Children’s physical activity in the school environment

DIRK DESSING
The studies presented in this thesis were performed at the Department of Public & Occupational Health and EMGO+ Institute, VU University Medical Center, Amsterdam, The Netherlands and at TNO, Department of Child Health, Leiden, The Netherlands.


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Children’s physical activity in the school environment
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Chapter 1

General Introduction
Benefits of physical activity for school-aged children

There is overwhelming evidence that being physically active with moderate-to-vigorous intensity is associated with a wide range of health benefits, also for school-aged children[1,2]. For example, regular physical activity (PA) is associated with increased bone mineral density [3], increased cardiovascular health [4] and improved muscular strength and endurance [5]. Moreover, the relationship between PA and childhood obesity has been extensively studied, showing that overweight children benefit from regular physical activity because it leads to lower BMI and a lower percentage of body fat, both of which are risk factors for the metabolic syndrome [2,6]. Besides the above mentioned health benefits, habitual PA has also been linked to better mental health [7], increased motor skills [8], improved cognition [9] and better academic performance [10]. Beneficial effects of PA during childhood may even carry over into adult health status, both through biological as well as behavioral mechanisms [11]. In particular, childhood obesity is associated with higher BMI and reduced cardiovascular health during adulthood [12,13]. Also, maximized bone mineral mass during childhood reduces bone fracture risk at an older age [14]. The most important downside of an increase in children’s PA level is that this may increase the likelihood of injury. However, this negative health outcome is considered to be outweighed by all of the beneficial effects of children’s PA [2]. Increasing the amount of moderate to vigorous intensity PA in school aged youth is, therefore, viewed as an important health promotion and disease prevention strategy by the World Health Organization [15].

Children’s physical activity levels in the Netherlands

Given the above, it is alarming that children’s current PA levels are well below recommended levels [16]. Dutch Guidelines for Healthy Physical Activity [17] and the WHO [15] have made recommendations that state that children should participate in at least 60 minutes of moderate to vigorous physical activity (MVPA) every day to achieve health benefits. Besides daily accumulating 60 minutes of MVPA, children are advised also to participate in activities that strengthen muscle and bone for at least three times a week. Guidelines do not state upper limits, e.g. the Australian guidelines recommend that children should engage in more PA to attain additional health benefits, i.e. up to several hours a day. In the Netherlands, recent research based on parent proxy report showed that only around 20% of Dutch children met the recommendations of 60 minutes of MVPA [18]. There even is a slight downward trend in the number of children in the Netherlands that adhered to the guidelines; in 2006 and 2010 the number of children that met the recommendation of 60 minutes of MVPA was around 30% [18]. Trend studies from other countries in the western world (i.e., Australia, USA and Europe) also report a low prevalence of children that meet the PA recommendations [19]. Based on self-report, in which the intensity and duration of PA is usually overestimated, between 30% and 40% of children can be considered to be sufficiently active in these countries [16]. Thus, given such small numbers of children that currently adhere to the PA guidelines, it is of vital importance to develop effective interventions that
promote children’s PA. To be able to this, there is a need to gain insight in how, when and where children in the Netherlands accumulate minutes of MVPA.

Measurement of children’s physical activity

The accurate assessment of children’s daily PA is a difficult task, which can be accomplished using different methods (i.e. calorimetry, doubly labeled water, direct observation, self-report and the use of monitoring devices), all of which pose their own challenges [20]. Some of the methods available are very precise, such as calorimetry or doubly labeled water, but are not suitable for assessment of day-to-day PA, because they are difficult to implement due to practical reasons [20]. Other methods, such as self-report through physical activity diaries or questionnaires, are more suitable for measuring daily PA while they are unobtrusive, quick to administer and relatively inexpensive [21]. However, self-report relies heavily on the ability of the participant to accurately recall their PA behavior during a certain period in the past, making it less desirable when measuring young children, even if the measurement is done through parent proxy report [22]. Direct observation of PA (e.g. through the SOPLAY method [23]), neither relies on the ability of children, nor on the parents to recall detailed information. This method is still limited, because such observations can be relatively expensive and can only be done at a small number of locations and contexts. Contemporary wearable mechanical devices, such as accelerometers [6], provide a valid, practical and objective way to assess children’s daily free-living PA. Accelerometers are typically worn on the children’s hip to record vertical displacement of their bodyweight. An accelerometer is considered to be the current best method to capture children’s free-living PA [24]. An added advantage of using accelerometer data is that it is very time precise, making it possible to combine accelerometer data with global positioning system (GPS) data, thereby adding contextual information to the data. Combining the assessment of PA with the location derived from GPS may help us to gain a better understanding of the influence of the built environment on PA [25,26]. To date, very few studies have investigated school-aged children’s PA using GPS and accelerometry; most of the studies that have used this method were done in the Anglo-Saxon countries [27]. Moreover, there is a need for longitudinal studies using this method to assess the influence of changes to the physical environment.
Chapter 1

Promoting physical activity in the school environment

The method of measuring PA with a combination of GPS and accelerometer data fits well with an ecological approach towards PA promotion and assessment, in which the link between PA and different levels of the environment (individual, social, physical and policy) are investigated [28-30]. The ecological model presented in Figure 1, adapted from Story et al. [30], illustrates the different levels of influence on children's PA. Examples of the individual-level factors in the model that influence PA include cognitions, behaviors, biological and demographic factors. The social environment entails interactions with family, friends, peers, and others in the community. The physical environment refers to the multiple settings in which children are physically active (e.g. home, neighborhood, school, recreation facilities, public roads). Finally, the macro-level environment refers to the broader environment that influences PA behavior, such as societal and cultural norms, legislation, funding, and policy. It is presumed that all of these levels interact and thereby influence PA behaviors both direct and indirectly.

In recent decades using this ecological model, combined with technological advancement, has led to a growing research interest in the influence of the physical environment on children's levels of PA. As such, a recent review concluded that for children the most important settings for accumulating minutes of MVPA are public roads, streets, the school environment, and children's home environment [27]. Out of these locations, especially the school environment is an interesting setting for policy makers and researchers. The school environment provides the opportunity to reach children with diverse sociodemographic backgrounds, and children spend a substantial proportion of their time at and around this location [31]. Children's PA in the school environment can take place in different forms. Besides structured PA during physical education [32], both school
recess and the schoolyard provide ample opportunities for increasing children’s PA during free play [33,34]. Also, the journey to and from school has been identified as a source of PA and as a potential hook for interventions. Depending on the distance traveled, the trip between home and school can contribute up to 30% of total daily MVPA accumulated [35,36]. To date, there are multiple experimental studies that have investigated changes to the school environment to promote PA in school-aged children (e.g. [37-39]). However, most of these studies have focused on changes to the schoolyard, whereas environmental changes regarding the route to school have been investigated less often. The apparent lack of research on school route interventions seems to be a ‘white spot’, as the proportion of children that use active transportation to school appears to be declining worldwide. For example, the percentage of actively commuting children in the US has lowered from around 40% in 1969 to 12% in 2007 [40]. A comparable shift from active to passive transportation has also been observed in Australia [41]. Although the proportion of children that actively commute is generally much higher in European countries, some studies suggested that the proportion of active transport is declining in Europe as well [42]. Therefore, there is a need for knowledge on what factors play a role in the choice for active transportation on the school journey.

Creating a safe school environment

One of these knowledge gaps on active transportation during the school journey relates to traffic safety in the school environment. Parental concern about road safety is thought to be related with children being allowed to use active transportation between home and school [43], and consequently, traffic safety problems in the school environment can be a major barrier for walking or cycling to school [44]. Recently, traffic safety problems have been shown to be linked with lower rates of PA in school children [45], for example a recent South African study showed a correlation between objectively measured traffic safety and the level of PA of school children [46]. Moreover, several studies have found associations of parental perceptions of traffic safety with children’s level of PA [47-49]. A US intervention study also revealed that providing ‘safe’ routes to school might be an effective method to increase walking and cycling in primary school children [50]. As such, intervening in the school route by creating a safer school environment might be a feasible measure to – in part – counteract the declining PA levels in youth in the Netherlands. Thus, by employing novel methods of PA assessment, i.e. combining GPS and accelerometer data, the aim of this thesis is: (1) to gain insights into children’s PA in and around the school environment in the Netherlands, (2) to investigate children’s active transportation on the journey between home and school and, (3) to evaluate the effect of infrastructural traffic safety changes in the school environment on children’s PA.
Chapter 1

Thesis outline

The main aim of this thesis is to examine children’s PA in and around the school environment, to investigate children’s active transportation on the journey between home and school, and to evaluate the effect of creating a safer school environment on children’s active transportation and PA levels. The studies that make up this thesis start in Chapter 2 by describing how long and at what intensity children are physically active at the schoolyard during different time segments of the day. The contribution of schoolyard physical activity towards achieving the recommended guideline for daily PA is also examined in this chapter. Chapter 3 investigates children’s choice of transportation mode on the school journey in relation to the distance between home and school. Chapter 4 also examines children’s transportation mode to school, but this chapter focuses on its relation with parental neighborhood perception. Chapter 5 explores children’s route choice between home and school by comparing characteristics of actual walked and cycled routes between home and school with the shortest possible route to school. Chapter 6 examines the effect of traffic safety measures in the primary school environment on the PA levels of the attending children. Chapter 7 investigates determinants that either facilitate or impede the implementation of infrastructural changes in the school environment at primary schools in the Netherlands. Finally, chapter 8 recapitulates the main findings of the thesis and reviews the theoretical, methodological and practical implications of these findings.
References


Chapter 1

Schoolyard physical activity of 6-11 year old children assessed by GPS and accelerometry

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Abstract

Background
Children’s current physical activity levels are disturbingly low when compared to recommended levels. This may be changed by intervening in the school environment. However, at present, it is unclear to what extent schoolyard physical activity contributes towards reaching the daily physical activity guideline. The aim of this study was to examine how long and at what intensity children are physically active at the schoolyard during different time segments of the day. Moreover, the contribution of schoolyard physical activity towards achieving the recommended guideline for daily physical activity was investigated.

