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School travel modes and children's spatial cognition

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Abstract
This study broadens understanding of how children's travel modes influence the development of their spatial cognition, specifically the development of their spatial representation of home–school routes. Data were collected using a questionnaire survey and a cognitive mapping process at an elementary school in northern Taiwan. The sample, which comprised 521 Grades 1–6 children aged 7–12 years, was analysed through linear regressions. Empirical results indicate that the use of independent, active or non-motorised transportation modes improved the children's spatial cognition regarding their home–school routes. This study not only provides new knowledge about the relationships between travel modes and the spatial cognition of children, but also identifies policy directions in relation to school transportation and the development of spatial cognition in children.

Keywords
Child, school travel, spatial cognition

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Introduction

Spatial cognition is defined as the acquisition, organisation, utilisation and revision of knowledge about the spatial properties of objects and events in the world (Montello, 2001). By exploring and experiencing environments, children develop their spatial cognition. Piaget (1950) suggested that the cognitive development of children during their maturity process has four stages, namely, sensorimotor stage, pre-operational stage, concrete operational stage and formal operational stage. Piaget's stages of cognitive development are generally used as the basis for depicting the growth of logical thinking in children and such use has been widely extended to explore issues in child psychology, such as the influence of advertising (Kinsky and Bichard, 2011), and in education, such as teaching strategies (Powell and

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Kalina, 2009). Children aged 7–11 years are typically in the concrete operational stage. At this stage, children begin to increase their awareness of external environments. Their self-absorption also declines as they begin to understand the concept of space in the relationships among proximity, separation, order, enclosure and continuity (Piaget and Inhelder, 1956). As they age, children transfer their reference points to other objects or people and start to identify their relative positions in the given space. Recognising place is at the core of spatial cognition. Notably, basic spatial cognition markedly influences performance in various fields, such as arts, math, architecture, aviation and design. Therefore, spatial cognition is crucial to a child's growth.

Research on the spatial cognition of children has been of interest to both geographers (e.g. Kitchin, 1996) and psychologists (e.g. Joshi et al., 1999). Previous studies identified numerous factors that influence a child's spatial cognition. These factors are physical attributes, such as age (e.g. Matthews, 1984) and gender (e.g. Ahmadi and Taniguchi, 2007); socio-cultural context (e.g. Parameswaran, 2003); behavioural experiences (e.g. Schmeinck and Thurston, 2007); and household attributes (e.g. Joshi et al., 1999). Gauvian (1993) argued that practical everyday activities influence individual spatial knowledge. Travelling to school is one of the most common daily activities of children. Children generally travel between their homes and schools twice on weekdays. On their way to and from school, children can interact with the surrounding environments and develop spatial cognition of their neighbourhood by exploring their surroundings. Through cognitive processes, children transform their experiences into spatial cognition, which represents their view of the world. However, only a few researchers have examined the relationships between travel to school and spatial cognition. Joshi et al. (1999) and Rissotto and Tonucci (2002) argued that children who travelled to school without an adult can draw more neighbourhood landmarks in their cognitive maps than children who were accompanied by an adult. Ahmadi and Taniguchi (2007) concluded that children who walked or took buses on their own to school can present more accurate sketch maps than those who were driven by car or took school buses. Parameswaran (2003), who compared cognitive maps by children from India and the USA, determined that the use of personal vehicles is related to reduction in the number of mapped neighbourhoods. The limited findings in previous research indicate that the independent, active or non-motorised travel modes for home–school journeys could benefit children's development of spatial cognition. Independent travel modes, which refer to walking, biking, or taking a school bus or public transit without adult company, provide children with more opportunities to explore surroundings along their routes. Active travel modes, which denote independent modes excluding taking a school bus, encourage children to perform way-finding action and to pay attention to environments. Non-motorised travel modes, which include walking and biking, allow children to travel at a low speed and observe their environments in detail. These three travel modes theoretically benefit spatial knowledge acquisition. Although independent and active travel modes have been examined individually by different surveys, empirical evidence of how non-motorised travel modes influence a child's spatial cognition has not been presented in literature.

The travel behaviours of children have markedly changed toward the use of dependent, passive and motorised travel modes over the last 40 years. In England, the proportion of children aged 7–8 who travelled to school independently in 1970 was 80%.

In 1990, this proportion declined to 10% (Hillman et al., 1990). In the USA, 48% of children aged 5–14 usually walked or biked to school in 1969. In 2009, only 12% of children walked and 1% biked to school (Federal Highway Administration, 2011). The statistics for Taiwanese children are similar. Lin and Chang (2010) surveyed elementary school children in Taipei in 2006 and found that only 35%–40% of school trips were independent (no adults) and more than 40% of school trips were by private motorised vehicles. To develop suitable policies for school travel that can improve a child's spatial cognition, the relationship between travel modes and spatial cognition development must be comprehensively elucidated. However, evidence in literature remains too fragmented and incomprehensive for policy development.

The current study examines the relationships between transportation mode for school travel and spatial representation along home–school routes in children aged 7–12. The study question is associated with the acquisition and development of spatial cognition, which compose one of the essential topics in geographic studies of spatial cognition that was argued by Montello (2001). The study sample comprised 521 elementary school students in a city in northern Taiwan; sample data were collected using a two-stage survey (general questionnaire and spatial cognitive mapping) in November and December 2012. To characterise the relationships, this study categorised travel modes as independent modes versus dependent modes, active modes versus passive modes and non-motorised modes versus motorised modes. This study examines spatial cognition using cognitive maps drawn by the participants and seven indicators that measure the richness, correctness and aggregation of spatial representations on the home–school routes of children. Compared with that of previous research, empirical evidence in this study contributes to literature in several ways. First, this study determines the effects of independent, active and non-motorised travel modes on spatial cognition simultaneously, whereas Joshi et al. (1999), Rissotto and Tonucci (2002), and Ahmadi and Taniguchi (2007) examined the individual effects of independent or active travel modes. Second, this study is the first to provide evidence of the effects of non-motorised travel modes on children's spatial cognition and to confirm the hypothesis of Parameswaran (2003), which has been previously untested. This original evidence supports theory development and will be a valuable reference for the development of policy directions. Third, this study investigates the comprehensive measures of spatial cognition, which include number of landmarks, paths, places and objects, and correctness of route direction and structure. These measures represent multiple components and provide more complete information about a child's spatial cognition. To the best of our knowledge, such comprehensive evidence has not been put forward by previous studies.

