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On foot or by car: What determines children's active school travel?

Children's active school travel can provide a daily source of physical activity, yet the number of children walking or biking to school is decreasing worldwide. This study analyses children's active school travel, its individual, family, socioeconomic and environmental determinants and spatial pattern in Leipzig, Germany. We evaluated the school travel behaviour of 217 eight-year-olds from a prospective birth cohort study called LINA (**L**ifestyle and Environmental Factors and their **I**nfluence on **N**ewborns **A**llergy Risk). Variables from the LINA questionnaire were combined with data from administrative bodies. We applied logistic regressions to identify the determinants of active travel. Our results show that active school travel decreases from city centre to suburban areas, and that route length, perceived traffic and the residential environment have the greatest influence on which mode of travel is selected. Our findings enable us to suggest improvements in school district delineation in suburban areas that would facilitate active travel.

Keywords: active school travel, school journey, children's travel, physical activity, health geography

1 Introduction

Children's levels of physical activity are decreasing worldwide (Guthold et al. 2019; Rodrigues, Padez, and Machado-Rodrigues 2018; Rothman et al. 2018). Insufficient physical activity in children is associated with motoric deficits, poor mental health, excess body weight and type 2 diabetes (WHO 2010). Not only are leisure activities becoming less physically active, but active travel is also decreasing (Pavelka et al. 2017; Schmidt et al. 2017; Grize et al. 2010).

Active school travel is a broadly analysed health behaviour in more developed countries as it represents children's overall active transport and is an essential part of children's daily routines. Actively traveling children are overall more physically active (Roth, Millett, and Mindell 2012; Cooper et al. 2005). Studies show associations of active school travel with general health benefits from higher physical activity rates, such as a lower prevalence of excess body weight or better cardiorespiratory fitness, but also an enhanced ability to concentrate at school, positive emotions, distinctive social behaviour and greater autonomy (Stark, Singleton, and Uhlmann 2019; Voss 2018; Ramanathan et al. 2014). Additionally, active travel decreases vehicle miles travelled and improves air quality and traffic safety (Nieuwenhuijsen 2016; Frank et al. 2006).

Active school travel is influenced by determinants on different levels: from individual, family and peers to socioeconomic, cultural and environmental variables. This multilevel approach was primarily described in the socio-ecological model by Bronfenbrenner (1977) and further developed for health promotion (Mitra and Manaugh 2020; Sallis, Owen, and Fisher 2008; Stokols 1992). Understanding children and their physical activity embedded in a larger socio-ecological system aims to address not only individual behavioural changes but also improvements of societal and environmental conditions. Thus, studies on children's active travel orientate on socio-ecological model and cover a growing range of variables in their analyses (Carver et al. 2019; Broberg and Sarjala 2015; Mitra and Buliung 2014).

Previous studies showed relationships between children's active school travel and *individual* variables: male gender and older age are associated with higher rates of active travel (Villanueva et al. 2013; Leslie et al. 2010; Davison, Werder, and Lawson 2008). *Family* variables are also relevant, such as the number of siblings, car ownership and travel behaviour of the parents (Fyhri et al. 2011; Rodrigues, Padez, and Machado-Rodrigues 2018). Route characteristics, in particular *distance* to school, were key factors of active school travel in a number of international studies (Ikeda, Hinckson, et al. 2018; Helbich et al. 2016; Larsen, Buliung, and Faulkner 2015; Mitra, Buliung, and Roorda 2010).

The *social environment* was found to impact children's travel behaviour: Actively commuting neighbours, seeing familiar faces along the route, and densely populated and low income neighbourhoods are positively associated with active travel (Ikeda, Stewart, et al. 2018; Hsu and Saphores 2013; Davison, Werder, and Lawson 2008). *Physical environment* characteristics influence active travel when land use is mixed, streets are green, weather supports walking and traffic volume is low (Sener, Lee, and Sidharthan 2018; Mah et al. 2017).

The growing focus on environmental factors of active school travel highlights the importance of country-specific and local conditions. Whereas in Australian, Canadian and American studies walkability measures of such as the street connectedness and land use mix as well as neighbourhood safety were shown to impact travel mode choice (Kim and Lee 2020; Carver et al. 2014; Mitra et al. 2014), in European case studies stronger focus on urbanity and pedestrians accident risk (Helbich et al. 2016; Broberg and Sarjala 2015). Furthermore, the varying supply of non-active transport modes such as school busses or public transport strongly influence school travel behaviour (Broberg and Sarjala 2015; Larsen et al. 2009). Spatial pattern of primary school supply as well as the role of school choice on route to school is rarely discussed, but might also influence distance to school and therefore active travel rates.

In Germany active school travel rates are decreasing as well and only for distances to primary schools shorter than 1 km more children are walking or cycling than being brought by car (Nobis 2019). Nevertheless, only few studies focus on the German situation of children's school travel mode. Well known factors such as age, gender and distance are confirmed in a studied medium-sized city and in particular wide pavements and traffic calming increase likelihood of walking and cycling (Scheiner, Huber, and Lohmüller 2019b). The impact of variables for the journey to and from school differ: in the mornings, the built environment is a stronger predictor whereas in the afternoons behavioural factors play an important role (Scheiner, Huber, and Lohmüller 2019a). In contrast to this another larger study from the south of Germany found a relationship between actives school travel and households educational and socio-economic status, as well as with the migration background and maternal health behaviour (Kobel, Wartha, and Steinacker 2019).

Moreover in Germany clear rules govern the primary school enrolment and therefore strongly impact children’s school journeys. The German public school district delineation aims to ensure short, safe and walkable school routes (Stadt Leipzig 2019). Depending on the place of residence each primary school children is assigned to a school district of one or more public primary schools. The school district delineation is depending on school’s capacities and the number of the school-aged children residing in school’s surrounding. The assignment to one certain public primary school is binding and only in exceptional cases (e.g. parents living separated) or when attending on of the far fewer private schools (in Leipzig 17% of primary schools) parents have an alternative choice.

Previous studies have analysed data from cross-sectional surveys (Chillón et al. 2014; Faulkner et al. 2013; van Sluijs et al. 2009). Regarding the analysis methods, regression models were applied to identify relevant factors (Easton and Ferrari 2015; Su et al. 2013). While several studies have analysed the individual and parental determinants of children’s active travel (Sims and Bopp 2019; Mah et al. 2017; Foster et al. 2014; Henne et al. 2014), fewer have included variables from all dimensions (individual, family, residential environment, route and school characteristics) (Rodrigues, Padez, and Machado-Rodrigues 2018; Timperio et al. 2006). Some studies identify general factors of active travel, but do not consider or even exclude uncommon patterns of travel behaviour (Ikeda, Stewart, et al. 2018). There is a lack of knowledge about school children who walk or cycle long distances or travel short routes by car. Only a few studies include GPS tracking (Helbich et al. 2016; Collins, Al-Nakeeb, and Lyons 2015) or qualitative approaches (Buttazzoni, Coen, and Gilliland 2018; Guell et al. 2012). Because active travel behaviour is shown to be dependent on socio-ecological determinants, location-specific research is needed. Knowledge on study-site specific factors of active school travel can inform evidence-based policy recommendations and intervention projects.

In this study, we analyse children's active school travel in the city of Leipzig in Germany using a cohort study expanded by environmental datasets. We aim to answer the following research questions:

- Q1 What are the determinants of active school travel in the city of Leipzig? Is active school travel associated with children's weight?
- Q2 How do these determinants vary spatially within the city?
- Q3 Where can we find uncommon travel behaviour and which determinants influence this divergent behaviour?

Finally, we discuss and conclude which possible policy recommendations can be drawn from this study.

2 Data and methods

2.1 Study population

This study analyses eight-year-old children from the prospective birth cohort study LINA (**L**ifestyle and Environmental Factors and their **I**nfluence on **N**ewborns **A**llergy Risk). In this study, 629 mother-child pairs were recruited during pregnancy in the city of Leipzig

(Germany) between May 2006 and December 2008. They were followed up annually, as has been described in more detail elsewhere (Herberth et al. 2011; Hinz et al. 2011). In the eight-year follow-up (2014-2017), 334 mother-child pairs participated in the study. Beside medical examinations with the 334 children, questionnaires were completed by the parents, predominately by the mothers (95%). The retention rate after 8 years is 53% and compared to other studies moderate due to the additional medical examinations including blood sampling, pulmonary function test and further tests (Kooijman et al. 2016; Greene et al. 2011). Questionnaires were excluded if information about the mode of travel to school (n=1) or the primary school (n=36) were missing, or if the place of residence or school were not located within Leipzig's boundaries (n=82). Therefore, our study population includes 217 children living and going to school in Leipzig. A comparison of our study population with the entire LINA cohort when they were eight years old shows no significant difference (Table 1). A representation bias was only found in the travel mode to school as all children living in rural areas covering longer distances to school were excluded.