Methods
Children (n=76) between the age of 6–11 years were recruited in six different schools in five cities (>70.000 residents) in the Netherlands. During the weekdays of a regular school week, childrens’ physical activity and location were measured with ActiGraph accelerometers and Travelrecorder GPS receivers. Data was collected from December 2008 to April 2009. From the data, the amount of moderate to vigorous physical activity (MVPA) on and outside the schoolyard was established. Moreover, the percentage of MVPA on the schoolyard was compared between the following segments of the day: pre-school, school, school recess, lunch break and post-school. Differences between boys and girls were compared using linear and logistic mixed-effects models.

Results
On average, children spent 40.1 minutes/day on the schoolyard. During this time, boys were more active on the schoolyard, with 27.3% of their time spent as MVPA compared to 16.7% among girls (OR=2.11 [95% CI 1.54 - 2.90]). The children were most active on the schoolyard during school recess, during which boys recorded 39.5% and girls recorded 23.4% of the time as MVPA (OR=2.55 [95% CI: 1.69 - 3.85]). Although children were only present at the schoolyard for 6.1% of the total reported time, this time contributed towards 17.5% and 16.8% of boys’ and girls’ minutes of MVPA.

Conclusions
On the schoolyard, children’s physical activity levels are higher than on average over the whole day. Physical activity levels are particularly high during school recess. The school environment seems to be an important setting for improving children's physical activity levels. Further research on the facilitators of these high activity levels may provide targets for further promotion of physical activity among children.
Background

Physical activity is an important lifestyle factor that is associated with a wide range of health benefits [1, 2, 3]. When compared to recommended levels, children’s current physical activity levels are disturbingly low [4, 5]. Dutch Standards for Healthy Activity [6] and recommendations by the WHO [7] state that children should participate in at least 60 minutes of moderate to vigorous physical activity (MVPA) every day. Recent data suggest that only 30% to 40% of children meet this requirement [4, 5]. Since these low levels of physical activity in childhood are likely to continue into adulthood and can have a significant impact on future public health [8, 9], it is clear that young children should be encouraged to be more physically active.

In the past decades, the ecological approach towards increasing physical activity has generated much interest among researchers and interventionists. Focus of research has shifted more and more towards the children’s environment [10]. This has led to growing evidence that the built environment is associated with children’s levels of physical activity [11, 12, 13]. Since young children spend a considerable part of their day in the school environment (for this paper defined as: inside the school and on the schoolyard) it is considered an especially important setting for promoting children’s physical activity [14, 15, 16].

Because nearly all children attend to school, the schoolyard provides the opportunity to reach almost all children. Several studies have already described children’s physical activity during school recess using the objective method of accelerometers [17, 18, 19]. These studies indicate that school recess is an important context for children’s physical activity. However, the schoolyard also provides opportunities for physical activity on other moments of the day (i.e. before and after school). No previous study has described the physical activity levels on the schoolyard during and outside school hours. Although the physical activity levels at the schoolyard are expected to be relatively high, it is unclear to what extent it contributes to achieving the standards for healthy physical exercise. Insight in to the contribution of specific locations (e.g. the schoolyard) to the accumulation of healthy physical activities is relevant for future recommendations to promote an healthy active lifestyle.

To be able to investigate how much time of their day children actually spend on the schoolyard during and outside school hours, exact information on the location of the children is essential. Whereas location was traditionally recorded by self-report or observations, the availability of small and accurate GPS devices has opened a new venue for more practical and objective personal tracking [20]. The present study combines positional data from GPS receivers with data from accelerometers. The additional GPS information on children’s location enables the assessment of the contribution of total physical activity on the schoolyard towards children’s total daily physical activity. It is of interest to study the differences in physical activity levels on different locations and times of the day for boys and girls, in order gain insight whether different interventions are needed by gender. The aim of this study was to examine how long and at what intensity boys and
girls are physically active at the schoolyard during different time segments of the whole day. Moreover, the contribution of schoolyard physical activity towards achieving the daily MPVA requirements was investigated.

Methods

Participants and setting
The present study was part of the Spatial Planning and Children’s Exercise (SPACE) study, which examined the relationship between the built environment and physical activity among school-aged children. The SPACE study was conducted in five neighborhoods that were due to be (partially) restructured between 2004 and 2008. These neighborhoods were located in five different municipalities with >70,000 residents in the Netherlands, i.e., Amersfoort, Haarlem, Hengelo, Rotterdam and Vlaardingen. In all neighborhoods, physical activity levels of primary school children of twenty schools were monitored through a 7-day physical activity diary, first in 2004 (n=401) and then once more in 2008 (n=292). Moreover, built environmental characteristics were collected through neighborhood observation. For further information, also see de Vries et al. [11] and de Vries et al. [21].

In 2008, from the twenty schools involved in the SPACE study, a convenience sample of six primary schools also agreed to participate in the present study. The neighborhoods of these six schools were similar in type of buildings (i.e., residence type, year of construction) and demographics (i.e., age distribution, social economic status, ethnicity). Moreover, the school building and the schoolyard of the six schools were comparable in size, with most of the schoolyard area that consisted of paved surface. All schools had only one schoolyard and were comparable in available fixed and portable equipment on the schoolyard.

Children that attended the six participating schools were invited through letters and pamphlets that were handed out by their teachers, resulting in a group of 97 children that were asked to wear accelerometers and GPS receivers. Informed consent was obtained from a parent or guardian of all participating children. Data were collected for one week per subject, in the period between December 2008 and April 2009. Average daytime temperatures were collected through a database of the Royal Netherlands Meteorological Institute. During data collection, average daytime temperatures ranged from 1 to 6 degrees Celsius. The study was approved by the ethics committee (IRB) of the Leiden University Medical Center.

Instrumentation/measures
Physical activity was measured every 15 seconds with an uniaxial accelerometer (GT1M, ActiGraph, Pensacola, Florida). Longer (e.g. 1 minute) sampling intervals might have masked short intermittent bursts of physical activity that are typical for young children [22]. In addition to an accelerometer, children simultaneously carried a GPS receiver (Travel recorder X, BT-Q1000X, QStarz International Co) which recorded the geographical location every 5 seconds (positional accuracy of
<3 m Circular Error Probability CEP (50%). Both recording devices are so-called ‘black boxes’. Meaning that during recording, children could not see anything indicating the measurements by the device.

Accelerometers and GPS receivers were distributed among the children during school hours. Both devices were attached to the waist with an elastic belt. After a short instruction, the children were asked to wear the belt from waking time to bedtime for 7 consecutive days. They were asked to remove the belt during activities where the devices might get wet (e.g. swimming, showering). The parents were asked to recharge the GPS receivers during the evening when the children were asleep. Children and parents could read back instructions in a manual that was handed out together with the devices.

Body height and weight of the children were measured with a microtoise (Stanley 04–116) and a digital scale (Seca 812, Vogel & Halke GmbH & Co) to the nearest 0.1 cm and 0.1 kg respectively. Measured weight and height were used to calculate children's body mass index (kg/m2) according to which participants were categorized into normal weight, overweight and obesity according to age- and sex-specific cut-offs for children [23]. In addition, a short questionnaire was completed by the parents to provide information on the children (i.e., date of birth, sex).

Data analysis
Accelerometer data were downloaded to a personal computer using the manufacturer’s software (Actilife v3.6.0, ActiGraph) and further processed within SPSS Version 20.0. Periods of ≥ 20 minutes of zero counts were deemed biological implausible. It was assumed that children did not wear the belt during such periods and all periods of ≥20 minutes of zero counts were excluded from the analysis [24, 25]. Only participants recording more than five hours of accelerometer data (after removal of non-wear periods) on at least two weekdays were used in the analysis. This minimum wear time of five hours was chosen to minimize data loss among the relatively small sample of participants. Weekend days were not included in the analysis because only a few children (n=15) recorded activity at the schoolyard in the weekend. Based on the findings of Trost et al. [26], moderate to vigorous physical activity (MVPA) was determined using the cut-off point of >574 counts per 15 second epoch [26, 27]. There was no requirement in terms of bouts of activity. Every single epoch that was recorded above this threshold contributed to time in MVPA.