Method

Participants and procedure

The sample in this study was selected from an elementary school located in a medium-sized city in northern Taiwan with a population of 413,488 at the end of 2012. The school's catchment area, which comprises residential areas, borders the city centre and covers approximately 1 km^2. Convenient transportation services are available in this catchment area: the school is served by a railway route, two bus routes and several roads. The longest distance from a residence to the school is approximately 1.2 km. Given that the school has a history that exceeds 56 years and a good reputation, many students living outside its catchment area travel relatively long distances to the school.

This study distributed a questionnaire in November and December of 2012 to all students in 32 classes; the classes were randomly selected from the 74 classes. The survey was reviewed and approved by the Research Ethics Committee of the National Taiwan University on 29 October 2012 (No. 201210HS022). Among the 906 surveyed students, 553 students agreed to participate, yielding 521 effective responses. The response rate was 61.04%, and effective response rate was 94.21%. The first part of the survey contained questions regarding travel to and from school (mode, distance, time and number of stops) during the previous week, individual attributes (age, gender, physical activity and travel experience), and household attributes (parental attitudes, education levels, income, vehicle ownership and years of residence in the catchment area). The surveyed students were requested to bring home the questionnaire forms of the first part of the survey and the informed consent forms (ICFs). After the parents have consented to their participation in the survey as evidenced by the parental signatures on the ICFs, the participants and their parents answered the questions together at home. The questions on household attributes were answered by parents, and the questions on school travel and individual attributes were answered by the children under their parents' supervision. The second part of the survey required participants to draw cognitive maps of the areas along their home–school routes in their classrooms.

Cognitive maps have been employed to record participants' spatial cognition by Ahmadi and Taniguchi (2007), Joshi et al. (1999), Matthews (1984), Mondschein et al. (2010), Parameswaran (2003), and Rissotto and Tonucci (2002). According to the review by Mondschein et al. (2010: 847), a cognitive map includes spatial information about environments, including place and route identity, location, distance and direction (Downs and Stea, 1977). In the cognitive mapping process in this study, each participant was given a sheet of A4 (210 mm × 297 mm) blank paper and was requested to draw a map of his or her route from home to school and the areas along that route within 15 minutes. Biel (1982) suggested that a child's home acts as a central reference point in his or her mental representation of environments. Moreover, participants were encouraged to draw as many significant landmarks, paths, places and objects as possible. Based on the definitions of elements in mental maps by Lynch (1960), landmarks, such as noticeable buildings or stores, are readily identifiable objects that serve as external reference points; paths are streets, sidewalks, trails and other channels on which people travel; places or districts, such as playgrounds, are spaces that distinguish their identity or character; and objects, such as bus stops, traffic signs or trees, are significant elements that differ from landmarks, paths and places. These definitions were explained by the investigators before the participants started to draw their cognitive maps. After the mapping process, the completed maps were checked by the investigators immediately and the participants were requested to interpret their maps if these were unclear. If a participant drew multiple nodal elements that were neither path nor place and were not clear enough to be identified as landmarks in his or her map, then the investigators requested this participant to interpret which elements were landmarks and which elements were objects.

Study variables

Figure 1 lists the study variables including outcome variables (spatial cognition) and explanatory variables (school travel modes and controls). Considering that multiple representations make up a cognitive map (Kuipers, 1978), the following seven

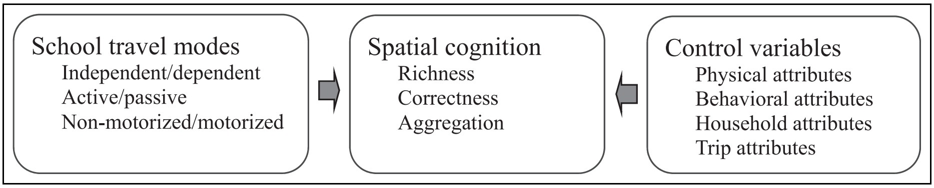

Figure 1. Study variables.

indicators on the cognitive maps served as the outcome variables representing a child's spatial cognition:

Landmark: The number of landmarks on a cognitive map
Path: The number of paths on a cognitive map
Place: The number of places on a cognitive map
Object: The number of objects on a cognitive map
Route orientation: The orientation correctness of a route from a child's home to his or her school drawn in a cognitive map
Route structure: The structural correctness of a travel route from a child's home to his or her school in a cognitive map
Aggregation: The summation of the above six variables, representing general performance considering richness (first four variables) and correctness (fifth and sixth variables) for a cognitive map

Route orientation is measured based on the definition of route orientation by Rissotto and Tonucci (2002: 70) and has a value between 6 (maximum) and 3 (minimum). The locations of home and school as indicated by a child were compared with their true positions according to their top/bottom and right/left laterality. A classification, erroneous = 1 / correct = 2, was used to code both types of laterality. Additional information concerning orientation was obtained from the comparison between the route drawn by a child and the real route, obtained by reversal/rotation. This attribute was also coded using a classification presence of rotation/reversal = 1, absence of rotation/reversal = 2. *Route structure* is a variable that is based on the definition of route structure by Rissotto and Tonucci (2002: 70) and has a value between 4 (maximum) and 2 (minimum). The route drawn by a child was compared with the real route in terms of proportionality among the different segments and the number of corners. Each of these attributes was coded using a classification erroneous = 1 / correct = 2.

Figure 2(a) illustrates a cognitive map drawn by a boy aged 9 in a third-grade class. The boy went to school daily by riding a motorcycle with his mother and left school by taking the school bus that was operated by a school-age child care centre. Figure 2(b) shows the real positions of the elements in the cognitive map. According to these two maps, the outcome variables of this observation were coded as landmark = 2, path = 2, place = 0, object = 0, route orientation = 5 (top/down and left/right literalities were both correct but presented rotation) and route structure = 3 (number of corners was correct but its proportionality among segments was erroneous). The two landmarks were a convenience store and a book store with brightly coloured appearances and were used as reference points in relation to the school.

This study applied linear regressions to identify the relationships between outcome variables and explanatory variables. Table 1 lists the definitions of explanatory variables and their hypothetical relationships with children's spatial cognition. The justifications of these hypotheses are as follows.

