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School site walkability and active school transport – association, mediation and moderation

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ABSTRACT

Increasing active school transport (AST) can improve population health, but its association with the urban form is not fully clear. This study investigated the association of an objective school walkability index with AST and how this association is mediated by the perceived physical and social environment. 1250 Danish students aged 11–13 years completed a commuting diary and a questionnaire. The walkability index was constituted of measures of road connectivity, traffic exposure and residential density. AST's share in all school trips was 85.4% with little difference between genders. The school walkability index was significantly associated with AST (Medium vs. Low OR 2.68; High vs. Low OR 2.49). Adding the perceived physical and social environment variables improved the model prediction of AST, with no change in the association with the school walkability index. Furthermore, distance to school significantly moderated the association between the school walkability index and AST. This research confirms the association between the urban form surrounding schools and AST. Medium and highly walkable school sites in combination with a distance to school below 2 km, no speeding traffic and many paths in the neighborhood was associated with the highest odds ratio for AST.

1. Introduction

Active school transport (AST) has the potential to contribute substantially to physical activity (PA) and health (Andersen et al., 2011; Faulkner et al., 2009; Shephard, 2008), but globally AST is declining (Faulkner et al., 2009; Fyhri et al., 2011; Hallal et al., 2012). The prevalence of AST varies between countries, with Danish studies reporting some of the highest prevalences globally, especially for cycling to school: approximately 50–70% for cycling and 10–20% for walking (Cooper et al., 2006; Jensen, 2008). Nevertheless, even in Denmark national reports show a negative trend in AST and large variations between schools (Fyhri et al., 2011; Jensen, 2008; Stock et al., 2012). Determining if the urban form contributes to variations between schools, and how and for whom it is influential could assist in curbing further declines in AST.

Walking or cycling to school has been shown to be associated with a number of variables at the individual, cultural, social, physical and political level (Chillon et al., 2011; Davison et al., 2008; Panter et al., 2008; Sirard and Slater, 2008; van Loon and Frank, 2011). This suggests that to understand this behavior a socio-ecological model that considers multiple levels of influences is useful as a theoretical framework (Giles-Corti et al., 2005; Sallis et al., 2006). Several examples of such frameworks incorporating possible determinants of active transport for children and adolescents at different levels have been published (McMillan, 2005; Panter et al., 2008; Sirard and Slater, 2008). Panter et al. (2008) present a detailed conceptual framework for AST, where physical environment factors are divided into neighborhood, route and destination attributes. Furthermore, it distinguishes between the urban form and other physical environment factors such as facilities to assist walking and cycling (Panter et al., 2008). The distinction between physical structure (urban form) and street design features has been put forward in prior research (Cervero and Kockelman, 1997), and it has been proposed that both long-term improvements to the physical structure and simple street design interventions for walking and cycling would have potential to increase active transport (Lee and Moudon, 2008). Characteristics of the urban form and street design do often covary, which can cause spatial multicollinearity and make the use of conventional statistical analyses inappropriate (Saelens et al., 2003; Sallis et al., 2012). Moreover, with the spatial covariation the possibility for both opposing and synergetic effects on active transport follows, as for example many supporting facilities for active transport are present in areas where

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traffic volume is high (Johansson, 2006; Mitra and Buliung, 2012). Therefore, it has been proposed to incorporate these interactions of the physical environment in active transport research, and be more aware of the urban form context (Moudon and Lee, 2003).

The socio-ecological frameworks suggests more than just associations on different levels, it also proposes that there may be both moderation and mediation between and within the levels (Kremers et al., 2006; McMillan, 2005). Yet very few studies have examined the relationship between the urban form surrounding schools with AST, and even fewer the roles of the perceived physical environment and social environment in this relationship (Giles-Corti et al., 2009; Pont et al., 2009; Wong et al., 2011). Distance as a barrier to AST is indisputable (Wong et al., 2011), but acceptable distances differs across countries due to both cultural and physical environment factors (D'Haese et al., 2011). Distance could also influence the association between AST and the physical environment, as very short distances minimize the time the students are present in the environment, and too long distances exceeds the physical capabilities or reasonable use of time (Panter et al., 2008).

Age and gender are other very frequent proposed moderators, as the perception of the environment and the perceptions of risk differ between boys and girls and between the young and the mature student. Parent support or decisions regarding AST are likely to be influenced by the physical environment, but can also be a potential moderator of the association between urban form and AST. The decision making process of active or passive transport happens in a dialogue between the parent and the child, and is influenced by multiple factors from both the physical environment and physical abilities of the child (Kullman, 2010; Panter et al., 2008). As the child matures the role of parents will shift from sole gatekeeper as proposed by McMillan (2005), through a process of practical skill acquisition with the environment and social interactions with friends, to more influence from the child itself on their own independent mobility (Kullman, 2010).