The GPS data were mapped with the URBIS III [28] software package. Exact location of the school building and schoolyard were defined with the use of TOP10NL. This contains topographic data (e.g. buildings, roads, rail road tracks, terrain water) from the digital database of the Dutch national land use register [29]. With the use of the TOP10NL data, polygons were drawn around the schoolyards of the six schools.
After construction of the polygons, accelerometer and GPS data were date- and time-matched to create a measure of activity and location for each 15 second accelerometer epoch. During this process, the location of every 15 second epoch
was defined as either being on the schoolyard (a), or inside the school building (b), or as outside the school environment (c). This was done by two methods: firstly by school class hours, and secondly by GPS location.

Firstly, all accelerometer epochs that fell during school classes, when children are known to be inside, where defined as ‘(b) inside the school building’. We chose to use these school class times instead of GPS location since the GPS may not record a position, or may record a highly inaccurate position, because inside a classroom the reception of satellite signals is often obstructed [20]. The assessment of school hours used to determine whether children were inside or outside the school building, is described further below.

Secondly, all remaining accelerometer epochs were assigned as (a) or (c) based on the three 5s GPS locations per 15s accelerometer epoch. When the majority (two or three) of the GPS epochs were situated within a distance of 10 meters of the schoolyard polygon, the accelerometer epoch was defined as ‘(a) on the schoolyard’. The buffer of 10 meters was chosen to account for the positional accuracy of the GPS receiver (e.g. due to urban canyoning) [20]. Remaining epochs were defined as ‘(c) outside the school environment’.

For school hours, a distinction was made between different segments of the day: (1) pre-school, (2) school, (3) school recess, (4) lunch break, and (5) post-school. The pre-school (1) segment started with children getting up from bed, the post-school (5) segment ended when the children went to bed for sleeping. The start and ending of the other segments were determined by visual exploration of the GPS-signal. This way, it was established per group of children sharing the same school program, at what time they entered or left their school building (see Figure 1). The accelerometer epochs recorded during the second segment (2) were labeled as (b) ‘inside the school building’, as described above. As can also be seen in Figure 1, some of the children’s activity inside the school was incorrectly projected as being on the schoolyard polygon because of the limited GPS accuracy indoors [20].

Furthermore, days on which children did not record data on the schoolyard were excluded from the analysis. On these days, children were considered not to have worn the GPS, or not to have visited school. After determining which accelerometer epochs were on the schoolyard, minutes of MVPA and percentage of time in MVPA were calculated for each participant and for each segment of the day. Moreover, mean physical activity per participant (mean counts per 15 seconds) was also calculated for the different segments of the day. Finally, the contribution of schoolyard MVPA to daily MVPA was determined by dividing the total number of minutes of MVPA that children recorded on the schoolyard through the total number of minutes of MVPA that children recorded during the whole day.
Statistical analysis
Student’s t-tests were used to test differences in age, BMI, body height or body weight between the original population and the final study population. P-values < 0.05 (two-sided) were considered statistically significant. Logistic mixed-effects models were used to estimate the difference in MVPA between segments of the day. In addition, differences between boys and girls were examined as well. The statistical analysis was conducted on the accelerometer epoch level, using similar methods as Wheeler et al. [13] to take into account the clustered data structure with individual differences in wear time and the varying duration of the segments of the whole day. In this way, the relative odds of an accelerometer epoch exceeding the MVPA cut-off could be estimated for physical activity on the schoolyard. Odds ratios were calculated for all segments of the day, with preschool as the reference category (OR= 1.00). Furthermore, differences in mean counts per 15 seconds between different segments of the day were compared with linear mixed-effects models. Analyses were performed in SPSS Version 20.0. Results for boys and girls were presented separately and models were adjusted for school attended, age and BMI category.
Results

Initially, a group of 97 children wore accelerometers and GPS receivers. Children that did not record sufficient accelerometer data (n=13), or did not record any data on the schoolyard (n=8), were excluded from the analysis. No significant differences in age, BMI, body height or body weight were observed between the original and the final study population. Thus, the final study population consisted of 76 children, including 32 boys and 44 girls. The age of the children ranged between 6 and 11 years, with an average of 8.6 years (SD=1.40). Around one third (n=23) of the children were classified as being either overweight or obese. Further descriptive statistics are presented in Table 1. All together, the children recorded 211 days with combined GPS and accelerometer data, 12 children provided one day of data, 17 children provided 2 days, 23 provided three days and 24 provided 4 days of data. Participants wore the accelerometer for an average of 11.2 hours/day (SD±1.9). There was no significant difference in mean wear time between boys and girls. The GPS location was available for 91.3% of all accelerometer data.

Table 1. General characteristics of the study population

<table>
<thead>
<tr>
<th>Total</th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (±SD) n</td>
<td>Mean (±SD) n</td>
</tr>
<tr>
<td>Age (years)</td>
<td>8.6 (±1.4) 76</td>
<td>8.5 (±1.4) 32</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>137.4 (±9.6) 76</td>
<td>137.8 (±9.5) 32</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>34.8 (±10.5) 76</td>
<td>34.6 (±9.9) 32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BMI Category</th>
<th>% n</th>
<th>% n</th>
<th>% n</th>
</tr>
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<tr>
<td>Normal</td>
<td>69.7 53</td>
<td>75.0 24</td>
<td>65.9 29</td>
</tr>
<tr>
<td>Overweight</td>
<td>18.4 14</td>
<td>12.5 4</td>
<td>22.7 10</td>
</tr>
<tr>
<td>Obese</td>
<td>11.8 9</td>
<td>12.5 4</td>
<td>11.4 5</td>
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<table>
<thead>
<tr>
<th>Location of school</th>
<th>% n</th>
<th>% n</th>
<th>% n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haarlem</td>
<td>10.5 8</td>
<td>6.3 2</td>
<td>13.6 6</td>
</tr>
<tr>
<td>Amersfoort</td>
<td>27.6 21</td>
<td>34.4 11</td>
<td>22.7 10</td>
</tr>
<tr>
<td>Amersfoort (2)</td>
<td>11.8 9</td>
<td>9.4 3</td>
<td>13.6 6</td>
</tr>
<tr>
<td>Hengelo</td>
<td>26.3 20</td>
<td>31.3 10</td>
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<td>12.5 4</td>
<td>9.1 4</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>13.2 10</td>
<td>6.3 2</td>
<td>18.2 8</td>
</tr>
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</table>
Physical activity
Overall, children recorded 48.9 (SD±22.2) minutes of MVPA per day. With 56.2 (SD±23.7) minutes of MVPA per day, boys spent significantly more time in MVPA than girls (OR=1.30 [95% CI: 1.04-1.62], who accumulated 43.6 (SD±19.6) minutes of MVPA/day. Out of the 76 children, 19 children (25.0%) accumulated an average of ≥ 60 minutes MVPA a day and met the recommended amount of physical activity. This group consisted of 11 boys and 8 girls.

Physical activity in the school environment
Table 2 provides a summary of children’s daily physical activity (in MVPA) on the schoolyard and inside the school building. When children were in the school environment, they spent most of their time inside the school building: on average this was around 4 hours/day. Only a small percentage of this time was MVPA, this was 2.1% (SD±2.1) for boys and 2.8% (SD±3.2) for girls. Children spent an average of 40.1 (SD±20.9) minutes per day on the schoolyard during which they recorded 7.8 (SD = 5.1) minutes of MVPA. Of the time recorded on the schoolyard, the percentage spent as MVPA was 27.3% (SD±13.7) for boys. Girls recorded 16.7% (SD±10.4) of time on the schoolyard as MVPA. Boys recorded higher numbers of MVPA/ minute when they were on the schoolyard (OR=2.11 [95% CI 1.54-2.90]). Most of the minutes of MVPA per day were accumulated outside the school environment, 42.5 (SD±21.9) minutes for boys and 29.5 (SD±14.7) minutes for girls. Schoolyard physical activity contributed towards 17.5% and 16.8% of boys’ and girls’ total minutes of MVPA. The proportion of time spent in MVPA on the schoolyard, for boys 27.3% (SD±12.7) and girls 16.7% (SD±10.4), was therefore much higher than the overall proportion

Table 2. Children’s physical activity on the schoolyard compared to physical activity inside school

<table>
<thead>
<tr>
<th></th>
<th>Schoolyard</th>
<th>Inside school</th>
<th>Whole day</th>
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</thead>
<tbody>
<tr>
<td>Total time (minutes) per day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>Mean 33.3</td>
<td>236.5</td>
<td>668.4</td>
</tr>
<tr>
<td>(±SD)</td>
<td>(±13.4)</td>
<td>(±48.7)</td>
<td>(±107.1)</td>
</tr>
<tr>
<td>Girls</td>
<td>Mean 45.1</td>
<td>244.9</td>
<td>679.2</td>
</tr>
<tr>
<td>(±SD)</td>
<td>(±23.9)</td>
<td>(±66.1)</td>
<td>(±124.3)</td>
</tr>
<tr>
<td>Minutes of MVPA per day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>Mean 8.8</td>
<td>4.9</td>
<td>56.1</td>
</tr>
<tr>
<td>(±SD)</td>
<td>(±5.1)</td>
<td>(±5.2)</td>
<td>(±23.7)</td>
</tr>
<tr>
<td>Girls</td>
<td>Mean 7.0</td>
<td>7.1</td>
<td>43.6</td>
</tr>
<tr>
<td>(±SD)</td>
<td>(±5.1)</td>
<td>(±8.2)</td>
<td>(±19.6)</td>
</tr>
<tr>
<td>Proportion of time spent as MVPA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>% 27.3*</td>
<td>2.1</td>
<td>8.5*</td>
</tr>
<tr>
<td>(±SD)</td>
<td>(±12.7)</td>
<td>(±2.1)</td>
<td>(±3.5)</td>
</tr>
<tr>
<td>Girls</td>
<td>% 16.7*</td>
<td>2.8</td>
<td>6.5*</td>
</tr>
<tr>
<td>(±SD)</td>
<td>(±10.4)</td>
<td>(±3.2)</td>
<td>(±2.9)</td>
</tr>
</tbody>
</table>

*significant difference between boys and girls (p<0.01).
of time spent in MVPA over the day (8.5% (SD±3.5) for boys and 6.5% (SD±2.9) for girls, respectively).