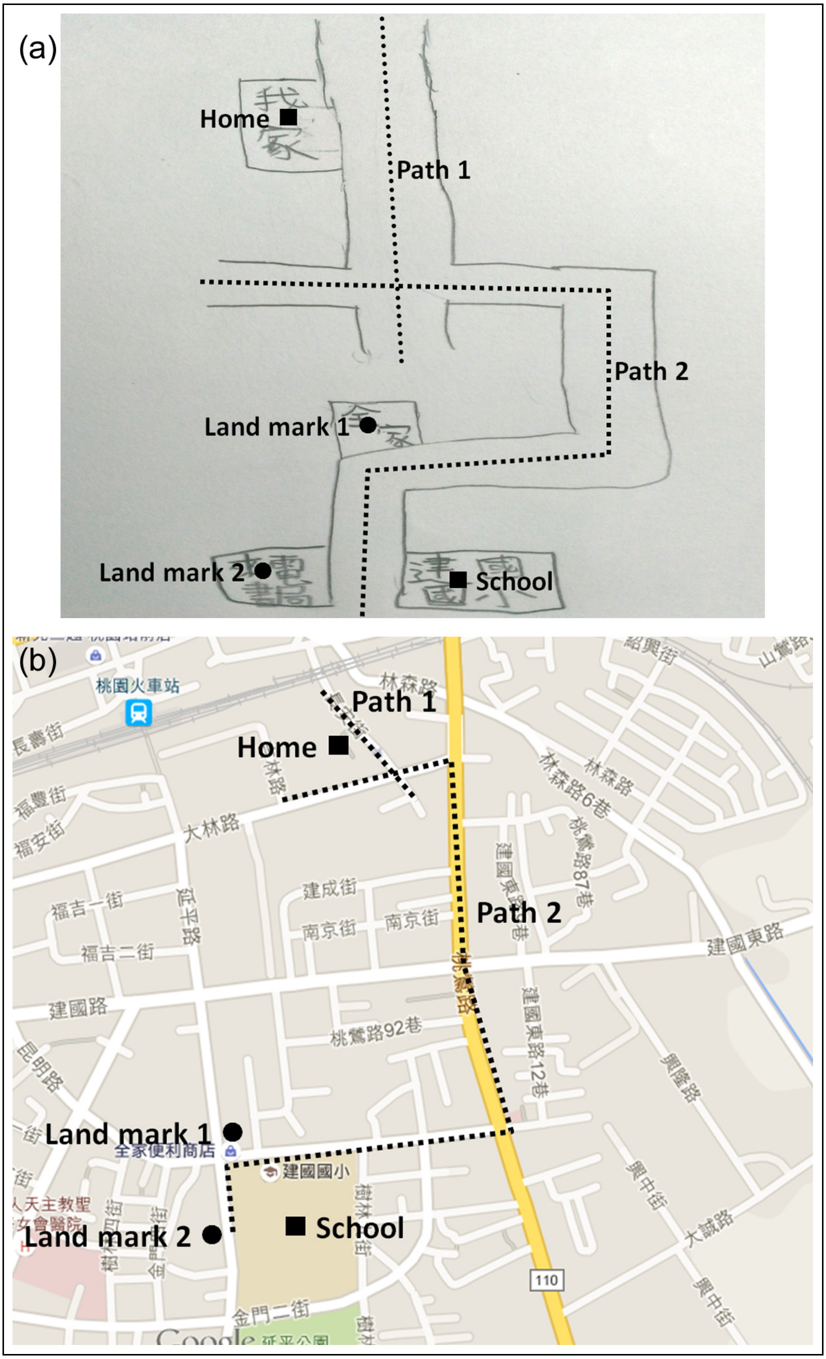

Figure 2. An illustration of (a) cognitive map and (b) the actual map.
Source: Google maps (https://www.google.com.tw/maps/@24.9866405,121.3145172,16z?hl=zh-TW).

Table 1. Definitions of explanatory variables and their hypothetical effects on outcome variables.

Name	Definition	Unit	Hypothesised effects [a]
School travel modes			
Independent mode	Frequency of walking, biking or taking a school bus or public transit to or from school without an adult in the last week	–	+
Active mode	Frequency of walking, biking or taking public transit to or from school without an adult in the last week	–	+
Non-motorised mode	Frequency of walking or biking to or from school in the last week	–	+
Controls			
Physical attributes			
Gender(male)	A child is male (0–1), while female is the base	–	Δ
Grade	Grade of participant	–	+
BMI	A child's body weight divided by the square of his/her height	kg/m^2	–
Behavioural attributes			
Leisure travel	Frequency of leisure trips in the last month	–	+
Long-distance travel	A child has (= 1) or has not (= 0) experienced long-distance travel (i.e. travel destinations beyond the county or city where he or she lived)	–	+
Freedom during off-school time	Parental agreement with the following statement: my child is free to arrange his or her activity during off-school time	Interval scale [b]	+
No worries about outdoor activities	Parental agreement with the following statements: I do not worry about my child playing in parks (Park); I do not worry about my child playing on streets (Street); I do not worry about my child going to stores within 1 km of home (Store1); I do not worry about my child going to stores 1 km away from home (Store2)	Interval scale [c]	+
Physical activity	Frequency of physical activity with moderate-to-vigorous intensity in the last week	–	+
Household attributes			
Father's education	Educational achievement of a child's father: junior high school (EduF1, 0–1); senior high school (EduF2, 0–1), Bachelor degree (EduF3, 0–1) or Master or PhD degree (EduF4, 0–1); uneducated or elementary school is the base	–	+
Mother's education	The educational achievement of a child's mother: junior high school (EduM1, 0–1); senior high school (EduM2, 0–1); Bachelor degree (EduM3, 0–1) or Master or PhD degree (EduM4, 0–1); uneducated or elementary school is the base	–	+
Household income	Household annual income is lower than the median (Inc1, 0–1); median (Inc2, 0–1); higher than the median (Inc3, 0–1); much higher than the median (Inc4, 0–1) or extremely high (Inc5, 0–1); low income is the base. Classified using the income thresholds of income quintile groups in Taiwan, 2011	–	+

(continued)

Table 1. (Continued)

Name	Definition	Unit	Hypothesised effects [a]
Residing years	The number of years a child lived in his or her current residence	Year	+
Car ownership	Household owns a car(s) (0–1); does not own a car is the base	–	–
Motorcycle ownership	Household owns a motorcycle(s) (0–1); does not own a motorcycle is the base	–	–
Bike ownership	Household owns a bike(s) (0–1); does not own bike is the base	–	+
Trip attributes			
(Travel distance) × (motorised mode)	(Travel distance) means the travel distance between a child's home and school; (motorised mode) means a child uses (= 1) or does not use (= 0) motorised modes during school travel	m	–
Stop number	Average number of stops on a child's school-to-home daily trips	–	+

Notes: [a] + represents positive effect, – refers to negative effect, and Δ denotes + and – both may exist.
[b]This variable was scored between 1 (most disagreeable) and 10 (most agreeable) points.
[c]This variable was scored between 1 (most disagreeable) and 4 (most agreeable) points.