This paper seeks to extend existing research on AST by examining the association between AST and the urban form measured by a school walkability index and how the perceived physical environment and social environment affect this relationship. We hypothesized that the urban form is associated with AST, and that this association would be mediated and moderated by the perceived environment and social environment factors. Furthermore, we investigated whether the associations were modified by gender and distance to school.

2. Methods

2.1. Study population

The study included 1250 students attending grade 5 or 6 (aged 11–13 years) in 14 schools in the Region of Southern Denmark. The present study draws data from the baseline measurements of the SPACE – for physical activity study which were conducted in spring 2010 (Toftager et al., 2011). AST was one of the intervention targets of the study, and schools with more than 50% of all students living further than 2 km away were considered ineligible for inclusion. We used a passive informed consent procedure, where students were included unless the parents withdrew consent. This procedure has been found to be ethically appropriate in low-risk research in adolescents (Santelli et al., 2003). The Danish National Committee on Health Research Ethics reviewed the study protocol and it is registered and listed in the Danish Data Protection Agency (reference number: 2009-41-3628).

2.2. Urban form

Relevant urban form measures for AST include attributes of the living neighborhood of the students, the school as the destination and the route between home and school. Few studies have examined the urban form of the school site in relation to AST (Panter et al., 2008; Sirard and Slater, 2008). In order to make comparisons possible between physical environments in different settings, we computed a cumulative urban form index that is an extension of the index developed by the TREK study (Giles-Corti et al., 2011; Trapp et al., 2011, 2012). The index in the TREK study is called a *school walkability index,* and is associated with both walking and cycling to and from school (boys only), and consists of two components: road connectivity and vehicular traffic exposure. We added a third component, residential density, which was designed to strengthen the index and suggested by the TREK study (Giles-Corti et al., 2011). Similar to the TREK study, the ratio between the 2 km pedestrian-enhanced network service area and the area of the 2 km Euclidian buffer was used to assess the *road connectivity* of the school site. V*ehicular traffic exposure*, *VTE*, was calculated using the Danish road classifications which divides roads into 4 categories: Roads more than 6 m wide; roads between 3 and 6 m wide; other roads; and paths. The ratio of the length of the roads more than 6 m wide to all other roads and paths in the walkable service area constituted the VTE. In addition, *residential density* was added as a third component, using the number of addresses divided by the area of the 2 km pedestrian-enhanced network (Fig. 1). The three components of the index were standardized to *z*-scores ($z = (x - \mu)/\sigma$). Then the *z*-score for VTE was reverse coded and the walkability was calculated by the sum of the three *z*-scores. The 14 schools were split into three groups based on the walkability index: 4 schools with a low index (<-0.60), 4 schools with a medium (-0.6 to 0.0) and 6 schools with a high index (>0.0) (Table 1). As evident from Fig. 2 the categorization of the composite index resulted in two groups with relative similar characteristics within the groups (low and high index), while there were less homogeneity between the four schools categorized as medium walkability.

2.3. Other independent variables

For statistical modeling purposes the other independent variables were categorized into three types: individual/demographic, perceived environment, and social environment variables. The individual/demographic variables included age, gender, household income, parent nativity, and distance to school. Age and gender were obtained directly from school records, and parental household income and nativity were obtained using the Danish Civil Registration System (Pedersen, 2011). Parent household income was recoded into tertiles (low, medium and high) and nativity was dichotomized (both parents born in Denmark or not). The shortest distance to school was measured with the network analyst extension to ESRI ArcGIS 10.0 using a pedestrian-enhanced network (paths and tracks included).

The perceived environment en route to school and in the neighborhood was assessed using a web-based questionnaire completed by the students at the school with teacher supervision. The questionnaire addressed overall safety en route to school and questions on cycle paths, road crossings, car traffic density and speed in the neighborhood of residence (see Table 3 for exact wording). The response options were on 5-point Likert scale from "strongly disagree" to "strongly agree", except from cycle route safety, for which the extreme options were "very safe" and "very unsafe". The questions were developed specifically for this study and were especially targeting conditions related to cycling. The question about route safety was also specific to cycling, so respondents who never cycled (10.6%) did not answer the question. The new items were pilot tested prior to the main data collection including cognitive interview validation (Collins, 2003; Toftager et al., 2011). The social environment variables were also obtained from the web-based questionnaire, and included perceived parental