Schoolyard physical activity during the different segments of the day
For the different segments of day, percentage of time spent in MVPA is shown in Figure 2 (for total number of minutes spent on the schoolyard, see Table 3). Children were most intensively physically active on the schoolyard during school recess (boys: OR= 4.23 [3.62-4.95], girls: OR 2.56 [2.21-2.97], compared to the pre-school segment, see Table 4). During school recess, children recorded 18.3 (SD±7.6) minutes on the schoolyard. For boys, during school recess the percentage of MVPA was 39.5% (SD±18.5) whereas girls recorded 23.4% (SD±13.0) of the time in MVPA. Differences between both sexes were significant (OR=2.55 [95% CI: 1.69 - 3.85]). Results of the statistical analysis are presented in Table 4, with the pre-school segment as the reference category.

Table 3. Description of total time recorded on the schoolyard for different segments of the day.

<table>
<thead>
<tr>
<th>Time Segment</th>
<th>Boys (Mean ± SD)</th>
<th>Schoolyard (±SD)</th>
<th>Lunch Break (±SD)</th>
<th>Post School (±SD)</th>
<th>Total (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre school</td>
<td>6.3 ± 3.6</td>
<td>15.7 ± 6.3</td>
<td>12.9 ± 12.8</td>
<td>11.1 ± 10.6</td>
<td>33.3 ± 13.4</td>
</tr>
<tr>
<td>School recess</td>
<td>6.0 ± 3.5</td>
<td>20.1 ± 8.0</td>
<td>19.3 ± 19.5</td>
<td>14.5 ± 16.5</td>
<td>45.1 ± 23.9</td>
</tr>
</tbody>
</table>

Table 4. Odds ratio of an epoch on the schoolyard exceeding the MVPA cut-off (>574 counts) for different segments of the day (adjusted for age, BMI category and school attended).

<table>
<thead>
<tr>
<th>Time Segment</th>
<th>Boys (n=32)</th>
<th>Girls (n=44)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>OR</td>
</tr>
<tr>
<td>Pre school</td>
<td>1670</td>
<td>1.00</td>
</tr>
<tr>
<td>School recess</td>
<td>3945</td>
<td>4.23</td>
</tr>
<tr>
<td>Lunch break</td>
<td>2737</td>
<td>2.11</td>
</tr>
<tr>
<td>Post school</td>
<td>3696</td>
<td>1.41</td>
</tr>
</tbody>
</table>

N=number of accelerometer epochs, n=number of children, OR=Odds Ratio, 95% CI = 95% Confidence Interval.
Discussion

This is the first study that examined the duration and the intensity of schoolyard physical activity during several school days using objective methods to assess physical activity. The aim of this study was to investigate how long and at what intensity children are physically active on the schoolyard, not only during school recess but also during other segments of the day. Children spent an average of 40.1 minutes/day on the schoolyard. While this represented only 6.1% of total registered time, this time on the schoolyard contributed towards 17.5% and 16.8% of boys’ and girls’ minutes of MVPA. Ridgers et al. [18] found very similar numbers, with time spent during school recess contributing towards around 17% of children’s total school day MVPA.

The intensity of schoolyard physical activity varied during the different segments of the day. On the schoolyard, children in this study recorded the highest intensity of physical activity during school recess. Boys spent 39.5% (SD±18.5) of the time during recess in MVPA compared to 23.4% for girls. Previous studies [18, 30] have suggested a guideline of 40% of MVPA during recess periods. In this study, 43.8% (n=14) of boys and 11.4% (n=5) of girls reached this percentage during school recess on the schoolyard.

During school recess children spent a relative high percentage of time in MVPA. Thus, the results of this study seem to confirm the importance of school recess for the accrual of minutes of MVPA. They support the recommendation recently made by Ridgers et al. [18], that policy makers should ensure that all children in primary school should have at least one recess period a day to provide an opportunity for
MVPA. Whether adding extra school recess time can contribute towards reaching MVPA requirements needs further investigation since current results are all based on cross-sectional data [17, 18, 19]. When considering the time at school dedicated to school recess, a relevant notion is the suggested beneficial effect of physical exercise for children’s cognitive development; a review by Trudeau and Shephard [31] suggests that this extra time for physical activity during school hours might be beneficial for academic performance.

Although in the present study proportionally more of the time on the schoolyard is spent as MVPA, it should be noted that most of the minutes of MVPA during schooldays were accumulated outside school hours and on other locations than the schoolyard. Moreover, almost no minutes were recorded on the schoolyard in the weekend or in the evening. Partially, this might be because most of the data was collected during winter when children are least active outside [32]. Also, in the current study, physical education lessons could not be differentiated from other activities. Most children had physical education outside their school building on other locations. Results from this study seem to confirm the finding by McGall et al. [19] that physical activity opportunities in the school environment alone were not enough for children to accrue adequate numbers of MVPA.

Remarkable are the low numbers of MVPA that were accumulated when children were inside school. For boys, only 2.1% (SD ±2.1) of time (see Table 2) that was recorded inside the school building was spent as MVPA. Girls recorded 2.8% (SD ±3.2) of the time inside school as MVPA. Nettlefold et al. [17] found slightly higher numbers during regular class time: 12.0% of time was spent as MVPA for girls and 14.1% for boys. This difference can partially be explained because of different threshold values used to define MVPA. The same study found that children spent 70% of regular class time as sedentary activity. A more recent study by Ridgers et al. [33] also showed that around 63% of class time is spent sitting. These number are in line with the findings of the current study that primary school children are relatively inactive when they are inside the school building. These low activity levels during class stress the importance of promoting physical activity outside class hours (e.g. at recess- and lunchtime by walking and cycling to school [34, 35]), but also the importance of interrupting sedentary behavior inside the school building (e.g. in-class physical activity breaks, environmental cues and prompts such as standing easels [36]). Recent studies suggest that physical activity during the school day, may stimulate children’s attention and academic performance [34, 37, 38, 39]. During almost all segments of day, boys were more physically active on the schoolyard than girls. Other recent studies, which also used accelerometry to measure physical activity, show similar results [17, 18, 19]. Thompson et al. [40] indicated that stage of maturation has an influence on the amount of physical activity, with more mature children being less physically active. Since girls mature earlier than boys, this might explain the difference observed between sexes. Moreover, Blatchford et al. [41] showed that boys and girls engage in different sorts of activities on the schoolyard. Boys are more likely to be involved in ball games and more vigorous play. Girls were most likely to engage in social conversation, sedentary play and skipping and avoid rough physical contact.
during play. In this respect, Ridgers et al. [18] recommend schools to consider organizing playgrounds to allow equal access to activities for boys and girls. Sallis et al. [42] have shown that improving the design of the play environment and extra equipment can be a beneficial strategies to promote girl’s physical activity levels. However, more detailed research on the effect of such interventions to reduce the observed differences between sexes is still needed.

Limitations
Compared to self-reports, questionnaires or observations, accelerometry combined with GPS is an objective method to measure physical activity [4]. However, the use of these objective measures also has its limitations. There is a chance of logging inaccurate positions because of signal inaccuracy (e.g. due to urban canyoning) and noise, especially when children are indoors [20]. In the current study, at least three GPS locations were available for each single accelerometer epoch, thus reducing positional inaccuracy. Furthermore, children’s school hours were determined to further reduce the chance of incorrectly classifying children as being on the schoolyard. Besides these issues associated with GPS measurements, accelerometer measurements also have their pitfalls. The threshold value to determine minutes of MVPA remains arbitrary and can have a considerable impact on the percentage of time spent in MVPA [43]. Because of the issues associated with choosing the right threshold for MVPA, this study also reports the accelerometer output independent of a threshold, in mean counts per 15 seconds (Additional file 1: Table S1). When using this outcome measure, differences between the segments of the day are similar to differences in the percentage of MVPA, with school recess as the segment where children are most active. Moreover, criteria used for minimum wear time could also have affected the outcome of the accelerometer measurements. The relative low wear time of some of our participants would mainly affect the analysis of accumulated minutes of MVPA during different segments of the day. We tested whether the accumulated minutes of MVPA were different for subjects with less than 10, and more than 10 hours of accelerometer data/day. This was not statistically different when tested with a student’s t-test. Future studies can consider to further improve classification of children’s activity levels by using additional methods to measure physical activity, such as heart rate monitoring [44].