School travel modes. Three travel mode attributes should be positively related to children's spatial cognition. The first attribute is independence. When children travel between home and school without adults, they have more opportunities to explore their surroundings along their route than children who travel with adults. We hypothesise that children's spatial recognition improves with the increase in the use of independent travel modes. Joshi et al. (1999) and Rissotto and Tonucci (2002) concluded that children who travel to school independently can perform better in terms of spatially representing landmarks than children who travel to school with parents. In addition to landmarks, other spatial cognition items, such as paths, places, objects and routes have not been examined in previous research. The second attribute is way-finding action. Independent children are motivated to actively recognise the ways to home or school; thus, they typically pay more attention to their environments and remember more spatial information than children who are escorted by parents or school bus drivers. Therefore, we hypothesise that increasing the use of active travel modes enhances children's spatial recognition. Taking a school bus is not an active travel mode because children are not required to pay attention to the route or stops when on a school bus. Ahmadi and Taniguchi (2007) showed that children who walked or took public buses to school on their own generated better sketch maps in terms of correctness of travel routes than those who were driven by cars or took school buses. The third attribute is speed. When children travel at a low speed, they have more time to observe. Thus, the likelihood of observing environments in detail is higher compared with children who use rapid travel modes. Thus, we hypothesise that increasing the use of non-motorised travel modes enhances the children's spatial cognition. Parameswaran (2003), who examined the differences in cognitive maps drawn by Indian children and US children, hypothesised that the use of motorised vehicles was negatively related to children's spatial knowledge of their immediate neighbourhood. However, this hypothesis was never empirically tested.

Controls. Physical, behavioural, household and trip attributes, in addition to school travel modes, are related to spatial cognition and are used as control variables. In terms of physical attributes, previous studies differ in their observations of the relationships between gender and spatial cognition. Herman et al. (1987), Mondschein et al. (2010) and Schmeinck and Thurston (2007) concluded that males can perform better than females; Ahmadi and Taniguchi (2007) and Gómez et al. (2011) found that females can perform better than males; and Kitchin (1996) and Sandamas and Foreman (2007) argued that no significant difference exists between the spatial cognition of males and females. Hence, we could not confidently hypothesise the relationship between gender and spatial cognition prior to the drawing task. Based on four-stage theory of Piaget (1950) and the large amount of empirical evidence including that in the work of Ahmadi and Taniguchi (2007), Herman et al. (1987), Matthews (1984), Parameswaran (2003), Poria et al. (2005) and Thommen et al. (2010), children's spatial cognition evolves as they age. Thus, we hypothesise that grades and spatial cognition are positively related. Given that overweight children often take part in outdoor activities and interactions with environments less often than healthy weight students, they may develop their spatial cognition slower than the other children. Gómez et al. (2011) found that body mass index (BMI) negatively affects the children's spatial cognition. We also hypothesise this finding.

For behavioural attributes, increasing the frequency or opportunity to engage in outdoor activities may improve the ability of children to observe and their interest in the neighbourhood environments, thereby enhancing their spatial cognition. Previous research suggested that travel experiences (Schmeinck and Thurston, 2007), freedom to engage in outdoor activities (Joshi et al., 1999; Torell and Biel, 1985), and frequency of physical activities (Gómez et al., 2011) are positively associated with the children's spatial cognition. Accordingly, these relationships are also hypothesised in this study.

In terms of household attributes, as the number of years that a child resides in the same neighbourhood increases, his or her familiarity with the neighbourhood improves, enhancing spatial cognition of his or her surroundings. Previous studies support this hypothesis. For example, Mondschein et al. (2010) found that as the number of years a person resides at the same address increases, his or her accuracy in geographical distance estimation increases. Parents with high socioeconomic status (SES) could pay more attention to their child's development in numerous aspects, including spatial cognition. Previous research mostly used parental education level and household income as determinants of parental SES and concluded that positive relationships exist between parental SES and a child's health (e.g. Flores et al., 1999) and academic achievement (e.g. Davis-Kean, 2005). We hypothesise that the same relationships exist for the study sample. Household vehicle ownership should affect the travel mode a child uses in his or her daily life. Parents who own motorcycles or cars may often transport their child using a motorised vehicle, thereby reducing their child's opportunities to observe his or her surroundings and to develop spatial cognition. Conversely, children of households that own bikes tend to frequently use bikes, thus increasing their opportunities to explore their environments and improve their spatial cognition.

For the trip attributes of home–school travel, travel distance and number of stops are two attributes that are related to spatial cognition. A stop denotes a pass-by stop along a school–home journey after school for specific purposes, such as shopping, visiting friends and learning activities that are not offered by transportation (e.g. traffic light or bus station) or active pauses during travels. Short period stops caused by transportation or active pauses are quite difficult to remember and record completely by children and thus were not counted in this study. Ahmadi and Taniguchi (2007) investigated children's stops for specific purposes and argued that as the number of stops during school travel increases, opportunities to interact with environments increases as well, benefiting the children's spatial cognition. Conversely, when travel distance is long, parents typically escort their children to or from schools via motorised vehicles, negatively affecting the children's spatial cognition. However, the effects of travel distance on spatial cognition appear to depend on travel mode. That is, walking or biking long distances should increase the number of opportunities to interact with environments, benefiting the children's spatial cognition (Gómez et al., 2011). Therefore, we hypothesise that children's spatial cognition is positively related to the number of stops and negatively related to travel distance when using motorised travel modes.

Results

Table 2 summarises the descriptive statistics for the study variables. According to the variation coefficients, most continuous variables have adequate variations for regression analysis. Relatively small variations exist in values for route orientation and BMI. In addition, highly diverse values exist for the variable number of stops. Among the participants, 55%, 31% and 49% used independent, active and non-motorised modes, respectively, for school travels at least once during the survey week. More than half of the participants did not use active or non-motorised modes for school travels during the survey period; hence, median values of zero were obtained for these two travel mode variables. The distribution of males and females in this study was approximately equal, and almost all had experience of travelling long distances. Most parents graduated from high school or earned bachelor's degrees. In terms of income, 70% of surveyed households were below the median (NT$786,324 or US$26,210 annually). Furthermore, 80% of the households owned one or more cars, motorcycles or bikes.