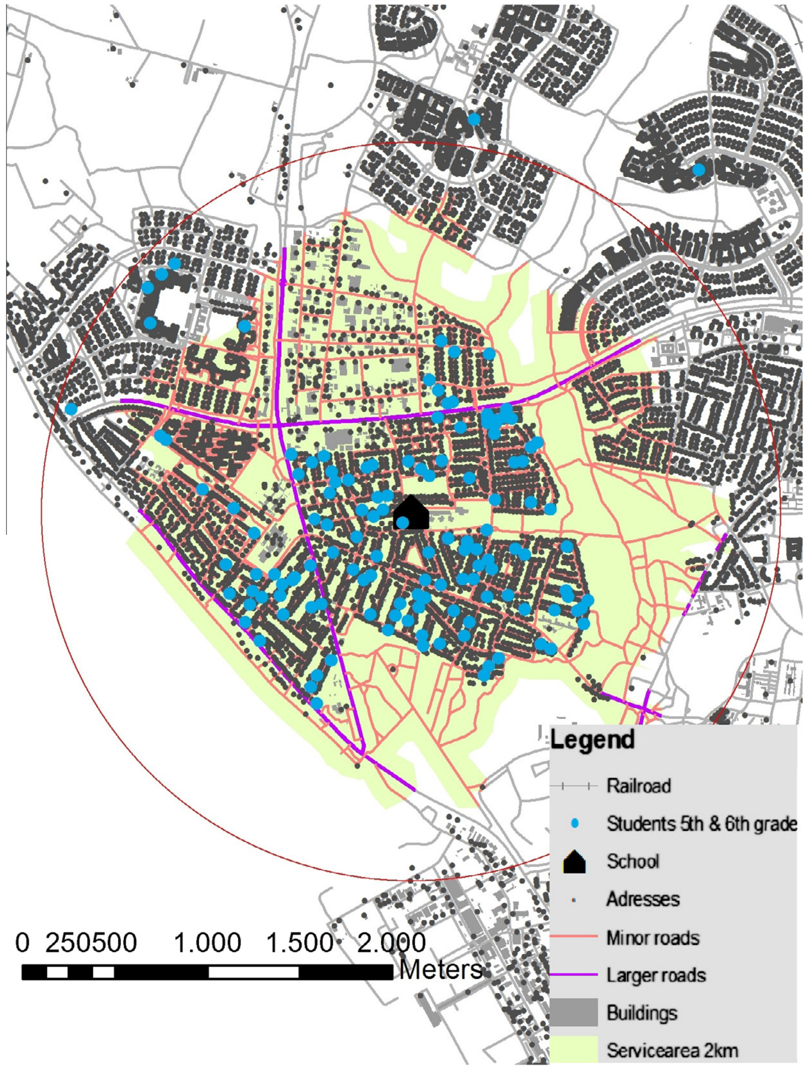

Fig. 1. The school walkability index. The index was based on the ratio between the 2 km service area and the area of the 2 km Euclidian buffer, the ratio of the length of the major roads and all other roads in the 2 km service area, and number of addresses in the 2 km service area.

Table 1
Raw index components and school walkability index stratified by low, medium and high walkability score.

	Low ($n = 4$) Mean (SD)	Medium ($n = 4$) Mean (SD)	High ($n = 6$) Mean (SD)
Pedshed[a]	0.44 (0.01)	0.38 (0.04)	0.47 (0.05)
Vehicular traffic exposure[b]	0.14 (0.03)	0.09 (0.05)	0.07 (0.03)
Residential density (addresses/km^2)[c]	315 (74)	506 (279)	400 (132)
School walkability index[d]	−1.6 (0.5)	−0.5 (0.02)	1.1 (1.0)

[a] A ratio closer to 1 = more connected neighborhood.
[b] A ratio closer to 1 = a greater exposure to traffic.
[c] A higher number = more addresses per km^2 within 2 km network distance from school.
[d] Standardized and summed values of the three components = z(pedshed) + z(reverse vehicular traffic) + z(residential density).

encouragement of cycling to school (social support) and the perceived prevalence of friends' and parents' cycling (social norm).

2.4. Dependent variable

Mode of transportation to and from school was assessed using a 5-day active commuting diary. The respondents marked their transportation mode(s) choosing between: *by bicycle; by foot; by car; by bus or train; by roller-skates, skateboard or the like;* or *wasn't in school*. For the analysis every trip was dichotomized to active transport all way (*by bicycle*, *by foot* or *by roller-skates, skateboard or the like*) or passive transport (*by car* or *by bus or train*). Together with the total number of reported trips it constituted the binomial outcome variable, i.e. a respondent could have x number of active trips out of n reported trips. There was no lower limit for the total number of reported trips to be included in the analyses.