Furthermore, results from this study are likely to be affected by seasonal influences and may not represent average physical activity levels over the entire year. Most of the data was collected during winter (December 2008-April 2009), this is commonly the time of year when children are least active because of the fewer daylight and poorer weather conditions [32, 45]. The winter season could have influenced the number of children on the schoolyard in the weekend and evening. Due to the low number of children that were present on the schoolyard during weekends or evenings in the current study, it was not possible to compare these segments with the other segments of the day.

Because of the relative small number of children that participated in each school, characteristics of the schoolyard and their association with physical activity could
not be assessed. By making changes in the physical school environment (e.g. by placing playground markings on the schoolyard [46]), it seems possible to improve children’s physical activity participation with low cost interventions [47, 48]. Future research using GPS and accelerometry is warranted to assess which physical and social elements of the schoolyard (e.g. surface area, available equipment, supervision, lighting) are associated with higher levels of physical activity amongst children. This may also provide more insight into the observed differences between boys and girls.

Conclusions

The proportion of time spent in MVPA is relatively high on the schoolyard compared to the total day, and the time inside the school building. Most of the minutes of MVPA on the schoolyard occurred during school recess. The schoolyard appears to be an important setting for children’s physical activity, especially during school recess. Moreover, children showed relative sedentary behavior when they were inside the school building. Policy makers should thus realize that school recess provides an excellent opportunity to accumulate minutes of MVPA. Interventions that focus on the promotion of physical activity during the school day have the difficult challenge to activate girls, as they currently lag behind in physical activity levels during all segments of the school day.
References


[29] Information on Kadaster, the Dutch land use register. http://www.kadaster.nl/web/artikel/productartikel/TOP10NL.htm


Chapter 3
Active transport between home and school assessed with GPS: a cross-sectional study among Dutch elementary school children
Abstract

Background
Active transport to school is associated with higher levels of physical activity in children. Promotion of active transport has therefore gained attention as a potential target to increase children's physical activity levels. Recent studies have recognized that the distance between home and school is an important predictor for active travel among children. These studies did not yet use the promising global positioning system (GPS) methods to objectively assess active transport. This study aims to explore active transport to school in relation to the distance between home and school among a sample of Dutch elementary school children, using GPS.

Methods
Seventy-nine children, aged 6-11 years, were recruited in six schools that were located in five cities in the Netherlands. All children were asked to wear a GPS receiver for one week. All measurements were conducted between December 2008 and April 2009. Based on GPS recordings, the distance of the trips between home and school were calculated. In addition, the mode of transport (i.e., walking, cycling, motorized transport) was determined using the average and maximum speed of the GPS tracks. Then, proportion of walking and cycling trips to school was determined in relation to the distance between home and school.

Results
Out of all school trips that were recorded (n = 812), 79.2% were classified as active transport. On average, active commuting trips were of a distance of 422 meters with an average speed of 5.2 km/hour. The proportion of walking trips declined significantly at increased school trip distance, whereas the proportion of cycling trips (Beta = 1.23, p < 0.01) and motorized transport (Beta = 3.61, p < 0.01) increased. Almost all GPS tracks less than 300 meters were actively commuted, while of the tracks above 900 meters, more than half was passively commuted.

Conclusions
In the current research setting, active transport between home and school was the most frequently used mode of travel. Increasing distance seems to be associated with higher levels of passive transport. These results are relevant for those involved in decisions on where to site schools and residences, as it may affect healthy behavior among children.
Background

Being sufficiently physically active is important for children. It is associated with a wide range of health benefits. For example, being physically active is related to improved cardiovascular risk factors, enhanced bone mineral density and improved psychological well-being [1, 2]. At present, when children’s physical activity is compared to recommendations made by the WHO [3] or Dutch Standards for Healthy Activity [4, 5], the low number of children that are sufficiently physically active is alarming. The WHO recommends children to be physically active for at least 60 minutes each day. International [6] and Dutch [7] research concluded that only 30-40% of the children currently meet this recommendation. Consequently, stimulating children to be physically active is part of current health promotion and disease prevention strategies. In this regard, the journey between home and school is gaining more and more attention as a potential source of physical activity for children [8, 9, 10, 11]. For example, a study by Cooper et al. [12] showed that for children that used active transport, the journey to school could contribute towards reaching daily physical activity requirements. Besides, not only children benefit from this, it could also be beneficial to people who live in proximity to the school. Traffic congestion in the areas surrounding schools can be significant. Furthermore, the reduction of motorized transport to school is likely to have a positive influence on the local environment, for example by reducing regional air pollution levels [13, 14]. Unfortunately it appears that, in the past decades, the number of children that actively commute to school has steadily declined. For example, the proportion of students in the US that walk or bike to school has dropped from around 40% in 1969 to 12% in 2007 [15]. Similar numbers have been observed in Australia [16]. Although the proportion of children that actively commute is generally much higher in Europe, there is some evidence that suggests the proportion of active travel is also declining in European countries [17]. Moreover, it is expected that changes in mode of transport will be different in countries where cycling is much more common (e.g. Denmark, Germany, the Netherlands) [18].

In recent research a wide spectrum of correlates for active commuting has been identified, ranging from individual and family factors, school characteristics, social factors to physical environmental factors [19, 20]. Of these correlates the reported distance to school seems to be the strongest predictor of using active rather than passive transport [21]. Literature shows that when the reported distance increases, the probability of active travel to school decreases [22, 23, 24, 25, 26]. The measurement of the distance traveled differs between studies. Most studies have used self-reported distance, others have calculated the shortest possible route along the road network by using geographic information systems (GIS). GIS estimations of the shortest route have the advantage that they do not suffer from recall bias by the respondents. On the other hand, they still do not always accurately reflect the actual traveled route [27]. A more accurate way to monitor the route to school is by the use of GPS. Moreover, there is also no standardized method for measurement of mode of travel [21]. Some studies used parents’ estimates of their children’s frequency of walking and cycling to school,
while others relied on self-reports from children, or used independent observers to report the mode of transport. Finally, although both walking and cycling are considered active forms of transport, they are two distinct modes of transport that should be separated in the analysis since they have been associated with different correlates in previous research [28, 29].

The use of global positioning systems (GPS) might be the solution to the previously mentioned issues associated with measurement of distance and assessment of mode of transport. Recent technological advancement in GPS receivers has made them easy to carry, and these devices have already been used for measuring free-living activities in children without interfering with their day-to-day activities [30, 31]. Thus, the use of GPS offers great potential for progress in the field of health research [32] and brings a new and objective method to monitor the actual distance traveled and mode of transport of children.

The aim of the present study was to analyze the relationship between the distance between home and school and the proportion of children actively traveling to school, using data collected with GPS receivers. With objective data, better informed decisions on potential school siting can be made, or other policy measures that might encourage active transport among school children.

Methods

Participants and setting

This study was part of the SPACE (Spatial Planning And Children’s Exercise) study, in which the relationship between physical environmental characteristics and children’s physical activity was investigated [26, 33].

Out of the twenty elementary schools that participated in the SPACE study, a convenience sample of six schools was selected to take part in this study. These six schools were located in five different Dutch cities with >70,000 residents (i.e. Amersfoort, Rotterdam, Hengelo, Haarlem and Vlaardingen). The schools are situated in neighborhoods that are demographically similar (i.e. age distribution, social economic status, ethnicity) and contain comparable types of buildings (i.e. residence type, year of construction).

Elementary school children, between the ages of 5 and 11 years old, were invited to take part in the study through letters and pamphlets that were handed out by teachers of the participating schools. This resulted in a group of 97 children that were all asked to wear GPS receivers for one week. All children lived in the same neighborhood as the school they attended. Furthermore, informed consent was obtained from a parent or guardian for all children that took part in the study. The measurements were conducted between December 2008 and April 2009, and temperatures during the recording period ranged between 1 and 6 degrees Celsius. The study was approved by the ethics committee (IRB) of the Leiden University Medical Center.
**Instrumentation / measures**

All children were requested to wear a GPS receiver (Travel recorder X, BT-Q1000X, QStarz International Co) on awakening in the morning until bedtime for eight consecutive days during a regular school week. The GPS receivers were set to record the geographical position of the children with a sampling frequency of 5 seconds. Children were instructed on the use of the GPS receivers when these were handed out during school hours. The GPS was attached to the children’s waist with an elastic belt. During activities where the GPS receiver could be damaged, or uncomfortable to wear, the children were asked to temporarily remove the device (e.g. during swimming, showering, sleeping). To ensure parents and children could read back all instructions, a manual was handed out with the device.

In addition, the children’s body height (without shoes and socks) and body weight (with clothes, without shoes) were measured with a microtoise (Stanley 04-116) and a digital scale (Seca 812, Vogel & Halke GmbH & Co) respectively. These measures were used to calculate BMI (kg/m²), and to categorize the children into ‘normal weight’ or ‘overweight’ according to age- and sex-specific cut-off points for children by Cole et al. [34]. All children that were above normal weight, including the obese, were classified as ‘overweight’. Furthermore, a parent or guardian completed a questionnaire to provide information on children’s age, gender, home address, and other demographic variables.