The SPSS 17.0 package and ordinary least squares method were employed for model estimation. For each outcome variable, the base model only considered the control variables and the expanded models considered the control and travel mode variables. Three travel mode variables, namely, independent mode, active mode and non-motorised mode, were used separately in three expanded models to prevent co-variation. The co-variation exists among these travel mode variables because each observation could be associated with more than one travel mode variables. For example, children who walk to schools without adult company are associated with using independent mode, active mode and non-motorised mode simultaneously. Explanatory variables with a coefficient significance below the confidence level of $1-\alpha = 80\%$ were withdrawn from regressions. Confidence levels of 99%, 90% and 80% for each variable in regression results represented strong, moderate and weak significance, respectively.

The Appendix lists the estimation results for the seven outcome variables. The regression models showed mostly acceptable goodness-of-fit with R^2 values exceeding 0.3.

Table 2. Descriptive statistics of study variables of study sample.

Continuous variable	Minimum	Maximum	Median	Mean	Variation coefficient
Spatial cognition					
Landmark	0	41	6	7.01	0.77
Path	0	19	2	2.92	0.96
Place	0	5	1	1.13	0.54
Object	0	37	2	3.77	1.44
Route orientation	0	6	5	4.93	0.24
Route structure	0	4	3	2.87	0.30
Aggregation	0	93	20	22.62	0.49
School travel mode					
Independent mode	0	10	5	3.51	1.05
Active mode	0	10	0	2.14	1.67
Non-motorised mode	0	10	0	3.35	1.18
Controls					
Grade	1	6	4	3.62	0.46
BMI	10.46	31.25	16.67	17.54	0.19
Leisure travel	0	20	2	2.59	1.03
Freedom during off-school time	1	9	6	6.28	0.38
No worries about outdoor activities					
Park	0	3	1	1.33	0.50
Street	0	3	1	0.87	0.80
Store1	0	3	1	1.64	0.59
Store2	0	3	1	0.90	0.64
Physical activity	0	50	3	4.16	1.19
Residing years	0.25	13	8	7.82	0.38
(Travel distance) × (motorised mode)	0	18,000	400	896.96	1.59
Stop number	0	6	0	0.40	1.99
Category variable	Category percentage [a]				
Controls					
Gender	Male: 49.9%; Female: 50.1%				
Long-distance travel	Yes: 95.78%; No: 4.22%				
Father's education	Base: 1.75%; EduF1: 7.20%; EduF2: 35.02%; EduF3: 42.02%; EduF4: 14.01%				
Mother's education	Base: 2.50%; EduM1: 5.97%; EduM2: 38.15%; EduM3: 49.33%; EduM4: 4.05%				
Household income	Base: 11.90%; Inc1: 26.68%; Inc2: 22.65; Inc3: 18.43%; Inc4: 16.12%; Inc5: 4.22%				
Car ownership	Yes: 89.44%; No: 10.56%				
Motorcycle ownership	Yes: 95.78%; No: 4.22%				
Bike ownership	Yes: 80.04%; No: 19.96%				

Note: [a]Category notations are defined in Table 1.

Although the models for place and route direction had relatively low R^2 values (approximately 0.1 and 0.2, respectively), their F tests yielded strong significance. Furthermore, all variance inflation factor values were less than 10. In other words, no significant multicollinearity existed among explanatory variables. Therefore, this study confirmed that these regressions are effective means for examining the relationships

Table 3. Empirical effects of school travel modes on children's spatial cognition.

Variable/outcome	Richeness				Correctness		Aggregation
	Landmark	Path	Place	Object	Route orientation	Route structure	
Independent mode				+ **	+ ***	+ ***	+ ***
Active mode				+ **	+ ***	+ ***	+ ***
Non-motorised mode					+ ***	−***	+ ***

Note: + : Positive effect; −: Negative effect; ***significant at α = 0.01; **significant at α = 0.1.

between explanatory variables and spatial cognition.

Among the regressions of the seven outcomes, the goodness-of-fit of the expanded models was insignificantly better than that of the base models; however, the travel mode variables added to the expanded models significantly explained the partial outcomes. Table 3 lists the travel mode variables that achieved moderate significances (α = 0.1) in the Appendix and their effects on children's spatial cognition. Use of independent, active or non-motorised modes during school travel in general was positively related to the number of objects, correctness of route orientation and structure, and aggregated scores for the spatial cognition maps of the participants. The empirically positive effects (Table 3) support the hypothesised effects (Table 1), whereas the negative relationship between non-motorised mode and correctness of route structure contradicts the hypothesised relationship. Furthermore, school travel modes were not associated with the number of landmarks, paths and places in the participants' cognitive maps (Table 3). The possible reasons for these contrasting or insignificant results of the hypothesised effects are discussed in the following section.

As for control variables, most of the empirical effects (Appendix) were consistent with the expected effects (Table 1). These relationships include the positive effects of the study variables, namely: male; grade; long-distance travel; no worries about outdoor activities (park, store1 and store2); physical activity; and household income as well as the negative effects of car ownership and travel distance using motorised mode on participants' spatial cognition. Certain controls, including BMI, leisure travel and years of residence in the same neighbourhood failed to significantly explain any of the outcomes. The negative effects of variables, such as no worries about outdoor activities (street), motorcycle ownership, bike ownership and number of stops on partial outcomes were contrary to the hypothesised effects (Appendix). Furthermore, some controls showed varying effects on different outcomes. The freedom during off-school time was negatively related to the number of objects but positively associated with the correctness of the route direction and structure. The father's education level was positively related to the correctness of route direction and structure and did not present a clear relationship with other outcomes. In addition, the mother's education level was negatively associated with the aggregation outcome and did not present a clear relationship with other outcomes. As the hypothetical effects were proposed based on findings from American (North and South), Asian (Middle East and South), and European studies, they could not fully explain spatial cognition of children in the Taiwanese context. Therefore, the inconsistent results require further exploration.

Discussion

Empirical evidence confirmed that school–home travel modes affect a child's spatial cognition. Specifically, using independent, active or non-motorised modes is positively associated with spatial cognition in terms of object richness and route correctness. These analytical results support the idea proposed by Hillman et al. (1990) that travelling to school by a motorised mode and with an adult negatively affects children's spatial cognition development.