2.5. Statistical analysis

Statistical analyses were carried out using STATA (v. 12), and the association between AST and the independent variables was evaluated using multilevel statistical models. To account for the

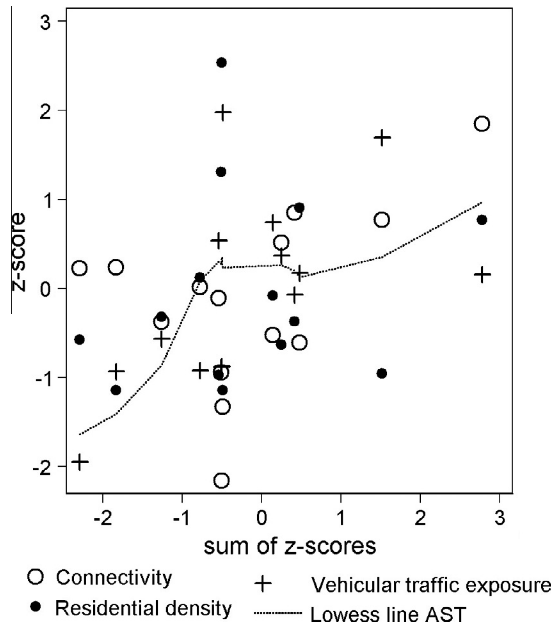

Fig. 2. Component *z*-scores and sum of *z*-scores for the walkability index. The *z*-scores for the three components of the index, and the sum of these *z*-scores. The percentage of AST-trips were standardized at school level, and depicted as a 'locally weighted scatterplot smoothing' curve (Lowess).

Table 2
Distribution of individual and demographic factors and odds ratio (OR) for the unadjusted association with AST.

	Distribution (%)	AST (%)	Bivariate model OR (95% CI)
Age group			
<12 years	27.5	86.0	1.0
=12 years	51.5	85.3	0.95 (0.83–1.08)
>12 years	21.0	84.6	1.05 (0.90–1.23)
Gender			
Boys	51.7	84.2	1.0
Girls	48.3	86.6	1.15 (1.03–1.28)*
Household income			
Low	32.5	80.7	1.0
Medium	33.8	87.3	1.44 (1.27–1.65)***
High	33.6	87.9	1.39 (1.21–1.59)***
Parent ethnicity			
Other	9.1	82.1	1.0
Both Danish	90.9	85.7	0.96 (0.80–1.16)
Distance to school			
<0.5 km	8.2	97.5	1.0
0.5–0.9 km	31.3	96.1	0.64 (0.41–1.01)
1.0–1.9 km	37.7	93.4	0.32 (0.21–0.50)***
2.0–2.9 km	8.1	73.6	0.07 (0.05–0.11)***
3.0–3.9 km	4.3	61.7	0.04 (0.02–0.06)***
>3.9 km	10.4	33.3	0.01 (0.01–0.01)***

p-Value for pairwise comparison between each level of the variable and the reference: $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$;95% CI: 95% confidence interval for odds ratio.

clustering of behavior in the 14 schools, a two-level structure of students (Level 1) nested in schools (Level 2) was applied. Bivariate logistic regression analyses were used to compare the proportion of active trips across each independent variable. Afterwards, a series of multivariable logistic regressions were applied to: (1) evaluate the association between AST and the school walkability index; (2) observe whether adding perceived environment and social environment variables changed the association (possible mediation); and (3) investigate whether the association was different

Table 3
Distribution of school walkability index, perceived environment and social environment variables and odds ratio (OR) for the unadjusted association with AST.

	Distribution (%)	AST (%)	Bivariate model OR (95% CI)
School walkability index			
Low	24.6	76.6	1.0
Medium	26.9	90.4	2.94 (1.67–5.17)***
High	48.6	87.0	2.12 (1.27–3.53)**
Perceived environment variables			
Route safety[a]			
Unsafe	9.3	61.0	1.0
Safe	81.5	90.5	6.35 (5.48–7.36)***
Don't know	9.2	64.2	1.21 (1.00–1.46)*
Many paths[b]			
Overall disagree	22.3	72.2	1.0
Overall agree	55.8	90.7	3.81 (3.35–4.33)***
Neither nor	21.9	85.1	2.19 (1.89–2.53)***
Safe crossings[c]			
Overall disagree	9.0	72.1	1.0
Overall agree	72.2	88.3	3.02 (2.59–3.53)***
Neither nor	18.8	80.3	1.74 (1.46–2.08)***
Heavily trafficked[d]			
Overall disagree	40.0	87.4	1.0
Overall agree	31.1	81.5	0.61 (0.53–0.69)***
Neither nor	28.9	86.6	0.86 (0.75–0.99)*
Speeding traffic[e]			
Overall disagree	42.0	90.6	1.0
Overall agree	27.6	73.9	0.27 (0.24–0.31)***
Neither nor	30.4	88.5	0.78 (0.67–0.90)**
Social environment			
Friends cycle[f]			
Overall disagree	1.4	73.0	1.0
Overall agree	89.4	85.7	1.86 (1.29–2.68)**
Neither nor	9.2	83.3	1.92 (1.29–2.86)**
Parents cycle[g]			
Overall disagree	28.6	77.3	1.0
Overall agree	47.9	91.7	3.00 (2.63–3.42)***
Neither nor	23.4	82.2	1.28 (1.12–1.46)***
Parents' support[h]			
Overall disagree	25.4	84.4	1.0
Overall agree	47.8	86.5	1.25 (1.10–1.43)**
Neither nor	26.9	84.3	0.98 (0.84–1.13)

p-Value for pairwise comparison between each level of the variable and the reference: $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; 95% CI: 95% confidence interval for odds ratio.
[a] "How would you describe your cycle route to or from school?".
[b] "There are many cycle paths in the area where I live".
[c] "I feel safe where I have to cross the street in the area where I live".
[d] "The streets are often heavily trafficked in the area where I live".
[e] "The cars drive fast in the area where I live".
[f] "Most of my friends cycle every day".
[g] "My mother or father cycle at least once a week".
[h] "My parents encourage me to cycle".