**Data handling**

All GPS data were downloaded to a computer with Q-Travel, a travel data management software package from Qstarz, and then mapped with the URBIS III software package [35]. First, the location of the home address and the school building of the children were determined based on the GPS-data. This was done based on a cluster detection method which can be used to distinguish indoor and outdoor activity [36]. Cluster detection was used because geocoding of the home and school addresses based on postal codes can result in inaccuracy [37]. The straight line distance between the children’s home address and the school location was then calculated using the Pythagorean theorem.

Second, for all children, each GPS track between the home address and the school location was identified with an automatic procedure in URBIS. The procedure to recognize these tracks started by identifying the first recorded GPS point that was located within 25 meters of the home address. Next, the recorded GPS data was searched chronologically until the first recorded GPS point was detected that was located within 25 meters of the school building. If a GPS point within 25 meters of the home location was detected first, this was used as the new starting point of the track. All data points between the two GPS points were considered to be part of the GPS track between home and school. Once a track between the two points of interest was identified, it was extended in both directions as close as possible to the actual location of the address. An example of such a track is shown in Figure 1. Once all relevant tracks starting from the home location were identified, the whole procedure was repeated, but
this time starting with all GPS points within 25 meters of the school building. This way, tracks going from school towards the home location could also be identified. Tracks going in either direction (i.e. home or school) were included in the analysis. For each of these tracks total distance, time duration, average speed and maximum speed were computed. To reduce the chance that the automated procedure incorrectly selected tracks that were not situated between the home and school location, all GPS tracks whose distance or duration deviated from the standard deviation within and between subjects were detected. This was done separately for active and passive transport tracks. All tracks that deviated beyond three times the standard deviation ± the mean were removed from the analysis. Third, the mode of transport was determined for each track using the average and maximum speed. In the present study, the following cut-off points were used: when the average speed of the track was below 10 km/h and the maximum speed was below 14 km/h, the track was categorized as ‘walking’. When the average speed of the track was below 25 km/h and the maximum speed was below 35 km/h, the track was categorized as ‘cycling’. All remaining tracks with maximum speeds under < 150 km/hour were categorized as ‘motorized transport’. These values are similar to the cut-off points used by Bohte and Maat [38]. Next, descriptive statistics of the tracks (average distance, average time duration, average speed and maximum speed) were calculated separately for each mode of transport. Furthermore, the distribution of the mode of transport was displayed in relation to the distance of the tracks. This was done by calculating the percentage of walk, cycle or motorized transport tracks for distance categories of 100 meters.

Figure 1. Example of a child traveling from home towards the school building.

The track starts when leaving the left cluster at the home address, the track ends before the start of the right cluster located at the school building.
Statistical analysis
A multinomial logistic mixed-effects model was used to assess whether the distance of the GPS track was related to the mode of transport of the children. This model was used to account for the clustered data structure where clusters of children lived in the same city and where individual children recorded a different number of tracks. Distance of the recorded track was used as the independent variable, mode of transport was the dependent variable. The analysis was done on the level of the GPS tracks. This way, the hypothesis was tested whether GPS tracks of relatively larger distance had a higher chance to be classified as passive transport. Within this model, this meant that the tracks defined as ‘walking’ were used as a reference category to estimate the relative odds of a track being either ‘cycling’ or ‘motorized transport’ as distance of the track increased. Since distance was not normally distributed, a logarithmic transformation was performed before it was used in the model. To examine whether the mode of transport was comparable for going home and going to school, the direction of the track (i.e. towards home or school) was also added to the model, using ‘going towards home’ as the reference category. Results were adjusted for city, gender and age of the children. All analyses were performed in SPSS version 20.0.
Results

Of the 97 children that carried a GPS receiver, 86 children recorded one or more tracks between home and the school building. Children (n = 3) that lived very close to the school building (< 50 meters) were excluded because the inaccuracy of GPS recordings (10-15 meters) has a relatively large influence on such short distances. After removal of tracks that deviated in distance, duration or maximum speed, the final study population consisted of 79 participants that recorded 812 GPS tracks for further analysis. The age of the children ranged between 5 and 11 years, with an average of 8.6 (SD ± 1.40) years. Average BMI of the final study population was 18.2 (SD ± 3.3) kg/m². Further descriptive statistics of the population are shown in Table 1.

Figure 2 shows the distribution of the (straight line) distance between the home address and the school building among the study population. The distribution is slightly skewed to the right: most of the children live within a perimeter of 500 meters from the school building. Average distance between home and school is 364 meters, median distance is 268 meters.

On average, participants recorded 10.3 tracks (SD ± 6.6) between the home address and the school building (and vice versa). Out of the 812 tracks, 44.6% were classified as walking, 34.6% as cycling and 20.8% as motorized transport. Thus, 79.2% of the recorded tracks were classified as active transport. Of all children, 92% (n = 73) recorded at least one trip to school that was classified as either walking or cycling. When children walked or cycled, they recorded an average track distance of 474 meters between home and school. On average, their journey between home and school took 8 minutes at an average speed of 5.2 km/h. Further descriptive statistics for the travel modes (i.e. distance, time duration, average speed and maximum speed) are shown in Table 2. Out of the 812 tracks in the analysis, more than half of the tracks (n = 434) were tracks from school towards the home address. There was no significant difference in mode of transport between the two directions, i.e. going home or going towards school (Beta = 0.37, p = 0.24). Most of active transport took place within a range of 200 and 600 meters. At distances of beyond 1500 meters, very few active transport tracks were recorded.
Table 1. Descriptive statistics of the population

<table>
<thead>
<tr>
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<td>Body weight (kg)</td>
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<table>
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</tr>
<tr>
<td>Vlaardingen</td>
<td>10.1</td>
<td>8</td>
<td>10.8</td>
<td>4</td>
<td>9.5</td>
<td>4</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>11.4</td>
<td>9</td>
<td>8.1</td>
<td>3</td>
<td>14.3</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 2. Average distance, time duration and speed of GPS tracks between home and school

<table>
<thead>
<tr>
<th>Mode of transport</th>
<th>Mean ± SD</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking (N=362)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (meter)</td>
<td>357 ± 264</td>
<td>288</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>6.9 ± 8.9</td>
<td>4.2</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>4.1 ± 1.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Max speed (km/h)</td>
<td>9.9 ± 2.4</td>
<td>10.1</td>
</tr>
<tr>
<td>Cycling (N=281)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (meter)</td>
<td>624 ± 383</td>
<td>560</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>8.4 ± 9.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>6.8 ± 3.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Max speed (km/h)</td>
<td>19.2 ± 4.8</td>
<td>17.4</td>
</tr>
<tr>
<td>Motorized transport (N=169)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (meter)</td>
<td>2941 ± 4208</td>
<td>1176</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>42.3 ± 72.8</td>
<td>7.4</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>10.6 ± 7.8</td>
<td>9.1</td>
</tr>
<tr>
<td>Max speed (km/h)</td>
<td>53.6 ± 18.6</td>
<td>48.8</td>
</tr>
</tbody>
</table>

N represents the number of tracks recorded for the different modes of transport.
Figure 3 shows how the mode of transport is distributed among the different track lengths. Since most children lived within a 500 meter perimeter around their school, the number of recorded tracks is distributed unevenly over the distance categories. For example, only 22 tracks were recorded between 900 and 1000 meters, while there are 162 tracks in the category 200-300 meters. As can be seen in the figure, almost no tracks \( (n=2) \) were classified as motorized transport within a distance below 300 meters. In contrast, of the tracks longer than 900 meters, more than half of the tracks were classified as motorized transport. There is a significant decrease in the percentage of walking tracks as the track distance increases. With ‘walking’ as the reference category, distance was significantly associated with an increase in cycling (adjusted Beta = 1.23, \( p < 0.01 \), crude Beta = 1.24, \( p < 0.01 \)) and motorized transport (adjusted Beta = 3.61, \( p < 0.01 \), crude Beta = 3.60, \( p < 0.01 \)).
Figure 3. Mode of transport distribution in relation to distance of the track (in categories of 100 meters).
Discussion

The aim of this study was to explore the relationship of the distance between home and school and the proportion of active transport trips. This study used objective methods to measure the distance and classify the mode of transport of children's journey between home and school. Other studies that have measured the route during active transport relied on subjective recall of the trip length, e.g. [39], or on the use of GIS to calculate the distance of a route, e.g. [22]. These methods are considered to be less accurate. The actual route distance to/from school has not yet been assessed objectively in previous research that focused on the mode of transport [21].

In the current study almost all of GPS tracks with a distance below 300 meters were classified as active transport (99.2%), and out of the tracks with distances above 900 meters, more than 50% was classified as motorized transport. A significant decline in the proportion of children that walked could be observed with increased distance. Results of this study confirm the findings of previous studies [22, 23, 28, 39] which also concluded that as the distance to school increases, the likelihood of active school travel decreases. For example, a study among Australian schoolchildren revealed that children were at least 5 times more likely to actively commute to school if their distance to school was shorter than 800 meters [22]. Most of the previous studies on active transport have been conducted outside of Europe where children generally live further from their elementary school and the distance between home and school tends to be longer. In the study from Yeung and colleagues [39] in Australia, active commuters traveled an average distance of 1.5 kilometers per trip whereas in the present study, almost all children lived within 1 kilometer of the school building. Average straight line distance between home and school was 364 meter, and active commuting trips had an average length of 422 meters. Our study showed that even when children live within a relative short distance from their school building (< 1 km), a decline in the proportion of children actively commuting to school can be observed with increasing distance of the school journey.