--- Table 1---

2.2 Outcome variables: Active school travel and children's weight

The mode of travel was assessed using questionnaires that were completed by the parents when their children were eight years old. The question was *"how does your child usually commute to school? a) on foot/by bike b) by public transport c) by car"*. As multiple answers were allowed, it was unclear whether the children combined different modes of transport (e.g. public transport and walking) or alternated between different modes (e.g. biking to school and being driven home from school). Therefore, the responses to "how does your child usually commute to school" were transformed into the following categories:

- active (on foot/by bike only)
- partially active (on foot/by bike combined or alternating with other modes)
- non-active (by car only)

The variable Body Mass Index (BMI) was used as a health outcome for active school travel. BMI z-scores were based on the eight-year-olds' weight/height and calculated according to the WHO reference population (de Onis et al. 2012).

2.3 Determinants of active school travel

Individual and family variables

Individual, psychosocial and family level information, such as gender, self-confidence and number of siblings, were derived from the questionnaires (ideally from the follow-up with the eight-year-olds, but if this was not available then data such as household structure and income were sourced from earlier questionnaires, pregnancy and six-year-old follow-up).

Residential environment variables

We chose 16 variables to describe elements of the social and natural residential environment that might influence the school travel mode. These variables include detailed characteristics, such as socio-demographic and socio-economic variables and the greenness of the neighbourhood. Further information on variables, specific indicators and data sources can be found in appendix Table A. Based on the findings of previous studies, we assumed that the travel mode choice would be impacted by factors such as neighbourhood income, car ownership rates, the presence of parks and perceived safety (Broberg and Sarjala 2015; Lee, Yoon, et al. 2013; Alparone and Pacilli 2012; Larsen et al. 2009). District-level social environmental variables such as employment rate, household income and neighbourhood satisfaction where only analysed around place of residence, as characteristics of the district where children live seem to dominate impact in contrast to the school environment (Mitra, Buliung, and Roorda 2010). The spatial pattern of these socio-demographic and -economic parameters depend on Leipzig's urban development and building structure. Suburban areas are characterised by detached houses, a lower population density and relatively lower unemployment rates, whereas districts closer to the city centre consist of a denser building structure with mainly Wilhelminian architecture and a relatively higher unemployment rate (Fig 1.). Exceptions of this urban suburban gradient can be found in the south and south east of the city where denser and more deprived districts reach the suburban areas.

--- Figure 1 ---

Residential environment variables were computed using GIS (ArcGIS 10.7 and QGIS 3.4.7). First, we geocoded the children's residential addresses through an online tool (www.koordinaten-umrechner.de) and visually checked the accuracy of our input within that tool. Then 400-metre buffers were created as a spatial measure for the residential surroundings. This buffering method is known from previous studies (Ozbil, Argin, and Yesiltepe 2016; Brownson et al. 2009). The buffers were intersected with various types of district level information about Leipzig, which were sourced from the federal statistical office, the population register, the federal labour office and the federal motor transport authority. Mean figures proportionate to the respective areas were calculated for variables such as population density, employment rate and car ownership.

The greenness proportion was assessed based on park and forest data from the Official Topographical Cartographic Information System (ATKIS).

School characteristics

We derived the school addresses from the LINA eight-year-old follow-up survey. We manually assigned each school name and type defined by the municipal office for youth, family and education. In Germany, the school district in which a child lives will determine which public primary school they will attend. The aim of school district delineation is to manage capacities and ensure short and safe school routes (Stadt Leipzig 2019). Besides identifying the type of school (public or private), we also used the school database of the State of Saxony to establish whether the schools support physical activity and active transport in general and if they are certified by the University of Leipzig as an 'Active School' (*Bewegte Schule*). By this information schools were categorized into three groups: 1. no stated physical activity promotion, 2. stated physical activity promotion in school database (e.g. additional physical education in the afternoon, physical active breaks) and 3. 'Active Schools' attending a one year certification process for implementing physical activity in children's everyday school life.

Route characteristics

We used the primary school addresses from the LINA eight-year-old follow-up survey to assign primary schools and their geolocations. This information enabled us to compute the shortest routes to school along the official topographic road network using the network analysis tool in QGIS (version 3.10.2). Data on the actual routes were not available. However, shortest route calculation is a widely applied method (Rodrigues, Padez, and Machado-Rodrigues 2018; van Heeswijck et al. 2015; Timperio et al. 2006) and environmental barriers along the shortest route can also be assessed.

We assessed route length along the road network and directness through a detour factor (route length by linear distance (Meeder and Weidmann 2018)). To describe the traffic conditions, which has been shown to be an important factor (Wilson et al. 2019; Davison, Werder, and Lawson 2008), we included information from the questionnaires about busy roads along the routes, as well as pedestrian accident counts and the proportion of main roads. The greenness of routes was represented through data from the municipal statistical office including the number of street trees and the proportion of parks and forests the child would cross through or pass by (Larsen et al. 2009; Ewing, Schroeer, and Greene 2004). For countable environmental variables, such as accidents and street trees, we built a 25-metre buffer around each route and calculated route proportional rates per 1000 m or 100 m. For assessing safety along each route, we calculated means proportionate to the area within a 100-metre buffer of the crime rate (number of offenses per inhabitants). Our geodata sources are the federal topographic information system (ATKIS), the urban green space department, the federal statistical office, the federal police and OpenStreetMap (Table A).

2.4 Statistical analysis

We summarised our data using mean and standard deviation for metric variables, and counts and proportions for categorical variables (Table 2). For a first variable selection from the 47 input variables included in the categories described above, we applied test statistics to identify differing variables for the travel modes. Similar to previous studies, we calculated chi-square tests for categorical variables and Kruskal-Wallis tests for metric variables (Rodrigues, Padez, and Machado-Rodrigues 2018; Helbich et al. 2016). Additionally, we conducted a pairwise comparison to discover the main differences between active and passive travellers (Lee, Yoon, and Zhu 2017; Easton and Ferrari 2015). Using Nemenyi post-hoc tests, we performed a multiple comparison of the mean ranks of variables regardless of normal distribution (Table 2). Based on that we found, 16 variables differ between active travellers and car users.

Accounting for multicollinearity, we conducted a principal component analysis to extract non-correlating variables for further analysis (appendix Table B). We identified four principal components of the variables. We identified four principal components of the variables. One variable was selected for each component and because one component differed contextually, from one component two variables were chosen (route length and school type). Aims of the variable selection were minimizing collinearity, adhering to realistic values for easy interpretation instead of abstract components and choosing valid and transferable variables, such as data from population register. The five identified variables were included in a binary logistic regression to define strength of association with the respective school travel mode. We mapped the identified variables in order to understand spatial pattern of active school travel. By visualising the variables at the individual level, it was possible to see a city wide pattern.

In addition, we contrasted two specific groups using a Bonferroni outlier analysis: children with long routes to school who travel actively and children with short routes to school being brought by car. Outliers for route length and actively traveling children were identified above the maximum whisker of the route length of this group. This threshold was used to extract the second group of children with short routes traveling passively to school. The two contrasting groups were then compared with regard to the variables from the regression analysis. Accounting for the low numbers of cases not having strong statistical evidence only descriptive statistics of outliers are presented. Variable discussion of uncommon travel behaviour allows for hypothesing which further variables might be relevant for individual travel mode choice.

All the statistical analyses were computed with R (version 3.6.1) in R-Studio (R Core Team 2019; Venables and Ripley 2002).

3 Results

Out of the sample of 217 children, 159 (73.3%) were reported to engage in active travel in general. 96 (44.2%) of them exclusively travel in an active way [active travel], whereas 63 (29.0%) mix or change their modes of transport [partially active travel]. 58 (26.7%) parents reported transporting their child to school exclusively by car [non-active travel]. The travel mode types are described in Table 2.

The school routes of active travellers are 771 metres long on average (median: 952 metres) and approximately 14% of such routes consists of main roads. Active travellers live in densely populated areas (average density in residential environment 6369 inhabitants/km²). The average values for partially active travellers are similar to those of the entire study population. Non-active travel appears on routes with a distance of 807 - 5579 metres (mean ± SD).

In our study population, the children's weight is not related to their school travel mode. Despite the low number of cases, there is a slight trend indicating that overweight and obese children are less likely to use active travel. However, the difference between active (12.50%) and non-active travel (14.29%) for overweight or obese children is not significant.

--- Table 2 ---

Global and pairwise tests revealed sixteen variables that differ significantly between the three travel modes, as seen in Table 2. None of the eight *individual and psychosocial variables* differed significantly ($p<0.05$) pairwise in comparisons of active with non-active travellers. However, fewer girls (44.79%) travel actively to school than boys (55.21%). And of the children reported by the parents to be anxious (38.03%), more are being brought by car (42.11%) than travel actively (36.84%).

Equally, none of the nine *family level variables*, differed significantly and were therefore excluded from further analysis. Still, it is interesting that children with one sibling (52.07%) are more often brought by car (60.34%) than walking or biking (45.83%) and children with two or three siblings are more likely to walk or bike (15.63%) than to travel non-actively (3.44%). The average household income group of families who bring their children to school by car is slightly higher (€ 3000-3500) than for active travellers (€ 2500-3000).