between certain groups (moderation). All analyses were adjusted for the individual and demographic variables (age, gender, parent nativity, household income and distance to school). Model improvement tests were performed using the likelihood ratio test to determine if the inclusion of the additional effects (main effects and interactions) significantly improved the prediction of the likelihood of AST (Cervero, 2002; McMillan, 2007). Goodness-of-fit for all models was assessed using the likelihood ratio index by McFadden (Windmeijer, 1995). To interpret the variation between the 14 schools an intraclass correlation coefficient (ICC) was calculated as $ICC = \frac{\sigma_2^2}{\sigma_1^2+\sigma_2^2}$ where σ_2^2 is the variance between schools (second-level variance) and σ_1^2 is the variance between individuals approximated as $\sigma_1^2 = \frac{\pi^2}{3}$ (Goldstein et al., 2002). A large ICC would indicate that differences at the school level account for much of the variation in AST, and if ICC decreases in the multivariable models, it implies that the included variables account for that part of the school level variation.

3. Results

From the eligible population sample of 1348 students, 1250 reported at least one trip to or from school and filled in the questionnaire, which gives a response rate of 92.7%. In total 91.1% of the included students reported eight or more trips and the average number of reported trips was 9.3. A total of 61.0% of the students reported the same travel mode on all trips, while 24.9% used two different travel modes and 14.1% used three or more different modes. Information about household income and parents' nativity were obtainable for all but five respondents, which were given the mean sample household income and coded as native Danes.

3.1. Sample characteristics

Of all reported trips, the share of walking (including roller-skating and skateboarding) and cycling to or from school was 15.9% and 69.5% respectively. A total of 87.1% of the students used the bicycle at least once, and 29.6% walked at least once. Six percent of the students used merely passive transport. There was considerable variation between the 14 schools. The share of walking trips ranged from 5.8% to 31.0% and for cycling the range was 41.8% to 85.4%. The overall share of active trips ranged from 71.6% to 94.7%.

Table 2 shows the descriptive characteristics of the included respondents and the unadjusted association with AST. One half of the respondents were 12 years (mean age: 12.5 years), 51.7% were boys and 9.1% had a least one non-native Danish parent. Girls and students in the medium and high household income tertile had significant higher odds ratio for AST (OR 1.15 CI 95% 1.03–1.28, OR 1.44 CI 95% 1.27–1.65 and OR 1.39 CI 95% 1.21–1.59). The median distance to school for all trips was 1.2 km (range: 0.02–42.6 km) and, as suspected, there was a significant difference in travel modes. For trips below 0.5 km, 1 km and 2 km, active travel modes accounted for 97.5%, 96.1% and 93.4% of all trips, respectively, and the active modal share was still most prevalent up to 4 km. In total 10.4% of students lived more than 4 km from school, and this was associated with much less AST (33.3%).

3.2. Bivariate analyses

Table 3 shows the unadjusted associations between AST and the school walkability index, perceived environment and social environment variables. Attending schools with middle or high walkability index were associated with significant higher odds ratios for AST. The association is non-linear in nature, and 76.6%, 90.4% and 87.0% of all trips were made by active transport in the schools with the lowest, middle and highest school walkability index, respectively (Fig. 2). In total 81.5% of students perceived their route as safe or very safe, which was associated with 90.5% of the trips made by active transport (OR 6.35 CI 95% 5.48–7.36). More trips were made by active modes if there were many paths and safe crossings (OR 3.81 CI 95% 3.35–4.33 and OR 3.02 CI 95% 2.59–3.53), while heavily trafficked neighborhoods and high-speed traffic were associated with less trips (OR 0.61 CI 95% 0.53–0.69 and OR 0.27 CI 95% 0.24–0.31). Almost 90% of the students reported that their friends cycled to school every day and one half reported parents cycling weekly or parents encouraging cycling. This was significantly associated with more AST (OR 1.86 CI 95% 1.29–2.68, OR 3.00 CI 95% 2.63–3.42 and OR 1.25 CI 95% 1.10–1.43, respectively).

