1.19	1.73	**<0.001**	1.06	0.90	1.26	0.479

OR: Odds Ratio. CI: Confidence Interval

Table 4. Odds ratios of active commuting with weather variables analysed with a multilevel logistic regression model (clustered by usual mode of commuting).

	Usually active commuting				Usually passive commuting			
	Active vs. Passive (per journey)				Active vs. Passive (per journey)			
All sample	OR	95% CI		P	OR	95% CI		P
Way: Come back	1.44	1.39	1.50	**<0.001**	1.49	1.35	1.65	**<0.001**
Direct sunlight (hours)	0.99	0.98	0.99	**0.004**	1.01	0.99	1.03	0.614
Mean temperature: 7-15 h (ºC)	0.99	0.98	0.99	**<0.001**	1.04	1.02	1.05	**<0.001**
Mean wind: 7-15 h (m/s)	1.02	1.01	1.02	**<0.001**	1.05	1.03	1.07	**<0.001**
Total precipitation: 7-15 h (L/m^2)	0.99	0.99	0.99	**0.002**	1.01	1.00	1.01	**0.021**
Season								
Winter	0.96	0.91	1.02	0.157	0.81	0.70	0.93	**0.002**
Spring	1.10	1.04	1.17	**0.002**	0.96	0.84	1.10	0.543
Children	OR	95% CI		P	OR	95% CI		P
Way: Come back	1.43	1.33	1.55	**<0.001**	1.46	1.25	1.71	**<0.001**
Direct sunlight (hours)	0.98	0.96	0.99	**0.030**	1.02	0.98	1.05	0.374
Mean temperature: 7-15 h (ºC)	1.02	1.00	1.03	**0.025**	1.00	0.98	1.03	0.839
Mean wind: 7-15 h (m/s)	1.00	0.99	1.01	0.974	1.00	0.98	1.03	0.805
Total precipitation: 7-15 h (L/m^2)	1.00	1.00	1.01	0.216	1.00	1.00	1.01	0.374
Season								
Winter	0.90	0.81	1.01	0.064	0.86	0.68	1.09	0.219
Spring	0.96	0.86	1.08	0.538	1.32	1.05	1.65	**0.016**
Adolescents	OR	95% CI		P	OR	95% CI		P
Way: Come back	1.45	1.38	1.52	**<0.001**	1.52	1.34	1.72	**<0.001**
Direct sunlight (hours)	0.99	0.98	1.00	0.098	1.00	0.98	1.03	0.876
Mean temperature: 7-15 h (ºC)	0.98	0.97	0.99	**<0.001**	1.04	1.02	1.06	**<0.001**
Mean wind: 7-15 h (m/s)	1.02	1.01	1.03	**<0.001**	1.06	1.04	1.09	**<0.001**
Total precipitation: 7-15 h (L/m^2)	0.99	0.99	0.99	**<0.001**	1.00	1.00	1.01	0.212
Season								
Winter	0.99	0.92	1.05	0.673	0.77	0.64	0.92	**0.003**
Spring	1.13	1.06	1.21	**<0.001**	0.91	0.77	1.08	0.287

OR: Odds Ratio. CI: Confidence Interval


6,979 Participants
2 Participants did not report gender and 5 participants did not report age
6,972 Participants
30 Journey observed per participant
209,160 Journey observations
45,094 Observations did not report the mode of commuting
164,066 Journey observations
220 Observations report as mode of commuting other or multimodal
163,846 Journey observations