For the *residential environment*, numerous variables differ between the travel modes: population density, youth rate, migration rate, employment rate, average household size, university graduate rate, car ownership, health satisfaction, average BMI and distance to the city centre. For example, active travellers live in more densely populated areas (mean: 6369 inhabitants/km²), closer to the city centre (mean: 3424 m) than non-active travellers (3200 inhabitants/km², 5336 m). Non-active travellers live in areas were the inhabitants own more cars (mean: 425 cars/1000 inhabitants) than active travellers (356 cars/1000 inhabitants). Interestingly, crime rate and green areas do not seem to have an impact on active travel to school.

Regarding *school characteristics*, public school attendees have significantly higher rates of active travel (48.68%) than private school attendees (14.29%). Schools with the ‘Active School’ certification show lower rates of children being brought by car (15.69%) than schools without the certificate (30.12%).

Among all ten *route variables* the following differed significantly: route length, reported busy road along route, accident rate, main road proportion and footpath proportion. Again, greenness of the routes to school (assessed by the parks and forests children cross through or pass by and the street tree coverage) does not appear to be relevant to the travel mode in this sample. Active travellers have significantly shorter routes (mean: 771 m) with a low main road share (14.36%) and only 50% report busy roads along the route.

Out of these 16 variables, the following five were selected through a principal component analysis: population density and employment rate representing the socio-demographic and socio-economic residential environment, route length as the known key factor of travel mode choice, reported busy road along route as a safety indicator and school type being relevant for school enrolment policy in Germany (appendix Table B). Beside component representation validity of data source and potential data availability in other contexts of the chosen variable were important criteria. Variables such as population density and employment rate from municipal statistical office were favoured instead of health satisfaction (derived by representative citizen survey) and car ownership.

Logistic regression with active and partially active versus non-active travellers shows that *population density, employment rate and route length* have a significant impact on active school travel (Table 3). Raising the significance level on $p<0.1$ reported busy road along route also influences the travel mode. Shorter routes, higher population density, lower employment rates and less perceived traffic make active travel more likely in general (Q1). The regression model has a pseudo R^2 (Nagelkerke) of 0.446 and is therefore suitable for explaining mode share (Hedderich and Sachs 2018).

--- Table 3 ---

When variables for the group of exclusively active traveling children are compared against all others, only route length and population density remain significant (Table 4). That underlines the importance of the residential environment. Active travellers live in denser populated areas closer to the city centre.

--- Table 4 ---

Travel mode types are distributed unevenly across the city (Fig 1). Active travellers are more likely to live closer to the city centre, whereas non-active travellers are more likely to live in suburban areas. Partially active travellers who combine modes or alternate between active and non-active modes do not show a specific spatial pattern (Q2).

--- Figure 2 ---

Population density and employment rate around place of residence show a clear urban-suburban gradient. The closer to the city centre the children live, the higher the population density and the lower the employment rate (including exceptions in the south and southwest of the city of Leipzig). Route length and parental reports about busy roads along the route are distributed evenly across cases within the city.

To answer our research question Q3, we performed an outlier analysis of active traveling children which suggested a route length threshold of 1333.71 m (maximum whisker). We used this threshold to identify two groups: five children walking or biking long routes to school (>1333.71 m) and 12 children being brought by car relatively short routes (<1333.71 m). Comparing further variables between very low number of outliers and others (appendix Table C), active travellers with long routes show higher shares of main roads and higher accident rates. Relocating during the school year might be the reason for being an outlier. Within the questionnaire parents might state a new address, but still the old mode of transport to school. Furthermore, the group of active travellers includes biking (see data and methods) and a comparison of route length with reported duration suggests biking is the preferred mode of transport (e.g. 4.9 km in 30 min). Non-active travellers with short routes live in more densely populated areas than non-active travellers with long routes and have lower shares of main roads. Particularly noteworthy is the high proportion of females (75%) among non-active travellers with short routes.

4 Discussion

We found that 44% of the study population travels actively to primary school, whereas 29% is brought by car. This result is in line with current numbers in Germany and another study from the UK that found similar active travel rates (Nobis 2019; Falconer et al. 2015), but is lower than a Swiss study showing active school travel rates above 80% for the 10-year-old age group (Grize et al. 2010).

For 27% of the study population, travel mode to school varies and includes walking or biking sometimes or along part of the route. This shows that there is a large group of children who combine different modes of transport or change modes under varying conditions. Most variables for this group are similar to the average for the overall study population. Research on this group is lacking, as most studies only compare active and non-active travellers (Helbich et al. 2016; Larsen et al. 2009). Future studies should not only raise the question of travel mode, but also of modal share and alternating travel modes under specific circumstances.

4.1 Determinants of active school travel

In accordance with other studies we found that the length of the route is the key determinant of the travel mode (Ikeda, Hinckson, et al. 2018; Helbich et al. 2016; Mitra, Buliung, and Roorda 2010). The shorter the route, the more likely it is that children will travel actively to school. Children from our eight-year-old study population are likely to commute actively if their route length is less than 2 km. This confirms well-known reasonable walking distances for children in this age (Carver et al. 2019; Rodrigues, Padez, and Machado-Rodrigues 2018). Children being brought by car travel about 3.2 km. Only very few children travelling such distances exclusively walk or cycle.

However, our dataset also includes cases where children travel actively along very long routes or are driven short distances to school. Reasons for such cases might include children living in two households, children who have relocated or changed schools during the school year, or children who cycle and can therefore cover greater distances in an active way. Children being brought by car along shorter routes are mainly female. Even though gender does not play a significant role for the entire study population, within the outlier group of driven children on short distances girls are more often brought by car (75%). Reason for this unequal distribution might be safety concerns, such as perceived 'stranger danger' (Larsen et al. 2009; Scheiner, Huber, and Lohmüller 2019b). Future studies could research why distance to school does not seem to be relevant for mode choice among certain families.

Besides distance, another factor for active school travel is population density confirming previous studies (Hsu and Saphores 2013; Ikeda, Stewart, et al. 2018). The highest proportion of non-active commuters live in suburban districts. The less densely populated and the more peripheral the location, the less likely it is that a child will walk or bike to school (Fig. 2). In such areas the routes to school are relatively long, because the population density is lower and the school districts are larger. Further interventions to increase the proportion of active school travel should certainly be implemented in suburban schools.

Surprisingly, none of the individual and family level factors we analysed were significant for active school travel. Even though we know that commuting decisions are made in social contexts, such as family structure, work and childcare schedules (Guell et al. 2012), these contexts could not be shown to be relevant in this study. We assume that variables derived from standardized questionnaires could not cover underlying complex family structure and routines, parental values and role distribution. Further variables might be needed (e.g. daily routines and parental activity patterns) to investigate this in greater detail.

Neither street greening, nor en route parks or urban forests were related to children's school travel. The role of the urban natural environment for active transport has been discussed controversially in other studies (van Heeswijck et al. 2015). Green areas might inhibit walking and biking, because they are less frequented, particularly in the morning hours, and can therefore be perceived as unsafe. However, they have been reported to be attractive for after-school activities (Schicketanz, Grabenhenrich, and Lakes 2018).

In our study, school travel was not related to children's BMI and vice versa, although numerous studies have confirmed that actively commuting children are generally more physically active (Collins, Al-Nakeeb, and Lyons 2015; Cooper et al. 2012; Daly-Smith et al. 2011; van Sluijs et al. 2009). Discussions surrounding the impact of active school travel on the prevalence of overweight children are controversial, because being overweight is considered an adverse medical condition and has numerous interdependent causes (Faulkner et al. 2009; Voss 2018). However, establishing active travel as a daily routine in childhood might lead to a more active lifestyle in later life.

4.2 Strengths and limitations

In our study we included a broad range of variables from all levels. The children's travel behaviour could be described in detail using individual and family level variables from the questionnaires, as well as information on the socio-demographic and socio-economic structure of the neighbourhoods, the natural and built environment along the route to school and the school characteristics. As the survey data did not primarily focus on travel behaviour, certain data is lacking such as differentiation of the travel mode (combined modes or alternating travel modes, walking or biking) and the actual routes reported by the individuals. The shortest routes does not necessarily correspond to actual routes and potential detours could not be detected (Ozbil, Argin, and Yesiltepe 2016).

Our study shows a high number of environmental variables from various data sources (Table A). This enriches the individual and family level information from the questionnaires, as we know active travel is influenced by different levels, from individual to environmental (Rodrigues, Padez, and Machado-Rodrigues 2018; Timperio et al. 2006). Nevertheless, the study lacks walking infrastructure data such as the quality of footpaths, which were shown to be relevant in other studies (Wilson et al. 2019; Lee, Yoon, et al. 2013). Furthermore, our findings are limited to the LINA study population: first, showing a slight selection bias in a greater health orientation and a comparably low migration rate and second, to the administrative city borders as environmental data was no available for the surrounding regions.

Considering spatial patterns and outliers in addition to the regression analysis enabled us to interpret our results more effectively. Socio-demographic and socio-economic variables appear in certain spatial patterns across the city, which also helps to understand the travel behaviour. Although numerous variables have no significant impact on the choice of school travel mode, they might differ for outliers and are therefore relevant for future studies.