3.3. Multivariable analyses

To examine problems of multi-collinearity we performed a Spearman's test and used $r > 0.60$ as an indicator of collinearity. None of the independent variables had an $r > 0.60$ and therefore all were kept in the analyses. Table 4 shows the adjusted analyses of the association between AST and the school walkability index, perceived environment and social environment variables. We only present the odds ratios between "unsafe" vs. "safe" and "disagree" vs. "agree" ("don't know" and "neither nor" are not shown). The association between the school walkability index and AST was almost unchanged after the adjustment for both the demographic variables and distance to school, i.e. odds ratio for medium walkability changed from 2.94 to 2.76 and for high walkability from 2.12 to 2.79 (Tables 3 and 4). The inclusion of the perceived and social environment variables in the model resulted only in minor attenuations in the magnitude of the parameter estimates of the coefficients. After inclusion of all independent variables in the model (Model 3), the odds ratio of AST was higher for students in the schools with greater walkability (Low vs. medium OR 2.68 CI 95% 1.69–3.77; Low vs. high OR 2.49 CI 95% 1.64–3.77). Furthermore, the odds ratio for AST was higher if the route was perceived as safe (OR 1.86 CI 95% 1.51–2.28) and if they had many paths in the neighborhood (OR 1.28 CI 95% 1.07–1.53). In contrast, perceiving high-speed traffic in the neighborhood was associated with significantly less AST (OR 0.50 CI 95% 0.40–0.61). Of the social environment variables, social norm seemed more important than parental encouragement. Students with parents cycling weekly had higher odds ratio for AST (OR 1.92 CI 95% 1.63–2.26), and this was also the case if their friends cycled daily (OR 1.63 CI 95% 1.06–2.62). Safe crossings and heavily trafficked streets in the neighborhood together with parental encouragement did not show a significant relationship in the adjusted model.

The model improvement tests showed that the inclusion of school site, perceived environment and social environment variables significantly improved the model ($p < 0.001$) and the McFadden's likelihood ratio index improved from 0.381 to 0.435. The intraclass correlation coefficient (ICC) was 8.9% for the individual and demographic adjusted model, and attenuated to 3.1% when the school walkability index was included in the model. The inclusion of the perceived built and social environment variables resulted in minor changes in the ICCs.

3.4. Interaction analyses

Table 5 shows the results of the interactions analyses in terms of marginal effects on active trips per week. The school walkability index categories medium and high were collapsed due to the non-linear relationship and to simplify the interpretation of the interactions. The association between AST and the school walkability index was moderated by distance, inasmuch as students living within 0.5 km network distance from school did not differ by school site walkability. The proportion of AST declined steadily from 0.5 km to 4 km for the low walkability schools, but for the medium and high walkable schools the very high levels of AST remained up to 2 km before declining. The interaction with gender and many paths in the neighborhood was almost significant. Girls in the low walkable schools used AST more often than boys, but there was no gender difference on AST in the high or medium walkability areas. Regarding the presence of many paths in the neighborhood, a positive answer increased odds for AST in both low and high walkable schools, but the odds increased more for the high and medium walkable schools. Perception of safe crossings in the neighborhood and parental encouragement for AST did not show any overall sign of having a moderating effect on the association.

Table 4
Multivariable logistic regression models of school site, perceived environment and social environment correlates of transportation mode adjusted for age, gender, ethnicity, household income and distance to school.

	Model 1 School site OR (95% CI)	Model 2 School site & perceived environment OR (95% CI)	Model 3 School site, perceived environment & social environment OR (95% CI)
School site variable			
School walkability index			
Low	1.0 (ref)	1.0 (ref)	1.0 (ref)
Medium	2.76 (1.70–4.48)***	2.79 (1.75–4.46)***	2.68 (1.69–4.24)***
High	2.79 (1.79–4.33)***	2.59 (1.69–3.96)***	2.49 (1.64–3.77)***
Perceived environment			
Perceived safe route[a]		1.85 (1.51–2.27)***	1.86 (1.51–2.28)***
Many paths[b]		1.38 (1.16–1.64)***	1.28 (1.07–1.53)**
Safe crossings[b]		1.09 (0.87–1.37)	0.99 (0.79–1.25)
Heavily trafficked[b]		1.11 (0.90–1.36)	1.11 (0.90–1.36)
Speeding traffic[b]		0.51 (0.42–0.63)***	0.50 (0.40–0.61)***
Social environment			
Parents cycle weekly[b]			1.92 (1.63–2.26)***
Friends cycle daily[b]			1.63 (1.06–2.62)*
Parents support cycling			1.14 (0.97–1.36)
Likelihood ratio index[c]:	0.383	0.423	0.435
ICC[d]	3.1%	2.8%	2.7%

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
[a] Unsafe route as reference, don't know category not shown.
[b] Disagree as reference, neither/nor category not shown.
[c] McFadden likelihood-ratio index, adjusted model only = 0.381.
[d] Intracluster correlation coefficient, adjusted model only = 8.9%.

Table 5
Marginal effects on active trips per week based on multivariable logistic regression models of interactions between school walkability index and proposed moderators.