The research results show that using independent or active travel modes is positively correlated with object richness, correctness of route orientation and structure, and aggregated score in a child's cognitive map. These relationships have not been identified in previous research. However, Joshi et al. (1999), Rissotto and Tonucci (2002) and Ahmadi and Taniguchi (2007) concluded that using independent or active travel modes enables children to draw several landmarks or places in cognitive maps. However, these effects were not identified in the present research. The above inconsistency may be related to the differences in the study designs. The first difference is in the survey instruments. Previous studies fixed and marked school positions and spatial boundaries with survey instruments and asked participants to draw cognitive maps within these restricted boundaries. These instruments stopped the children from drawing items beyond the given boundaries, adversely affecting the completeness of the cognitive maps. The present study used blank paper and asked participants to mark the positions of their school, home and all other items on their cognitive maps. In the absence of any spatial boundary, children were able to draw more comprehensive cognitive maps. The second difference is in terms of the measures for travel mode variables. This study measured travel mode variables by the frequency of travel to and from the school using different modes within a single week. However, previous research used dummy variables to code the most frequent mode used for school travel and ignored the possibility of using different travel modes day by day and between travels to and from schools. With its thoughtful design, the empirical evidence gathered in this study should be more reliable than those in previous research.

For non-motorised travel modes, the research results indicate that walking or biking to and from schools is positively related to the correctness of route orientation and aggregated scores of cognitive maps. This positive relationship confirms the hypothesis put forward by Parameswaran (2003), which has never been examined empirically. Notably, non-motorised modes are negatively correlated with the correctness of route structure. This finding is not consistent with the hypothesis in this study. Two possible reasons exist for this test result. First, a significant proportion of the children who lived in neighbouring areas were driven to or from the school and these children were very familiar with the routes between their homes and the school because the distances were short. Among the surveyed children living within 1000 m of the school, 42.6% were routinely transported to or from the school by motorcycle or car. In such cases, using non-motorised travel modes did not account for the negative relationship. Second, walking or biking benefits route direction cognition but could adversely affect route structure cognition. Based on the definition of Rissotto and Tonucci (2002), route structure is related to the spatial scale relations among itinerary segments and turns on a home–school route. According to numerous studies, including those by Crompton and Brown (2006), Durgin et al. (2005) and Hanyu and Itsukushima (1995), movement speed is an influential factor for distance cognition. Walking or biking at a low speed, when compared with riding a motorised vehicle, could result in biased distance estimations which in turn negatively affect a child's cognition of route structure. Among the 34 observations on children whose travel distances between residence and school were roughly equivalent (600 m–1000 m), the average route structure score of children using non-motorised modes more than five times during the study week was relatively lower than that of children using motorised modes more than five times during the study week ($2.5 < 2.7$). This result denotes that fast travellers could represent better route structure than slow travellers and speed could influence the cognition of the route structure. However, the negative relationship between non-motorised travel modes and the cognition of route structure warrants further study.

In addition to travel modes, several controls that are related to travel activity present meaningful associations with children's spatial cognition. Experiences of leisure travel and long-distance travel are positively related to the representation of the landmarks, places and objects in a child's cognitive map. This result supports the argument of Schmeinck and Thurston (2007) that increasing travel experiences improves children's abilities to observe and develops their interest in their neighbourhood environments. Moreover, the interactive variable of travel distance using motorised modes is negatively related to the representation of the places and the correctness of the route direction and structure in a child's cognitive map. This finding supports the view of Gómez et al. (2011) that increasing walking or biking distances increases the opportunities to interact with environments and benefits children's spatial cognition. The above evidence denotes that school travel modes and other travel experiences, such as frequency and distance, are important to children's spatial cognition.

These discussions emphasise that the empirical findings contribute to literature in two significant ways. First, this study examined the comprehensive measures of travel modes (i.e. independent, active and non-motorised travel modes) and spatial cognition (i.e. richness of landmarks, paths, places and objects, and correctness of route direction and structure). To the best of our knowledge, such comprehensive evidence does not exist in previous child cognition studies. Second, this study analysed the unique conditions of a Taiwanese city, including motorcycle ownership and parental attitudes. Moreover, the study results are a valuable reference for developing policy directions in relation to school transportation and the development of spatial cognition of children. Improving spatial cognition is important to the general population because spatial cognition plays a major role in one's daily tasks and specialised tasks, which include way-finding as part of navigation, acquiring and using spatial knowledge from direct experience, using spatially iconic symbolic representations, using spatial language, imaging places and reasoning with mental models and location allocation (Montello and Raubal, 2013). To encourage parents to allow their children to travel to or from schools using active or non-motorised travel modes without an adult for spatial cognition development, city managers should develop safe and child-friendly transportation systems and built environments within the school catchment areas.

Limitations

To further clarify the relationships between travel modes and children's spatial cognition, future studies should closely examine three issues, which reflect the limitations of this study. The first issue is related to the study population. This study enrolled children from a single elementary school. Although a school may be located in an urban area with similar socioeconomic circumstances, variations probably exist for different contexts, which could include elementary schools versus high schools and general Chinese society versus aboriginal society. To generate comprehensive information about the relationships between travel mode and spatial cognition, future research should investigate populations with different socioeconomic contexts and ages.

The second issue is connected with the survey method. This study obtained the travel mode uses and school trip attributes via a self-reported questionnaire survey. Such a survey method could result in measurement errors. Revealed surveys, which objectively record real behaviours, are normally more reliable than stated surveys in recording travel behaviours; however, the significant costs of monitoring equipment and the inconvenience of sample observations generally make this method unsuitable for recording travel behaviours over an entire week. When monitoring equipment such as a global positioning system is available and sample children cooperate during a survey period, recording travel behaviours is preferable over the self-reported survey.

The third issue is associated with the performance measures for spatial cognitive maps. Very few studies have developed measurements that can quantitatively evaluate spatial cognitive maps. The definitions for outcome variables in this study followed those that were used in a limited number of studies. These definitions directly aggregated different cognition items and correct orientation or structure of routes in a cognitive map. However, these direct measurements do not deal with differences in spatial sizes among cognitive maps or do not consider the different levels of importance of items on a map. To prevent measurement errors, reliable and unbiased measurements for spatial cognitive maps must be developed.

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Appendix: Linear regression models

Outcome variable: Landmark.

Explanatory variables	Basic model			Expanded model 1			Expanded model 2			Expanded model 3		
	Coef.	t	VIF	Coef.	t	VIF	Coef.	t	VIF	Coef.	t	VIF
Grade	1.426	12.602***	5.078	1.447	11.636***	5.791	1.448	11.666***	5.768	1.466	12.598***	5.078
Long-distance travel	1.766	3.631***	5.349	1.786	3.654***	5.395	1.784	3.652***	5.39	1.957	3.42**	7.397
Physical activity	0.088	2.082***	1.746	0.086	2.04***	1.757	0.086	2.047***	1.754	0.085	2.015***	1.761
Inc1	−1.357	−2.95***	1.335	−1.363	−2.96***	1.337	−1.362	−2.957***	1.336	−1.347	−2.925***	1.337
Independent mode				0.027	0.442	1.554						
Active mode							0.026	0.428	1.532			
Non-motorised mode										0.034	0.635	2.93
F	331.26***			264.634***			264.625***			264.782***		
R^2	0.72			0.72			0.72			0.72		
Adj R^2	0.718			0.717			0.717			0.717		

Note: VIF, variance inflation factor (a measure of multicollinearity); ***significant at α = 0.05; **significant at α = 0.1; * significant at α = 0.2.