5 Conclusion

Our study shows that three interlinked aspects have the greatest influence on the choice of travel mode: route length, parental perception of road traffic and residential environment (population density and employment rate) (Q 1). The shorter the route, the higher the population density and the less perceived traffic reported by parents, the more likely it was that the children would walk or bike to school.

The findings of our study are in line with previous international studies highlighting the importance of school distance and of the residential social environment (Carver et al. 2019; Collins et al. 2012; Davison, Werder, and Lawson 2008; Lee, Zhu, et al. 2013). For future studies this emphasizes the role of analysing the local context in regard to the urban structure and spatial pattern of socio-demographic and -economic variables as well as country-specific school policies. In Germany, school district delineation and the binding assignment to one public primary school is a powerful planning tool for enabling walkable routes to school.

Contrary to the socio-ecological model and previous case studies, the choice of travel mode in our study is not related to individual or family level determinants (e.g. parental income, educational qualifications) (Mitra and Manaugh 2020; Kobel, Wartha, and Steinacker 2019; Rodrigues, Padez, and Machado-Rodrigues 2018; Villanueva et al. 2013; Sallis, Owen, and Fisher 2008). Instead, the choice of travel mode is determined by the characteristics of the child's route to school. Besides distance to school, the choice was influenced by the parental perception of busy roads along the route. This highlights the importance of the parental perception of the route environment. A growing number of studies on children's active and independent travel consider parental perceptions of traffic and safety and find similar impacts on travel mode (Alonso et al. 2017; Kelly et al. 2011; Wilson et al. 2019). Further analyses should focus on parental and children's perspectives on environmental characteristics (e.g. perceived traffic safety, aesthetics) and respective decision-making and habits within families.

Our results show that the choice of travel mode varies substantially between the children in one city and is dependent on the local conditions, urban structure and spatial pattern of environmental variables. Car use mainly appears in suburban areas, whereas active or partly active travel is more of an inner city phenomenon (Fig. 1). Neighbourhood characteristics such as population density are related to school district zoning: high population density in inner city areas is linked to smaller school districts and shorter distances to school which supports active school travel. Population density might therefore be one of the main environmental determinants.

Even though we did not find a relationship between travel mode and prevalence of excess body weight in our study population, the spatial pattern of non-active travel is in line with the rates of overweight children in Leipzig (Igel et al. 2016). In addition to analysing the determinants of health outcomes, such as obesity, we also suggest future studies focus on spatial patterns of health behaviour, such as active travel, to better understand environmental health determinants (e.g. population density, road type).

It might be useful for school planning and school district delineation to consider route characteristics. In our study area, we found that distances of less than 2 km and options for avoiding main roads may increase children's active school travel (the ideal route distance would be less than 1.3 km). School district planning certainly is a complex process balancing the demand and supply of all public primary schools including annual variations, traffic infrastructure and accessibility, However, newly built primary schools in suburban areas should complement the existing net of primary schools to enable walkable school journeys. Additionally, when planning or adjusting school capacities suburban primary schools should be allowed to have fewer students than inner-city schools, so that the school district areas can be made smaller. With regard to children who attend private schools or have longer routes to school, the focus should be on a partly active combination of modes, e.g. by promoting use of public transport or establishing kiss-and-go-zones within walking distance of schools.

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Table 1 Description of the LINA cohort (eight-year-old follow-up) and comparison with our study population

	LINA cohort n (%), n = 334	Study population n (%), n=217	χ^2 -test
Gender			0.484
Female	164 (49.10)	103 (47.47)	
Male	170 (50.90)	114 (52.53)	
Household members (6 y.)			0.784
2	14 (4.19)	8 (7.37)	
3	89 (26.65)	60 (28.11)	
≥ 4	227 (67.96)	146 (64.52)	
Parental education			
Low	4 (1.20)	2 (0.92)	0.320
Middle	64 (19.16)	37 (17.05)	
High	266 (79.64)	178 (82.03)	
Household income (pregnancy)			0.066
< € 2000	107 (32.04)	70 (34.65)	
€ 2000 - 4000	177 (52.99)	108 (53.47)	
> € 4000	29 (8.68)	24 (11.88)	
Mode of travel to school			0.001 **
On foot/by bike	124 (37.24)	96 (44.24)	
Partially on foot/by bike	106 (31.83)	63 (29.03)	
By car	103 (30.93)	58 (26.73)	
Body Mass Index (BMI)			0.161
Not overweight	243 (72.75)	159 (73.27)	
Overweight	25 (7.49)	19 (8.76)	
Obese	5 (1.50)	5 (2.30)	

** p<0.01

Table 2 Respondent characteristics: descriptive statistics and bivariate tests for influencing variables for travel mode types (χ^2: chi-square test, H: Kruskal-Wallis test)

Variable	Study population	**Active travel**	**Part. active travel**	**Non-active travel**	Bivariate test	p-value	Pairwise test (act-car)
Number of children (n (%))	217 (100)	96 (44.24)	63 (29.03)	58 (26.73)			
Health outcome							
Body Mass Index (BMI) (n (%))					χ^2 = 0.087	0.958	
normal weight	159 (86.89)	70 (87.50)	47 (87.04)	42 (85.71)			
overweight/obese	24 (13.11)	10 (12.50)	7 (12.96)	7 (14.29)			
Individual variables							
Gender: female (n (%))	103 (47.47)	43 (44.79)	32 (50.79)	28 (48.28)	χ^2 = 0.570	0.752	
Sleep duration [h] (mean ± SD)	9.88 ± 0.75	9.85 ± 0.74	9.86 ± 0.82	9.93 ± 0.70	χ^2 = 8.004	0.628	
Average time spent outside in summer [h]	4.34 ± 1.62	4.28 ± 1.65	4.75 ± 1.54	4.00 ± 1.59	H = 6.172	**0.046**	0.760
Loner [true or partly true] (n (%))	54 (25.12)	29 (30.20)	14 (22.95)	11 (18.48)	χ^2 = 4.408	0.354	
Low self-confidence [true or partly true] (n (%))	98 (45.58)	42 (43.75)	29 (47.54)	27 (46.55)	χ^2 = 9.291	0.054	
Is anxious [true or partly true] (n (%))	81 (38.03)	35 (36.84)	22 (36.07)	24 (42.11)	χ^2 = 9.886	**0.042**	0.802
Behaves carelessly around traffic (n (%))	11 (5.14)	6 (6.25)	3 (4.92)	2 (3.51)	χ^2 = 0.560	0.756	
Family variables							
Number of siblings (n (%))					χ^2 = 7.271	0.297	
no siblings	79 (36.41)	37 (38.54)	21 (33.33)	21 (36.42)			
one sibling	113 (52.07)	44 (45.83)	34 (52.97)	35 (60.34)			
2-3 siblings	25 (11.52)	15 (15.63)	8 (12.70)	2 (3.44)			
Dog owner (n (%))	13 (6.00)	5 (5.21)	5 (7.94)	3 (5.17)	χ^2 = 0.597	0.742	
Academic qualification level (n (%))	179 (82.49)	78 (81.25)	53 (84.13)	48 (82.76)	χ^2= 1.180	0.881	
Household income group [1-8]	5.50 ± 2.23	5.36 ± 2.08 2500-3000	5.31 ± 2.11 2500-3000	6.18 ± 2.53 3000-3500	χ^2 = 34.895	**0.010**	0.2079

Maternal sport frequency (n (%))					χ^2 = 8.098	0.231	
never	66 (30.84)	25 (26.32)	14 (22.22)	17 (30.36)			
several times per week	42 (19.63)	25 (26.32)	12 (19.05)	5 (8.93)			
Life satisfaction [1-4] (mean ± SD)	3.33 ± 0.54	3.34 ± 0.50	3.27 ± 0.60	3.37 ± 0.52	χ^2 = 6.434	0.169	
Household size	3.67 ± 0.99	3.71 ± 1.06	3.56 ± 1.03	3.72 ± 0.83	χ^2 = 15.622	0.337	
Children in household	1.85 ± 0.78	1.92 ± 0.85	1.76 ± 0.76	1.83 ± 0.68	χ^2 = 8.178	0.612	
Maternal employment [h]	31.08 ± 11.12	30.35 ± 12.36	31.72 ± 10.46	31.54 ± 9.84	H = 0.036	0.982	
Residential environment							
Population density [inh./km²]	5132 ± 3744	6369 ± 3732	5027 ± 3496	3200 ± 5336	H = 29.993	**<0.001**	**<0.001**
School children rate [%]	7.19 ± 1.17	7.20 ± 1.03	7.16 ± 1.02	7.20 ± 1.51	H = 0.279	0.870	
Youth rate [%]	21.07 ± 2.62	21.57 ± 2.29	20.75 ± 2.51	20.61 ± 3.11	H = 8.504	**0.014**	**0.015**
Migration rate [%]	11.20 ± 4.94	11.64 ± 4.02	12.45 ± 6.22	9.11 ± 4.10	H = 15.270	**<0.001**	**0.003**
Employment rate [%]	59.02 ± 4.16	58.82 ± 3.21	57.52 ± 4.66	60.98 ± 4.28	H = 16.447	**<0.001**	**0.005**
Unemployment rate [%]	4.86 ± 2.09	4.86 ± 1.92	4.98 ± 2.37	4.74 ± 2.05	H = 0.432	0.806	
Household size	1.81 ± 14.05	1.78 ± 0.11	1.82 ± 0.17	1.85 ± 0.14	H = 8.632	**0.013**	**0.010**
Household income	1959 ± 291	1964 ± 272	1926 ± 308	1988 ± 305	H = 1.075	0.584	
University graduate rate	0.43 ± 0.15	0.48 ± 0.13	0.43 ± 0.15	0.38 ± 0.14	H = 17.634	**<0.001**	**<0.001**
Cars per 1000 inh.	379 ± 90	356 ± 71	372 ± 99	425 ± 93	H = 20.533	**<0.001**	**<0.001**
Crimes per 1000 inh.	148 ± 211	131 ± 85	178 ± 368	143 ± 87	H = 0.259	0.878	
Satisfaction with neighbourhood	2.03 ± 0.23	2.00 ± 0.23	2.05 ± 0.26	2.04 ± 0.21	H = 2.417	0.299	
Satisfaction with own health status	2.19 ± 0.19	2.14 ± 0.16	2.19 ± 0.18	2.27 ± 0.20	H = 15.219	**<0.001**	**<0.001**
BMI	25.42 ± 1.02	25.18 ± 0.94	25.37 ± 0.99	25.89 ± 1.03	H = 17.488	**<0.001**	**<0.001**
Green areas [%]	15.94 ± 13.90	13.74 ± 11.83	17.45 ± 16.34	17.94 ± 13.93	H = 2.925	0.232	
Distance to city centre [m]	4169 ± 2274	3424 ± 1813	4229 ± 2468	5336 ± 2272	H = 24.136	**<0.001**	**<0.001**