In the current study population, most of the tracks (79.2%) were classified as active transport. It is likely that this is an underestimation of the percentage of active transport trips in other seasons, since most of the measurements were conducted during the winter period [40]. The finding that the majority of children used active transport in the current study is in contrast with other studies that have found motorized transport to be the most frequently used mode of transport (e.g.[23]). This might be partly due to the fact that cycling is a very popular and practical method of transport in the Netherlands, especially when compared to the UK and US where only about 1% of trips are conducted by bicycle [18]. Results from the present study thus might not be applicable to populations of schoolchildren outside the Netherlands. Key to the high levels of cycling in the Netherlands seem to be the separate bicycle lanes, combined with traffic calming measures in residential neighborhoods [18]. Moreover, schools in the Netherlands are relatively close to their residents. Even in the least densely populated
municipality, the average distance to an elementary school is smaller than 2 kilometer [41].

In this study, no difference was found in the mode of transport to school and the mode of transport on the way back home. Research by Mitra et al. [42] did reveal a moderating effect for time of day on the mode of transport to school. Parents are thought to find it convenient to drive to school and drop their children on their way to work, but cannot drive their children back home. Also, parents may worry about traffic danger and ‘stranger danger’ on the road to school. The darkness in the morning influences both road safety and social safety, making cycling or walking to school more dangerous [43]. In the Netherlands, with a high prevalence of vulnerable road users such as cyclists, road safety is also influenced by the phenomenon of ‘safety in numbers’ [44]. This means that because of the high percentage of active transport among school children, motorists adjust their behavior and thereby increase road safety. How these aforementioned barriers and facilitators are associated with active transport among children living in close proximity (<1 km) from their school needs further investigation.

Strengths and limitations
A strength of this study is that we have automatically detected trips between the two points of interest (i.e. school and home). When collecting GPS data among children, distinguishing all tracks between home and school can be a time consuming process, even in the current study which had a relatively small sample size. Southward et al. [45] have done this by manually assessing all GPS tracks between 8 am and 9 am and tracks between 15 pm and 17 pm. With the automated method, all trips during the day, including trips during lunch breaks, could be used in the analysis. This method could be helpful in future research, for example when information from GPS-enabled mobile phones is unaccompanied by additional information (e.g. travel diaries) from students to code journeys as active or not. On the other hand, the use of the automatic process was the reason that some of the tracks between home and school included stop-overs at other destinations, for example a stop at a friend’s house or at extracurricular childcare facilities. This explains why distance and duration of some of the passive transport tracks is longer than expected solely based on the straight line distances between home and school. Next to trip detection, the mode of transport was also automatically classified in our study. This was done using the average and maximum speed of the recorded tracks. With this method, Bohte and Maat [38] could correctly classify the right mode of transport in around 70% of journeys. Results of the current study are thus expected to be influenced by similar inaccurate classification of transport mode. Unfortunately, the additional validation system that they suggest could not be applied to the present study because data collection took place in 2009. In this validation system parents are requested to give additional feedback after the classification of transport mode is made. In future studies the classification accuracy might be further improved by using such automated validation systems and integrating GPS data with other objectively recorded data, for example with data from accelerometers. This combined method may also be used to distinguish active cycling from passive transport on
the bicycle (i.e. children sitting on the back of the parent’s bicycle). Recently, a Danish research group has successfully classified transport to school into active or passive with the use of accelerometers [46]. The combination of accelerometers and GPS might offer a reliable way to further refine the classification of transport mode, for example by identifying types of activity through the use of neural networks [47], but these methods need to be validated and refined in future research.

Conclusions

In conclusion, within the current research setting with a relatively small sample of elementary school children, there was a significant relationship between the distance between home and school and the transport mode. Active transport was the most frequently used mode of travel, and with increasing distance between home and school, significantly higher proportions of motorized transport were observed. Future studies should investigate whether the results found in our study can be generalized to older children, children living in other countries, more rural areas or areas with different urban form. Meanwhile, urban planners should realize that distance to school seems to be important when designing the mobility infrastructure and when planning housing and potential school sites. Unfortunately, this is not as easy as it might seem. Distance between home and school is shaped by complex social and economic processes that influence the location of the home and school address [21]. Understanding of these processes might provide ways to stimulate active transport among school children [28]. Furthermore, it should be realized that, although distance between home and school seems to be an important correlate associated with children’s transport mode, there are other correlates that are also associated with transport mode, such as individual, family, school, social and physical environmental factors.
References


Chapter 3


Chapter 4

The association between parental neighborhood perceptions and children’s active transportation to school

Submitted

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Geertje Hegeman
Evert Verhagen
Willem van Mechelen
Frank H Pierik
Abstract

Introduction
Promoting active transportation to school is a way to incorporate regular physical activity into children’s daily lives, and is therefore viewed as an important health promotion and disease prevention strategy. This study aims to examine the association between parental neighborhood perceptions and children’s transport mode to school.

Methods
Two hundred and thirteen 8- to 12-year old children from 11 schools in the Netherlands carried a Global Position System (GPS) device for a week to assess their transport mode between home and school. Parents of the children filled in a questionnaire on individual and family characteristics, attributes of school environment (e.g. zebra crossings, pedestrian signals, traffic around school, school facilities), attributes of the home-school route (bicycle and sidewalk availability and quality), attributes of the home neighborhood (attractiveness, personal safety, social cohesion), and parental attitude towards physical activity. Multivariate mixed model analyses were performed to assess the association between parental perceptions of the home school environment and the odds of walking or cycling on the journey to school.

Results
A total of 1,297 GPS tracks (17.4% walking, 65.5% cycling and 17.0% motorized transport) was recorded between home and school. When traffic speed in the school environment was perceived to be low, this was associated with higher odds of walking on the school journey (OR=1.48, 95%CI=1.11-1.96). Perception of car parking availability in the school environment was inversely associated with cycling between home and school (OR=0.73, 95%CI=0.59-0.89). Moreover, perceived personal safety in the neighborhood was associated with lower odds for walking (OR=0.43, 95%CI=0.24-0.78), but higher odds for cycling on the school journey (OR=1.88, 95%CI=1.21-2.90). None of the other perceived environmental characteristics or attributes were significantly associated with transport mode on the journey to school.

Conclusion
This study confirmed that a number of attributes of perceived traffic safety in the school environment were associated with increased odds of walking on children’s school journey. Mixed results were found for perceived personal safety and active transportation to school. Future prospective studies to promote active transportation are warranted to further investigate the effects of alleviating parental concerns on traffic and personal safety. In the meantime, urban planners should focus on limiting traffic speed in the school environment and should be cautious not to invest in facilities that could possibly stimulate motorized travel to school.
Introduction

Active transportation between home and school can contribute 10% to 30% of daily moderate to vigorous physical activity in children [1,2]. Promoting active transportation to school is a way to incorporate regular daily physical activity into children’s lives, and can therefore be regarded as an important health promotion and disease prevention strategy [3]. An integral part of such a strategy is to make sure that children live and play in an environment that supports being physically active [4]. There are many environmental barriers for children’s active school transport, of which distance is the most recognized and well-studied barrier [5-8]. However, there might also be other factors at play, such as characteristics of the neighborhood the children live in (e.g., personal safety, aesthetics, social cohesion), characteristics of the route itself (e.g. safety, sidewalk availability) and characteristics of the school environment (e.g. facilities, traffic safety) [9,10]. The conceptual framework of Panter et al. [11] incorporates such factors to describe environmental determinants of children’s active travel to school, and identifies parental perceptions of these environmental factors as a key intermediating factors (e.g.,[12-16]). Previous studies into children’s transport mode to school and parental neighborhood perceptions reported inconsistent results. For example, mixed results were found for parental perceptions of traffic safety, personal safety and crime safety in relation to active transportation to school [9,12,16-19]. These inconsistencies between studies may partly be the result of methodological limitations [20]. First, a limitation is that the active transportation modes, i.e. walking and cycling, were often analyzed together. However, walking and cycling are separate behaviors that are influenced by specific environmental characteristics [20,21]. Moreover, previous studies that separated these behaviors used self-reported data regarding children’s transport mode to school, rather than objective data [19,22]. Defining how children ‘usually’ go to school is difficult, as some children interchangeably use different transport modes [7]. Global Position System (GPS) devices offer a more objective method to define children’s transport mode to school. Also, most of the studies on active transportation were conducted in the U.S. or Australia, implying that more research is needed in regions that are more prone to walking and cycling (i.e. countries in Europe, Asia) [20] where built environmental characteristics influencing active transportation might be different. For instance, the proportion of active transportation is generally much higher in Europe, and children mostly live in closer proximity to their school building [7].