	School walkability index		Significance of model improvement test
	Low	High or medium	
	Active trips per week		*p*
No interactions	7.5	8.2	
Interaction by distance			
<0.5 km	8.8	8.8	0.005
0.5–0.9 km	8.1	8.8	
1.0–1.9 km	7.6	8.6	
2.0–2.9 km	7.0	7.6	
3.0–3.9 km	6.6	7.6	
>3.9 km	6.0	7.2	
Interactions by gender			
Boys	7.3	8.2	0.07
Girls	7.6	8.2	
Interactions by many paths			
Disagree	7.4	8.1	0.10
Agree	7.5	8.3	
Interactions by easy to cross			
Disagree	7.5	8.3	0.78
Agree	7.5	8.3	
Interactions by parents support cycling			
Disagree	7.5	8.2	0.66
Agree	7.7	8.3	

All models adjusted for age, ethnicity, household income, distance to school, heavily trafficked streets, high-speed traffic, parents cycle weekly, friends cycle weekly and perceived route safety. Each model is adjusted for the variables: gender, parents support cycling, many paths and safe to cross, if not included in interaction. Model improvements are tested with likelihood ratio test against full model (Table 4, model 3) and with school walkability index dichotomized (low index vs. medium to high index).

4. Discussion

In this study, the share of AST, and especially cycling to school, was very high compared with other international studies. However, there was still considerable variation within the schools included in the study, with an ICC of AST at 9.2%. Much of this variation was explained by the school walkability index, with a decrease in ICC to 3.1% when the index was included in the model. Notably, the variation was low between the schools with medium and high walkability, which was evident with from the small difference in odds ratios. This could imply a threshold effect of the school walkability index, which is supported by the 'locally weighted scatterplot smoothing' curve of standardized AST in Fig. 2.

We focused on the school site, perceived environment and social environment and adjusted the analyses for important independent variables, including distance to school and gender. Girls and boys had almost the same level of AST, which is similar to other studies with overall high levels of AST (Cooper et al., 2006; de Bruijn et al., 2005; Johansson et al., 2011). In other studies, the lower level of AST among girls is explained by more protective or restrictive parents (Davison et al., 2008; McMillan, 2005), and higher perceptions of fear in the neighborhood among girls than boys (Johansson et al., 2010). The tradition and culture supporting female bicycling in Denmark (Carstensen and Ebert, 2012) in combination with a sufficiently active-transport-friendly infrastructure may explain the findings of no gender difference in our study. We hypothesized that girls would use less AST at the lowest walkable school sites, but the results from the interaction analysis indicated the opposite, i.e. girls used AST on more trips at the low walkable schools. One possible explanation might be found in an earlier maturation in girls combined with lower fear of stranger danger, which previously has been described in a Swedish study of children's independent mobility (Johansson, 2006).

As anticipated, distance to school was an important independent variable associated with AST. A distance of 3 km has been proposed as a reasonable maximum distance for active transport in Belgium (11–12 years), but in this study 60.7% of all trips of 3–4 km were still made by bicycle (D'Haese et al., 2011). This supports the hypothesis that the acceptable distance for students to use AST varies by country and could potentially be expanded by improving the infrastructure and creating a safer active transport environment. In addition to being an important independent variable, distance has also been proposed as an important moderator of the relationship between AST and the environment (Panter and Jones, 2010; Panter et al., 2008). We hypothesized a non-linear moderating relationship with distance, where the walkability index had the lowest association when the distance was either very short or very long. In fact, we found that within 0.5 km there was no difference between the low and the medium/high walkable school sites. The high level of AST remained up to a distance of 2 km at the medium/high walkable school sites, but dropped as distance increased above 0.5 km at the low walkable school sites. The difference did not attenuate as hypothesized for the longest distances, implying that the school site environment also has an association for students living further away.

The high levels of AST in Denmark has previously been explained by the persistent effort by the Danish government and municipalities to run campaigns and safe route to school programs (Jensen, 2008). By far most students in our sample perceived their cycle route as safe or very safe, and this was associated with higher levels of AST. Differences in the perceived neighborhood environment showed significant associations with AST and may account for variations in students AST. The three elements, paths, traffic, and crossings, which previously have been reported and theorized to have an effect on AST (McMillan, 2005; Panter et al., 2008; van Loon and Frank, 2011), also showed associations in our study. In the multivariable model "*many paths*" was positively associated with AST ($p < 0.01$), and "*speeding traffic*" was negatively associated with AST ($p < 0.001$). Additionally, having many paths in the neighborhood was associated with larger increase in marginal effects in the high and medium walkable schools ($p = 0.10$), indicating an extra effect where both conditions were in favor of AST. This finding supports the hypothesis of synergetic effects (Sallis et al., 2012), and should be investigate further. Heavily trafficked streets in the neighborhood were associated with less AST in the unadjusted analyses, but this association was attenuated in the adjusted analysis, which suggests that the speed of the cars may be perceived as a more serious barrier to AST than the presence of many cars. A similar attenuation occurred with safe crossings, which in addition did not moderate the urban form association with AST.