School characteristics							
Public school (n (%))	189 (87.1)	92 (95.8)	55 (87.3)	42 (70.7)	χ^2 = 17.649	**<0.001**	**0.040**
School certified as an 'Active School' (n (%))	51 (23.50)	22 (43.14)	21 (41.18)	8 (15.68)	χ^2 = 13.436	**0.009**	0.998
Route characteristics							
Route length [m]	1648 ± 1891	771 ± 1157	1560 ± 1320	3193 ± 2386	H = 98.183	**<0.001**	**<0.001**
Reported route duration [min]	10.8 ± 6.84	8.58 ± 4.55	14.61 ± 8.09	10.36 ± 6.87	H = 30.002	**<0.001**	0.465
Detour factor	1.32 ± 0.26	1.36 ± 0.32	1.29 ± 0.22	1.28 ± 0.16	H = 0.888	0.641	
Reported busy road along route: yes (n (%))	131 (60.37)	48 (50.00)	40 (63.49)	43 (74.14)	χ^2 = 9.167	**0.010**	**0.033**
Crimes per 1000 inh. along route	152 ± 146	148 ± 132	163 ± 178	149 ± 128	H = 0.089	0.957	
Green route proportion	0.16 ± 0.14	0.14 ± 0.12	0.18 ± 0.16	0.18 ± 0.14	H = 3.302	0.192	
Street trees per 100 route metres	4.54 ± 4.05	4.65 ± 4.8	4.45 ± 3.69	4.46 ± 2.97	H = 1.090	0.580	
Accidents per 1000 route metres	1.06 ± 1.73	0.95 ± 1.81	1.31 ± 2.07	0.97 ± 1.07	H = 8.079	**0.018**	**0.036**
Main road proportion [%]	21.28 ± 25.30	14.36 ± 23.51	24.00 ± 25.10	29.78 ± 25.65	H = 23.249	**<0.001**	**<0.001**
Footpath proportion [%]	10.75 ± 13.47	10.14 ± 14.23	11.06 ± 15.91	11.41 ± 10.09	H = 5.883	**0.053**	**0.042**

Table 3 Logistic regression for mode of transport (active and part. active vs. non-active) (Nagelkerke: 0.446)

Variable	**ß estimate**	**OR**	**95% CI**	**p-value**	
Intercept	9.4040	12142	26 - 17374020	0.0054	**
Population density (inh./km²)	0.0001	1.0001	1.0000 - 1.0002	0.0246	*
Employment rate (%)	-0.1251	0.8824	0.7847 - 0.9748	0.0222	*
Route length (m)	-0.0006	0.9994	0.9991 - 0.9997	<0.0001	***
Reported busy road along route	-0.7988	0.4499	0.1919 - 1.0096	0.0578	.
School type	-0.8011	0.4488	0.1353 - 1.5704	0.2008	

$p<0.1$., $p<0.05$ *, $p<0.01$ **, $p<0.001$ ***

Table 4 Logistic regression for mode of transport (active vs. part. active and non-active) (Nagelkerke: 0.379)

Variable	**ß estimate**	**OR**	**95% CI**	**p-value**	
Intercept	-2.0310	0.1312	0.0010 - 16.8014	0.3477	
Population density (inh./km²)	0.0002	1.0002	1.0001 - 1.0003	0.0017	***
Employment rate (%)	0.0419	1.0428	0.9628 - 1.1315	0.2523	
Route length (m)	-0.0010	0.9990	0.9985 - 0.9994	<0.0001	***
Reported busy road along route	-0.5086	0.6013	0.2980 - 1.1989	0.1281	
School type	0.0059	1.0605	0.2317 - 4.5119	0.9898	

p<0.1, p<0.05 *, p<0.01 **, p<0.001 ***

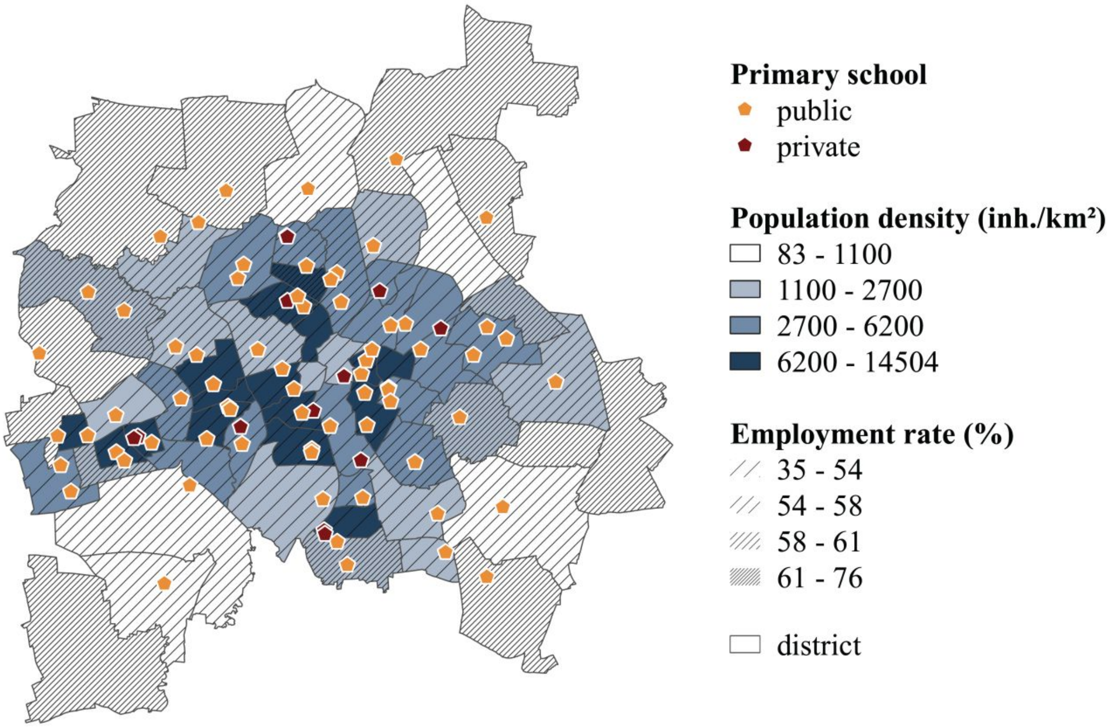

Fig. 1 Case study: Leipzig, Germany (data sources: municipal office for youth, family and education, population register, federal labour office)