(2) Outcome variable: Path.

Explanatory variables	Basic model			Expanded model 1			Expanded model 2			Expanded model 3		
	Coef.	t	VIF	Coef.	t	VIF	Coef.	t	VIF	Coef.	t	VIF
Gender (male)	0.318	1.539*	1.863	0.317	1.534*	1.864	0.318	1.534*	1.864	0.32	1.532*	1.893
Grade	0.676	11.28***	4.987	0.694	10.986***	5.527	0.691	10.973***	5.497	0.677	11.152***	5.1
Store1	0.235	1.96**	4.575	0.241	1.009***	4.592	0.24	2.003***	4.593	0.235	1.959**	4.578
Store2	0.48	2.707***	3.136	0.493	2.771***	3.159	0.491	2.761***	3.158	0.481	2.69***	3.184
Car ownership	−0.304	−2.21***	2.923	−0.318	−2.295***	2.961	−0.315	−2.278***	2.957	−0.302	−2.099***	3.192
EduM2	−0.516	−2.355***	1.589	−0.527	−2.399***	1.593	−0.526	−2.394***	1.594	−0.515	−2.326***	1.616
EduM4	1.124	2.043***	1.068	1.069	1.929**	1.082	1.076	1.942**	1.082	1.126	2.041***	1.071
Independent mode				−0.028	−0.837	1.6						
Active mode							−0.025	−0.764	1.578			
Non-motorised mode										0.001	0.051	2.612
F	129.704***			113.534***			113.472***			113.27***		
R^2	0.639			0.64			0.64			0.639		
Adj R^2	0.634			0.634			0.634			0.634		

Note: VIF, variance inflation factor (a measure of multicollinearity); ***significant at α = 0.05; **significant at α = 0.1; *significant at α = 0.2.

(3) Outcome variable: Place.

Explanatory variables	Basic model			Expanded model 1			Expanded model 2			Expanded model 3		
	Coef.	t	VIF	Coef.	t	VIF	Coef.	t	VIF	Coef.	t	VIF
Constant	1.211	2.908***		1.220	2.924***		1.223	2.933***		1.175	2.806***	
Grade	0.124	4.942***	2.721	0.126	4.884***	2.900	0.128	4.940***	2.883	0.125	4.977***	2.728
Long-distance travel	0.321	2.404***	1.033	0.319	2.393***	1.033	0.319	2.387***	1.034	0.311	2.324***	1.040
Motorcycle ownership	0.070	2.761***	1.062	0.069	2.700***	1.074	0.068	2.674***	1.076	0.066	2.580***	1.092
Bike ownership	−0.042	−2.282***	1.069	−0.042	−2.284***	1.069	−0.042	−2.279***	1.069	−0.042	−2.242***	1.071
EduF3	−0.078	−1.468*	1.057	−0.079	−1.481*	1.058	−0.079	−1.487*	1.058	−0.078	−1.481*	1.057
EduM4	−0.963	−1.623*	1.062	−0.948	−1.593*	1.066	−0.941	−1.582*	1.066	−0.895	−1.495*	1.081
Inc1	−0.165	−2.716***	1.104	−0.165	−2.712***	1.104	−0.165	−2.715***	1.104	−0.165	−2.716***	1.104
Inc4	0.111	1.511*	1.139	0.108	1.467*	1.149	0.107	1.449*	1.149	0.105	1.430*	1.148
(travel distance) × (motorised mode)	−0.000	−2.065***	5.811	−0.000	−2.099***	6.222	−0.000	−2.148***	6.187	−0.000	−2.120***	10.032
Independent mode				−0.003	−0.407	1.335						
Active mode							−0.005	−0.600	1.327			
Non-motorised mode										−0.008	0.846	2.000
F	6.617***			6.016***			6.035***			6.084***		
R^2	0.117			0.117			0.117			0.118		
Adj R^2	0.099			0.097			0.098			0.099		

Note: VIF, variance inflation factor (a measure of multicollinearity); ***significant at α = 0.05; **significant at α = 0.1; *significant at α = 0.2.

(4) Outcome variable: Object.

Explanatory variables	Basic model			Expanded model 1			Expanded model 2			Expanded model 3		
	Coef.	*t*	VIF	Coef.	*t*	VIF	Coef.	*t*	VIF	Coef.	*t*	VIF
Grade	0.665	5.049***	5.331	0.602	4.420***	5.726	0.596	4.382***	5.719	0.678	5.123***	5.393
Leisure travel	0.110	1.319*	1.905	0.114	1.368*	1.907	0.114	1.371*	1.906	0.117	1.396*	1.919
Freedom during off-school time	−0.131	−1.685**	5.311	−0.121	−1.559*	5.338	−0.121	−1.557*	5.335	−0.106	−1.292*	5.907
Park	0.807	2.276***	5.408	0.744	2.094***	5.462	0.746	2.101***	5.451	0.820	2.312***	5.417
Store2	0.528	1.338*	3.420	0.495	1.257	3.428	0.489	1.242	3.429	0.554	1.402*	3.437
EduF1	−2.068	−2.173***	1.273	−2.037	−2.143***	1.273	−2.026	−2.133***	1.273	−2.043	−2.145***	1.274
EduM1	3.254	3.148***	1.257	3.086	2.979***	1.268	3.079	2.976***	1.266	3.198	3.089***	1.261
Inc1	0.707	1.332*	1.432	0.709	1.339*	1.432	0.713	1.347*	1.432	0.731	1.376*	1.435
Inc3	1.518	2.504***	1.338	1.506	2.491***	1.338	1.501	2.484***	1.338	1.508	2.488***	1.338
Stop number	−0.521	−1.802**	1.293	−0.497	−1.723**	1.296	−0.497	−1.724**	1.296	−0.521	−1.802**	1.293
Independent mode				0.120	1.754**	1.572						
Active mode							0.133	1.942**	1.547			
Non-motorised mode										0.054	0.962	2.630
F	33.140***			30.532***			30.637***			30.207***		
R^2	0.398			0.401			0.402			0.399		
Adj R^2	0.386			0.388			0.389			0.386		

Note: VIF, variance inflation factor (a measure of multicollinearity); ***significant at $\alpha = 0.05$; **significant at $\alpha = 0.1$; *significant at $\alpha = 0.2$.