Adding the social environment variables significantly improved the prediction of the likelihood of AST, but did not affect the AST and school site association. In general, there was a strong social norm of cycling and one half of the students perceived parental support for cycling as well. In the adjusted analysis the social norm was significantly associated with AST, but parental support was not. Furthermore, the interaction analysis with parental support showed no moderating effect with the AST and school site association, implying that the school site environments are associated with AST independent of parent support.

The school walkability index presented here is a further development of the school walkability index used in the TREK study in Perth, Australia (Giles-Corti et al., 2011; Trapp et al., 2011). Due to a different study design and availability of other types of geographical data it was not possible to replicate the Australian TREK study exactly. We added a residential density variable to strengthen the index as proposed by the TREK study authors, as denser neighborhoods first of all imply shorter distances to school for more students. We provide further evidence confirming that the urban form around schools has an important impact on AST in a setting where cycling to school is very prevalent, and recommend future research to further elaborate on this relationship.

We also investigated how the perceived built and social environment affected the AST and school site association, but found that the association was very stable i.e. independent of the perceived built and social environment urban form is associated with AST. The puzzling question remains: why did the inclusion of perceived environment variables not attenuate the association as proposed in frameworks of AST (McMillan, 2005; Panter et al., 2008). One explanation could be that the perceived physical environment characteristics were answered from a subjective point of view, with limited amount of knowledge about other type of environments. The student would compare his/her neighborhood and route to school – *the action space* – with neighborhoods and routes which he/she possesses knowledge about – *the activity space* (Horton and Reynolds, 1971).This would imply that the student compares their route or neighborhood with other students in the same environment, and not against a common reference. Another explanation could be that the school walkability index is capturing the environment within a 2 km walkable service area of the school. Even though most students lived within 2 km from school, there would be individual differences within the school perimeter, and for the students living outside the perimeter. These general good or poor conditions for the majority could affect the overall levels of AST, but also explain the individual variations.

The only significant moderator was distance to school, which attenuated the association below 0.5 km. At the same time, this interaction analysis supported the hypothesis that the acceptable distance for young people to use AST is associated with urban form characteristics: Students in this study attending medium/high walkable schools had the highest level of AST up to 2 km from school, while AST steadily diminished at the low walkable schools beyond 0.5 km.

4.1. Strengths and limitations

The cross-sectional design and the enlisting of interested schools for the intervention study make it impossible to draw conclusions about causal relationships and generalize the results directly to other Danish schools. The urban form surroundings the schools were measured with a composite measure of attributes within 2 km network distance. The composite measure cannot directly be translated to practice or general recommendations, but was intended to increase the understanding of the interactions between urban form characteristic and other important potential determinants of AST. The low number of participating school made it impossible to investigate the importance of the three components separately, or to apply interaction analyses of their interrelationships. It is possible that a different scale than the 2 km would have altered the relationships presented here (Mitra and Buliung, 2012), but as 77.2% of the sample lived within that distance, and therefore within a 10 min cycle trip from home, we found it reasonable to keep the distance from the original TREK study (Giles-Corti et al., 2011; Moudon and Lee, 2003).

AST was very prevalent in this study, but like other Danish surveys, we found variation between schools. The high prevalence is considered a strength of the study, as non-AST is more likely to be caused by an intentional choice rooted in "real" barriers. The response rate on 92.7% for the questionnaire and the active commuting diary, in addition to the high specificity of both dependent and independent variables, are further strengths of the study. By using trips as the binomial outcome instead of "usual travel mode", we included the important information that one-third of the students used more than one mode of transportation during a week. We made a binary distinction between active versus passive travel, but future research should identify determinants of different active travel modes e.g. walking compared to bicycling. We used a pedestrian-enhanced network that included cycle paths and smaller tracks to calculate the shortest distance between school and home. However, there can still be reasons for students to take alternative routes than the shortest routes calculated. Finally, we investigated a specific age group, which increased the precision of the estimates, but also decreased the variability and generalizability to other age groups.

5. Conclusion

Distance to school is a very important aspect of AST, but this study found that for distances up to 4 km cycling remained the preferred transportation mode. The school walkability index was associated with AST and the variation between schools was largely explained by it. This association was barely affected by the perceived and social environment, suggesting a direct relationship between AST and school walkability. We recommend that future studies incorporate the active commuting diary to ensure high sensitivity of the outcome variable and further develop the school site walkability index approach to guide future interventions. At schools with high walkability, promotion and education strategies would probably be an effective strategy, while other environmental interventions are needed in low walkable school sites. Here, interventions that would create more supportive environments, such as speed limits, cycle paths and safe crossings, should be investigated further.

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