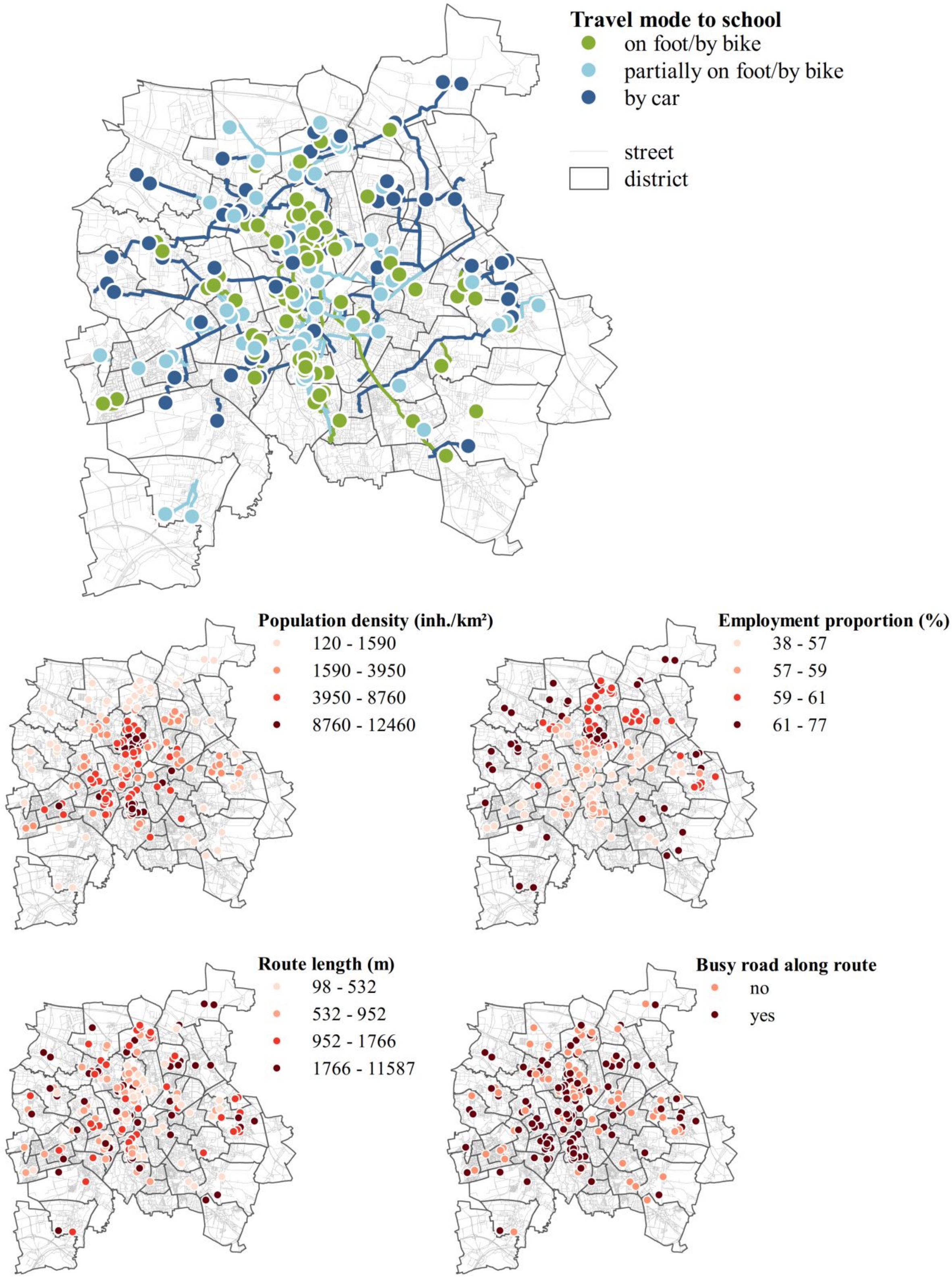

Fig. 2 LINA children and active school travel variables in the city of Leipzig (geolocations were relocalised for anonymisation purposes)

Table 1 Description of the LINA cohort (eight-year-old follow-up) and comparison with our study population

	LINA cohort n (%), n = 334	Study population n (%), n=217	χ^2 -test
Gender			0.484
Female	164 (49.10)	103 (47.47)	
Male	170 (50.90)	114 (52.53)	
Household members (6 y.)			0.784
2	14 (4.19)	8 (7.37)	
3	89 (26.65)	60 (28.11)	
≥ 4	227 (67.96)	146 (64.52)	
Parental education			
Low	4 (1.20)	2 (0.92)	0.320
Middle	64 (19.16)	37 (17.05)	
High	266 (79.64)	178 (82.03)	
Household income (pregnancy)			0.066
< € 2000	107 (32.04)	70 (34.65)	
€ 2000 - 4000	177 (52.99)	108 (53.47)	
> € 4000	29 (8.68)	24 (11.88)	
Mode of travel to school			0.001 **
On foot/by bike	124 (37.24)	96 (44.24)	
Partially on foot/by bike	106 (31.83)	63 (29.03)	
By car	103 (30.93)	58 (26.73)	
Body Mass Index (BMI)			0.161
Not overweight	243 (72.75)	159 (73.27)	
Overweight	25 (7.49)	19 (8.76)	
Obese	5 (1.50)	5 (2.30)	

** $p<0.01$

Table 2 Respondent characteristics: descriptive statistics and bivariate tests for influencing variables for travel mode types (χ^2: chi-square test, H: Kruskal-Wallis test)

Variable	Study population	**Active travel**	**Part. active travel**	**Non-active travel**	Bivariate test	p-value	Pairwise test (act-car)
Number of children (n (%))	217 (100)	96 (44.24)	63 (29.03)	58 (26.73)			
Health outcome							
Body Mass Index (BMI) (n (%))					$\chi^2 = 0.087$	0.958	
normal weight	159 (86.89)	70 (87.50)	47 (87.04)	42 (85.71)			
overweight/obese	24 (13.11)	10 (12.50)	7 (12.96)	7 (14.29)			
Individual variables							
Gender: female (n (%))	103 (47.47)	43 (44.79)	32 (50.79)	28 (48.28)	$\chi^2 = 0.570$	0.752	
Sleep duration [h] (mean ± SD)	9.88 ± 0.75	9.85 ± 0.74	9.86 ± 0.82	9.93 ± 0.70	$\chi^2 = 8.004$	0.628	
Average time spent outside in summer [h]	4.34 ± 1.62	4.28 ± 1.65	4.75 ± 1.54	4.00 ± 1.59	H = 6.172	**0.046**	0.760
Loner [true or partly true] (n (%))	54 (25.12)	29 (30.20)	14 (22.95)	11 (18.48)	$\chi^2 = 4.408$	0.354	
Low self-confidence [true or partly true] (n (%))	98 (45.58)	42 (43.75)	29 (47.54)	27 (46.55)	$\chi^2 = 9.291$	0.054	
Is anxious [true or partly true] (n (%))	81 (38.03)	35 (36.84)	22 (36.07)	24 (42.11)	$\chi^2 = 9.886$	**0.042**	0.802
Behaves carelessly around traffic (n (%))	11 (5.14)	6 (6.25)	3 (4.92)	2 (3.51)	$\chi^2 = 0.560$	0.756	
Family variables							
Number of siblings (n (%))					$\chi^2 = 7.271$	0.297	
no siblings	79 (36.41)	37 (38.54)	21 (33.33)	21 (36.42)			
one sibling	113 (52.07)	44 (45.83)	34 (52.97)	35 (60.34)			
2-3 siblings	25 (11.52)	15 (15.63)	8 (12.70)	2 (3.44)			

Dog owner (n (%))	13 (6.00)	5 (5.21)	5 (7.94)	3 (5.17)	$\chi^2 = 0.597$	0.742	
Academic qualification level (n (%))	179 (82.49)	78 (81.25)	53 (84.13)	48 (82.76)	$\chi^2 = 1.180$	0.881	
Household income group [1-8]	5.50 ± 2.23	5.36 ± 2.08 2500-3000	5.31 ± 2.11 2500-3000	6.18 ± 2.53 3000-3500	$\chi^2 = 34.895$	**0.010**	0.2079
Maternal sport frequency (n (%))					$\chi^2 = 8.098$	0.231	
never	66 (30.84)	25 (26.32)	14 (22.22)	17 (30.36)			
several times per week	42 (19.63)	25 (26.32)	12 (19.05)	5 (8.93)			
Life satisfaction [1-4] (mean ± SD)	3.33 ± 0.54	3.34 ± 0.50	3.27 ± 0.60	3.37 ± 0.52	$\chi^2 = 6.434$	0.169	
Household size	3.67 ± 0.99	3.71 ± 1.06	3.56 ± 1.03	3.72 ± 0.83	$\chi^2 = 15.622$	0.337	
Children in household	1.85 ± 0.78	1.92 ± 0.85	1.76 ± 0.76	1.83 ± 0.68	$\chi^2 = 8.178$	0.612	
Maternal employment [h]	31.08 ± 11.12	30.35 ± 12.36	31.72 ± 10.46	31.54 ± 9.84	H = 0.036	0.982	
Residential environment							
Population density [inh./km²]	5132 ± 3744	6369 ± 3732	5027 ± 3496	3200 ± 5336	H = 29.993	**<0.001**	**<0.001**
School children rate [%]	7.19 ± 1.17	7.20 ± 1.03	7.16 ± 1.02	7.20 ± 1.51	H = 0.279	0.870	
Youth rate [%]	21.07 ± 2.62	21.57 ± 2.29	20.75 ± 2.51	20.61 ± 3.11	H = 8.504	**0.014**	**0.015**
Migration rate [%]	11.20 ± 4.94	11.64 ± 4.02	12.45 ± 6.22	9.11 ± 4.10	H = 15.270	**<0.001**	**0.003**
Employment rate [%]	59.02 ± 4.16	58.82 ± 3.21	57.52 ± 4.66	60.98 ± 4.28	H = 16.447	**<0.001**	**0.005**
Unemployment rate [%]	4.86 ± 2.09	4.86 ± 1.92	4.98 ± 2.37	4.74 ± 2.05	H = 0.432	0.806	
Household size	1.81 ± 14.05	1.78 ± 0.11	1.82 ± 0.17	1.85 ± 0.14	H = 8.632	**0.013**	**0.010**
Household income	1959 ± 291	1964 ± 272	1926 ± 308	1988 ± 305	H = 1.075	0.584	
University graduate rate	0.43 ± 0.15	0.48 ± 0.13	0.43 ± 0.15	0.38 ± 0.14	H = 17.634	**<0.001**	**<0.001**
Cars per 1000 inh.	379 ± 90	356 ± 71	372 ± 99	425 ± 93	H = 20.533	**<0.001**	**<0.001**
Crimes per 1000 inh.	148 ± 211	131 ± 85	178 ± 368	143 ± 87	H = 0.259	0.878	
Satisfaction with neighbourhood	2.03 ± 0.23	2.00 ± 0.23	2.05 ± 0.26	2.04 ± 0.21	H = 2.417	0.299	