(5) Outcome variable: Route direction.

Explanatory variables	Basic model			Expanded model 1			Expanded model 2			Expanded model 3		
	Coef.	*t*	VIF	Coef.	*t*	VIF	Coef.	*t*	VIF	Coef.	*t*	VIF
Constant	4.368	28.856***		4.335	28.827***		4.334	28.768***		4.522	27.106***	
Gender (male)	0.153	1.574*	1.029	0.15	1.553*	1.029	0.149	1.544*	1.029	0.154	1.591*	1.029
Freedom during off-school time	0.126	5.01***	1.024	0.107	4.191***	1.082	0.109	4.258***	1.078	0.121	4.826***	1.032
Physical activity	0.025	2.577***	1.033	0.03	2.32***	1.041	0.023	2.372***	1.039	0.023	2.382***	1.041
EduF3	0.249	2.546***	1.007	0.261	2.696***	1.009	0.26	2.676***	1.008	0.255	2.624***	1.008
EduF4	2.232	2.031***	1.019	2.206	2.024***	1.019	2.202	2.019***	1.019	2.14	1.953**	1.02
(travel distance)× (motorised mode)	−0000	−7.633***	1.028	−0.000	−6.736***	1.088	−0.000	−6.722***	1.094	−0.000	−6.651***	1.131
Independent mode				0.045	3.149***	1.142						
Active mode							0.042	2.957***	1.142			
Non-motorised mode										0.029	2.155***	1.127
F	19.292***			18.244***			18.038***			17.319***		
R^2	0.186			0.202			0.2			0.194		
Adj R^2	0.177			0.191			0189			0.182		

Note: VIF, variance inflation factor (a measure of multicollinearity); ***significant at α = 0.05; **significant at α = 0.1; *significant at α = 0.2.

(6) Outcome variable: Route structure.

Explanatory variables	Basic model			Expanded model 1			Expanded model 2			Expanded model 3		
	Coef.	t	VIF	Coef.	t	VIF	Coef.	t	VIF	Coef.	t	VIF
Gender (male)	0.52	5.373***	1.94	0.504	5.287***	1.943	0.503	5.271***	1.944	0.487	5.054***	1.961
Freedom during off-school time	0.255	17.562***	3.923	0.246	17.022***	4.013	0.246	16.988***	4.019	0.236	15.224***	4.555
Store1	0.448	9.751***	3.181	0.401	8.6***	3.384	0.402	8.609***	3.381	0.432	9.456***	3.215
Physical activity	0.042	4.181***	1.707	0.037	3.75***	1.729	0.037	3.803***	1.725	0.043	4.34***	1.709
EduF4	1.841	1.633*	1.021	1.809	1.629*	1.021	1.802	1.622*	1.021	1.986	1.777**	1.023
(travel distance)× (motorised mode)	−0.000	−3.022***	1.706	−0.000	−2.071***	1.797	−0.000	−2.02***	1.806	0.000	−4.044***	1.961
Independent mode				0.058	4.073***	1.510						
Active mode							0.059	4.088***	1.501			
Non–motorised mode										−0.043	−3.322***	2.949
F	533.559***			473.768***			473.894***			467.964***		
R^2	0.863			0.868			0.868			0.866		
Adj R^2	0.862			0.866			0.866			0.864		

Note: VIF, variance inflation factor (a measure of multicollinearity); ***significant at α = 0.05; **significant at α = 0.1; *significant at α = 0.2.

(7) Outcome variable: Aggregation.

Explanatory variables	Basic model			Expanded model 1			Expanded model 2			Expanded model 3		
	Coef.	*t*	VIF	Coef.	*t*	VIF	Coef.	*t*	VIF	Coef.	*t*	VIF
Constant	8.244	3.852***		8.305	3.893***		8.319	3.902***		9.675	4.338***	
Grade	2.838	10.383***	1.234	2.684	9.521***	1.322	2.679	9.515***	1.319	2.819	10.347***	1.235
Park	1.702	2.458***	1.245	1.539	2.217***	1.261	1.548	2.234***	1.258	1.582	2.287***	1.253
Street	−1.139	−1.729**	1.244	−1.181	−1.79^{7**}	1.245	−1.186	−1.806**	1.245	−1.137	−1.732**	1.244
Store1	0.784	1.624*	1.282	0.735	1.528*	1.285	0.731	1.520*	1.285	0.745	1.548*	1.284
Store2	1.825	2.284***	1.226	1.744	2.18^{8***}	1.229	1.738	2.180***	1.229	1.798	2.258***	1.226
Physical activity	0.161	1.891**	1.060	0.150	1.766**	1.064	0.151	1.783**	1.062	0.143	1.679**	1.070
EduF1	−3.089	−1.802**	1.161	−3.096	−1.812**	1.161	−3.087	−1.808**	1.161	−3.133	−1.835**	1.161
EduM2	−2.545	−1.831**	2.675	−2.448	−1.766**	2.678	−2.464	−1.779**	2.677	−2.557	−1.847**	2.676
EduM3	−2.703	−1.959**	2.806	−2.628	−1.910*	2.808	−2.652	−1.929**	2.807	−2.721	−1.979***	2.806
Inc2	1.518	1.369*	1.286	1.524	1.379***	1.286	1.506	1.363*	1.286	1.503	1.361*	1.286
Inc3	4.127	3.382***	1.338	4.122	3.390***	1.338	4.107	3.379***	1.338	3.945	3.238***	1.344
Inc4	3.756	2.880***	1.376	3.987	3.057***	1.386	3.983	3.056***	1.384		2.996***	1.379
Car ownership	−1.180	−1.844**	1.060	−1.108	−1.735**	1.063	−1.110	−1.740**	1.063	−1.126	−1.764**	1.062
Motorcycle ownership	0.757	1.844**	1.071	0.856	2.080***	1.085	0.864	2.100***	1.086	0.893	2.160***	1.096
Independent mode				0.267	2.108***	1.208						
Active mode							0.281	2.221***	1.194			
Non-motorised mode										0.247	2.186***	1.068
F	16.098***			15.426***			15.473***			15.458***		
R^2	0.312			0.318			0.319			0.319		
Adj R^2	0.293			0.297			0.298			0.298		

Note: VIF, variance inflation factor (a measure of multicollinearity); ***significant at α = 0.05; **significant at α = 0.1; *significant at α = 0.2.