Satisfaction with own health status	2.19 ± 0.19	2.14 ± 0.16	2.19 ± 0.18	2.27 ± 0.20	H = 15.219	**<0.001**	**<0.001**
BMI	25.42 ± 1.02	25.18 ± 0.94	25.37 ± 0.99	25.89 ± 1.03	H = 17.488	**<0.001**	**<0.001**
Green areas [%]	15.94 ± 13.90	13.74 ± 11.83	17.45 ± 16.34	17.94 ± 13.93	H = 2.925	0.232	
Distance to city centre [m]	4169 ± 2274	3424 ± 1813	4229 ± 2468	5336 ± 2272	H = 24.136	**<0.001**	**<0.001**
School characteristics							
Public school (n (%))	189 (87.1)	92 (95.8)	55 (87.3)	42 (70.7)	χ^2 = 17.649	**<0.001**	**0.040**
School certified as an 'Active School' (n (%))	51 (23.50)	22 (43.14)	21 (41.18)	8 (15.68)	χ^2 = 13.436	**0.009**	0.998
Route characteristics							
Route length [m]	1648 ± 1891	771 ± 1157	1560 ± 1320	3193 ± 2386	H = 98.183	**<0.001**	**<0.001**
Reported route duration [min]	10.8 ± 6.84	8.58 ± 4.55	14.61 ± 8.09	10.36 ± 6.87	H = 30.002	**<0.001**	0.465
Detour factor	1.32 ± 0.26	1.36 ± 0.32	1.29 ± 0.22	1.28 ± 0.16	H = 0.888	0.641	
Reported busy road along route: yes (n (%))	131 (60.37)	48 (50.00)	40 (63.49)	43 (74.14)	χ^2 = 9.167	**0.010**	**0.033**
Crimes per 1000 inh. along route	152 ± 146	148 ± 132	163 ± 178	149 ± 128	H = 0.089	0.957	
Green route proportion	0.16 ± 0.14	0.14 ± 0.12	0.18 ± 0.16	0.18 ± 0.14	H = 3.302	0.192	
Street trees per 100 route metres	4.54 ± 4.05	4.65 ± 4.8	4.45 ± 3.69	4.46 ± 2.97	H = 1.090	0.580	
Accidents per 1000 route metres	1.06 ± 1.73	0.95 ± 1.81	1.31 ± 2.07	0.97 ± 1.07	H = 8.079	**0.018**	**0.036**
Main road proportion [%]	21.28 ± 25.30	14.36 ± 23.51	24.00 ± 25.10	29.78 ± 25.65	H = 23.249	**<0.001**	**<0.001**
Footpath proportion [%]	10.75 ± 13.47	10.14 ± 14.23	11.06 ± 15.91	11.41 ± 10.09	H = 5.883	**0.053**	**0.042**

Table 3 Logistic regression for mode of transport (active and part. active vs. non-active) (Nagelkerke: 0.446)

Variable	**ß estimate**	**OR**	**95% CI**	**p-value**	
Intercept	9.4040	12142	26 - 17374020	0.0054	**
Population density (inh./km²)	0.0001	1.0001	1.0000 - 1.0002	0.0246	*
Employment rate (%)	-0.1251	0.8824	0.7847 - 0.9748	0.0222	*
Route length (m)	-0.0006	0.9994	0.9991 - 0.9997	<0.0001	***
Reported busy road along route	-0.7988	0.4499	0.1919 - 1.0096	0.0578	.
School type	-0.8011	0.4488	0.1353 - 1.5704	0.2008	

$p<0.1$., $p<0.05$ *, $p<0.01$ **, $p<0.001$ ***

Table 4 Logistic regression for mode of transport (active vs. part. active and non-active) (Nagelkerke: 0.379)

Variable	**ß estimate**	**OR**	**95% CI**	**p-value**	
Intercept	-2.0310	0.1312	0.0010 - 16.8014	0.3477	
Population density (inh./km²)	0.0002	1.0002	1.0001 - 1.0003	0.0017	***
Employment rate (%)	0.0419	1.0428	0.9628 - 1.1315	0.2523	
Route length (m)	-0.0010	0.9990	0.9985 - 0.9994	<0.0001	***
Reported busy road along route	-0.5086	0.6013	0.2980 - 1.1989	0.1281	
School type	0.0059	1.0605	0.2317 - 4.5119	0.9898	

p<0.1, p<0.05 *, p<0.01 **, p<0.001 ***

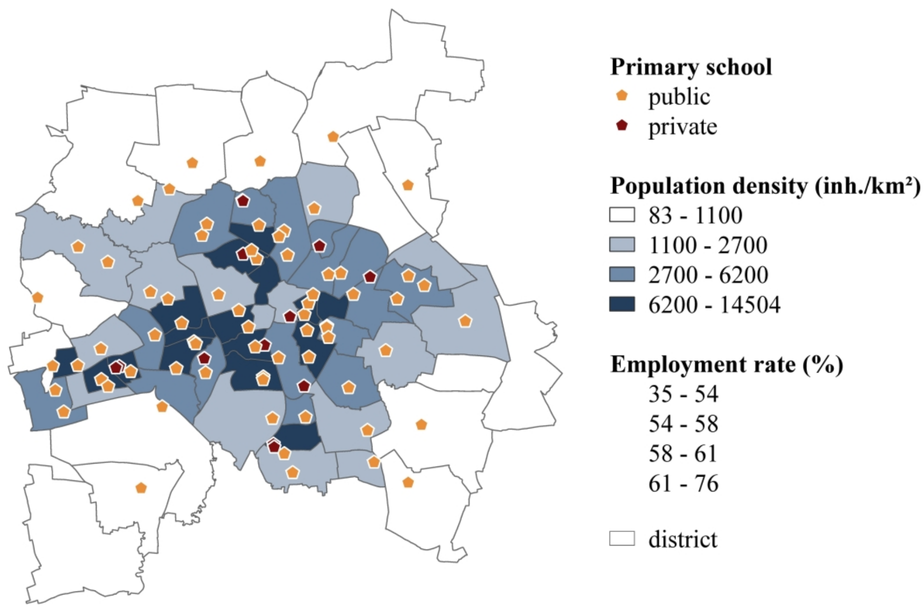

Fig. 1 Case study: Leipzig, Germany (data sources: municipal office for youth, family and education, population register, federal labour office)

284x185mm (300 x 300 DPI)

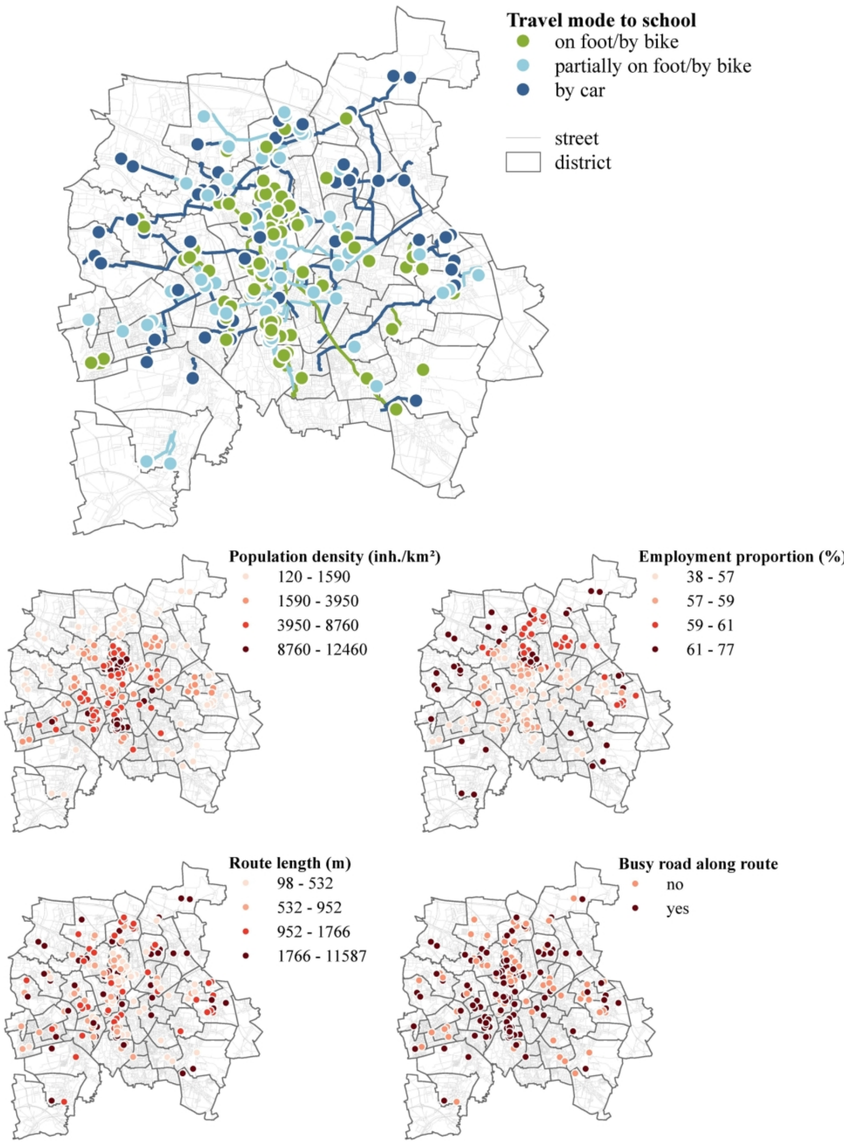

Fig. 2 LINA children and active school travel variables in the city of Leipzig (geolocations were relocalised for anonymisation purposes)

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Appendix

Table A Outcome and predictor variables included in the analysis

Variable	Indicator	Year/Date	Data source
Outcome variable			
Mode of transport to school	*excl. on foot/by bike (1), part. on foot by bike (2), excl. by car (3)*	2014-2017	LINA (8 y. own classification)
Individual variables			
Gender	*gender (male/female)*	2006-2008	LINA (after birth)
Sleep duration	*sleep duration hours*	2014-2017	LINA (8 y.)
Time outside	*average reported hours spent outside (summer/winter)*	2014-2017	LINA (8 y.)
Loner	*loner [true or partly true] (n (%))*	2014-2017	LINA (8 y.)
Low self-confidence	*low self-confidence [true or partly true] (n (%))*	2014-2017	LINA (8 y.)
Is anxious	*is anxious [true or partly true] (n (%))*	2014-2017	LINA (8 y.)
Behaves carelessly around traffic	*behaves carelessly around traffic (n (%))*	2014-2017	LINA (8 y.)
Body Mass Index (BMI) classes	*BMI based on examination or questionnaire (normal weight, overweight/obese - reference population WOF)*	2014-2017	LINA (8 y.)
Family variables			
Siblings	*number of siblings living in household*	2014-2017	LINA (8 y.)
Dog ownership	*dog ownership (y/n)*	2014-2017	LINA (8 y.)
Education qualification level	*highest education qualification level*	2006-2008	LINA (pregnancy)
Household income	*net household income*	2006-2008	LINA (pregnancy)
Maternal sport habits	*frequency of sport activities during pregnancy*	2006-2008	LINA (pregnancy)
Life satisfaction	*maternal life satisfaction (1-5) during pregnancy*	2006-2008	LINA (pregnancy)
Household size	*number of household members*	2012-2015	LINA (6 y.)
Children in household	*number of children in household*	2012-2015	LINA (6 y.)
Maternal employment	*Maternal working hours*	2012-2015	LINA (6 y.)
Residential environment			
Population density	*inhabitants per km²*	31.12.2016	Ordnungsamt Leipzig: Einwohnerregister
School children rate	*proportion of children aged 6 to 15 in entire population*	31.12.2016	Ordnungsamt Leipzig: Einwohnerregister
Youth rate	*proportion of children aged 0 to 14 compared to proportion of inhabitants aged 15 to 65*	31.12.2016	Ordnungsamt Leipzig: Einwohnerregister
Migration rate	*proportion of migrants in population*	31.12.2016	Ordnungsamt Leipzig: Einwohnerregister
Employment	*employment rate in working-aged population*	31.12.2016	Bundesagentur für Arbeit
Unemployment	*unemployment rate in working-aged population*	31.12.2016	Bundesagentur für Arbeit
Household size	*average number of household members*	31.12.2016	Amt für Statistik und Wahlen Leipzig

Household income	*average net household income*	31.07.2016	Amt für Statistik und Wahlen Leipzig: Kommunale Bürgerumfrage 2016
University graduates	*proportion of university graduates among inhabitants aged 18 and over*	31.07.2016	Amt für Statistik und Wahlen Leipzig: Kommunale Bürger-umfrage 2016
Car ownership	*number of private cars/1000 inhabitants*	31.12.2016	Kraftfahrt Bundesamt
Crime rate	*number of offenses/1000 inhabitants*	2016	Landeskriminalamt Sachsen
Satisfaction with neighbourhood	*satisfaction with neighbourhood (1: very satisfied – 5: dissatisfied) from citywide questionnaire (n= 6423, approx. 100 inh. per district)*	31.07.2016	Amt für Statistik und Wahlen Leipzig: Kommunale Bürgerumfrage 2016
Satisfaction with own health status	*satisfaction with own health status (1: very satisfied – 5: dissatisfied) from citywide questionnaire)*	31.07.2016	Amt für Statistik und Wahlen Leipzig: Kommunale Bürgerumfrage 2016
Weight status	*average BMI (citywide questionnaire)*	31.07.2016	Amt für Statistik und Wahlen Leipzig: Kommunale Bürgerumfrage 2016
Green areas	*proportion of parks, forests in 400 m buffer around place of residence*	01.06.2016	ATKIS
Distance to city centre	*Euclidean distance between place of residence and city centre*		own calculation
School characteristics			
School type	*public school, private school*	school year 2016/17	Amt für Jugend, Familie und Bildung
Primary school promoting physical activity	*primary school certified as 'Active School' (2), promoting physical activity (1), not promoting physical activity (0)*	03.06.2019	Sächsiche Schuldatenbank
Route characteristics			
Route length	*shortest route (m)*	2014-2017	LINA (own calculation)
Perceived duration	*route duration (in min)*	2014-2017	LINA (8 y.)
Detour factor	*route length/linear Euclidean distance (school, home)*	2014-2017	LINA (own calculation)
Busy road along route	*perceived busy road along route (y/n)*	2014-2017	LINA (8 y.)
Crime rate	*number of offenses/1000 inhabitants within 100 m buffer along route*	2016	Landeskriminalamt Sachsen
Green areas	*during route crossed or passed (+2m) parks, forests*	01.06.2016	ATKIS
Street trees	*number of street trees within 25 m buffer per 100 route metres*	16.02.2015	Amt für Stadtgrün und Gewässer
Accidents	*accidents involving pedestrian(s) or cyclist(s) on weekdays (6:00-17:59) per 1000 route metres*	31.12.2016	Statistisches Landesamt des Freistaates Sachsen
Main road proportion	*main road proportion (%)*	14.11.2017	OpenStreetMap
Footpath proportion	*footpath proportion (%)*	14.11.2017	OpenStreetMap

Table B Principal component analysis

Factor loadings	**Factor I:** socio-demographics	**Factor II:** socio-economics	**Factor III:** route length, school type	**Factor IV:** traffic
Population density	-0.68			
Youth rate	-0.64			
Migrant proportion		-0.82		
Employment rate		0.82		
Household size		0.90		
University graduate rate	-0.87			
Private cars/1000 inh.		0.82		
Health satisfaction	0.90			
BMI	0.88			
Distance to city centre	0.72			
Route length			0.82	
Reported busy road				0.47
Accidents/1000 m				0.46
Main road proportion				0.59
Footpath proportion				-0.70
School type			0.79	
proportion of variance	0.27	0.25	0.12	0.10
cumulative variance	0.27	0.51	0.64	0.73

Table C Outlier analysis

	Active travel		Non-active travel	
	long route (n=5)	**others** (n=91)	**short route** (n=12)	**others** (n=46)
Route length	4524.66 ± 3333.73	565.17 ± 305.90	890.38 ± 245.33	3793.63 ± 2326.70
Population density	6439 ± 4543	6365 ± 3713	4890 ± 4000	2759 ± 2842
Employment rate	59.84 ± 1.97	58.76 ± 3.27	59.49 ± 3.24	61.37 ± 4.47
Reported busy road (n (%))	3 (60%)	45 (49.45%)	7 (58.33%)	36 (78.26%)
Accidents per 1000 route metres	3.70 ± 1.57	0.80 ± 1.70	0.90 ± 1.37	0.98 ± 1.00
Public school attendees (n (%))	89 (97.80%)	3 (60.00%)	12 (100.00%)	30 (65.22%)
Main road proportion	35.40 ± 21.71	13.21 ± 23.16	17.67 ± 20.93	32.93 ± 26.01
Female (n (%))	2 (40.00%)	41 (45.05%)	9 (75.00%)	19 (41.30%)