The current study aims to examine the association between parental neighborhood perception and children’s actual transport mode to school, in a population of children that lives relatively close to the school building. The findings of the current study add to the current knowledge base on children’s transport mode to school. Such new insights may help in formulating recommendations for municipalities to create a neighborhood that stimulates children to walk or cycle to school.
Methods

Participants and setting
The current study is a cross-sectional study with data from baseline measurements of the Schoolzone project (2013-2016). The Schoolzone project was a longitudinal intervention study that investigated the effect of increasing traffic safety around primary schools on daily physical activity levels of schoolchildren. This study was approved by the Medical Ethics Committee of the VU University Medical Center, Amsterdam, The Netherlands. For the study, children between the age of 8 and 12 years old and their parents were recruited in five municipalities in the Netherlands. In consultation with the municipalities, schools were recruited based on geographical location, degree of urbanization, child demographics, and neighborhood characteristics. This resulted in eleven participating primary schools: three schools in Zaanstad, two in Haarlemmermeer, two in Edam-Volendam, two in Hilversum and two in The Hague. Baseline measurements in Zaanstad, Haarlemmermeer and Edam-Volendam were conducted during the Spring (April-June) of 2014. Measurements on the other schools took place in the Spring of 2015. Before measurements started, children and their parents were informed about the study through letters and pamphlets that were handed out by their classroom teacher. Written informed consent was then obtained from the parent or guardian of the participating children (n=299). Parents then received an envelope containing further instructions on study procedures and a questionnaire to be returned a week later.

Instrumentation / measures
Transport mode of the children between home and school was measured using a GPS receiver (Travel recorder X, BT-Q1000X, QStarz International Co). After a brief instruction, these GPS devices were handed out by research assistants during school hours and attached to the children’s waist using an elastic belt. In addition, written instructions were presented in a manual and provided to the parents of the children. The GPS was set to measure the geographical position of the children every 5 seconds. The children were asked to wear the GPS for 8 consecutive days, from the moment they were awake until bedtime. On moments when the GPS device could get damaged, the children were instructed to temporarily remove the device (e.g. rough sports, swimming, shower).

The questionnaire for the parents contained questions regarding both child and parent characteristics, i.e., age and gender of the child, highest completed education of the parents, parent’s place of birth, car ownership, and body weight and body height of their child. Reported body weight and body height of the children were used to calculate the body mass index (kg/m2) according to which children were categorized into either normal weight or overweight, using age- and sex-specific cut-offs for children [23]. Parental education level was based on the highest completed education of one of the parents and divided into three categories: low (no education, primary education, or lower education), middle (pre-university education, or intermediate education), or high (higher education or university). Ethnicity of the children was based on the place of birth of the parents.
Children were regarded to be non-Dutch if either one of the parents was born in a foreign country. Parental neighborhood perception was assessed with questions based on the Dutch version of the Neighborhood Environment Walkability Survey (NEWS) [24,25] which has also been used in previous Dutch studies [26,27]. Questions were answered on a 5-point Likert scale with the following answer categories: strongly agree, agree, neither, disagree and strongly disagree. Before being entered into the statistical analysis, questionnaire items measuring similar theoretical constructs were evaluated with Cronbach’s Alpha reliability test. When Cronbach’s Alpha was 0.7 or higher, items were grouped into a new variable by calculating the mean score of the respective items. For all variables that were measured with multiple questionnaire items, the number of questionnaire items (n) and Cronbach’s Alpha (α) is reported below. When Cronbach’s Alpha was lower than 0.7, the questionnaire items were included into the analysis as a separate variable. This procedure resulted in 6 variables that represented perceived attributes of the school environment (i.e. zebra crossings and pedestrian signals around school, traffic speed around school, amount of traffic around school, drivers exceeding speed limit, bicycle parking availability (n=2, α=0.77), and car parking availability), 1 variable representing perceived attributes of the home-school route (bicycle and sidewalk availability and quality (n=8, α=0.81)), and 7 variables representing perceived attributes of the home neighborhood (i.e. amount of street litter, attractive buildings, amount of trees, amount of dog mess, amount of noise, personal safety (n=6, α=0.70), and social cohesion (n=5, α=0.86)). Furthermore, a variable representing a positive parental attitude towards their children’s physical activity was also created (n=5, α=0.75). A full description of questionnaire items, answer categories and descriptive statistics is available as Appendix 1.

Data analysis
The recorded GPS data was processed with data management software Q-travel and mapped with URBIS, a geographic information system (GIS) software package for working with maps and analyzing geographic information [28]. Location of the school building was determined based on TOP10NL (topographic map of the Netherlands, scale 1: 10.000 provided by the Dutch Land use register ‘Kadaster’). The home address of the children was determined using a clustered detection method for clusters of GPS data recorded during the night time [29]. Next, an automatic procedure in URBIS detected the GPS tracks between the home and school address of the children [7]. Based on the two addresses, the linear distance between these locations was calculated. The average and maximum speed of every GPS track was used to determine the transport mode of the children, i.e. walking, cycling or motorized transport. A full description of the GPS data handling and specific cut off points to determine the transport mode has been described elsewhere [30].

GPS data and the parental questionnaire were available for 224 parent-child dyads (74.9%). Cases with missing values (N=4) in questions regarding the parental perceptions of the neighborhood were excluded. Furthermore, children were excluded from data analysis when they lived within 50 meters from school
(N=2), since these short trips were difficult to detect given the inaccuracy of the GPS recordings (10-15 meters). In addition, children living relatively far away from school were also excluded (N=5), as it was assumed that these children did not have the option to use active transportation. This was done based on the study population’s mean distance to school, plus three times the standard deviation (≥2910 meters). This resulted in data from 213 parents and their children, with a total of 1297 home-school trips – in either direction - that were used for further analysis.

**Statistical Analysis**

Binomial mixed models were used at the school trip level to assess the association between parental neighborhood perceptions and the two outcomes of interest (i.e. walking and cycling). In the models, a random intercept at the individual level was used to account for the multiple trips between home and school available for each child. First, univariate analyses with walking as the binomial outcome measure were performed for each individual and environmental factor. These univariate analyses were used to make a selection of candidate variables that were of a significance level below 0.20. The candidate variables were then entered into a backward selection process to construct a multivariate model for individual and environmental factors associated with walking between home and school. Second, this procedure was repeated to construct a multivariate model for individual and environmental factors associated with cycling on the school journey as the binomial outcome factor. Regression coefficients are reported as odds ratio’s (OR) and their 95% confidence interval (95% CI). The analyses were carried out using SPSS version 22.0.
Results

Participant's characteristics and mode of transport
The participating children (n=213, 49.8% boys, 50.2% girls) were of an average age of 10.1 (±0.9) years and lived at a median distance of 477.8 (IQR:306.0-691.7) meters from school. Most of the children were in the normal body weight category (83.6%) and of Dutch origin (60.1%). Further participant characteristics are shown in Table 1. On average children recorded 6.1 GPS tracks between home and school, resulting in a total of 1297 GPS tracks. Out of these tracks, 226 tracks (17.4%) were classified as walking, 850 tracks (65.5%) as cycling and 221 tracks (17.0%) as motorized transport. Cycling was the most used mode of transport; 83.6% of children recorded at least one day on which they cycled between home and school. Moreover, 39.4% of children used motorized transport to school on at least one day. The majority of walking trips (90.2%) was made by children living within a 600 meter straight-line distance from school, and a small proportion of

Table 1. General characteristics of the study population

<table>
<thead>
<tr>
<th>Participant characteristics</th>
<th>n</th>
<th>%</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>Mean (±SD) 10.1 (±0.9)</td>
<td>213</td>
<td></td>
</tr>
<tr>
<td>Distance of home to school (meters) Median (IQR) 477.8 (306.0-691.7)</td>
<td>213</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Boy 49.8%</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Girl 50.2%</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>BMI Category of children</td>
<td>Normal weight 83.6%</td>
<td>178</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overweight 16.4%</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Ethnicity of children</td>
<td>Dutch 60.1%</td>
<td>128</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-Dutch 38.0%</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Parental education level</td>
<td>Low 22.5%</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle 30.0%</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High 38.0%</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Car availability</td>
<td>Yes 85.9%</td>
<td>183</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No 12.2%</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Mode of transportation*</td>
<td>Walk 40.4%</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cycle 83.6%</td>
<td>178</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Car 39.4%</td>
<td>84</td>
<td></td>
</tr>
</tbody>
</table>

*Number of children that recorded at least one track in this transportation mode
** SD=Standard deviation, IQR=Interquartile range
motorized trips (4.1%) was made by children living close to school (<400 meters). Figure 1 shows how transport mode of the GPS tracks was divided along straight-line distance between home and school. Univariate mixed model analysis showed a negative association of walking between home-school and straight line distance to school (OR=0.99, 95% CI=0.99-0.99). Univariate analysis of personal and family characteristics also revealed that girls were less likely to walk to school than boys (OR=0.50, 95% CI=0.26-0.95). Also, Dutch children were less likely to walk to school (OR=0.27, 95% CI=0.14-0.52), but more likely to cycle to school compared to non-Dutch children (OR=1.85, 95% CI=1.17-3.09). Children in households with a car available were more likely to walk (OR=6.28, 95% CI=2.47-16.01) and less likely to cycle to school (OR=0.37, 95% CI=0.17-0.83). When parental education was classified as low, children were more likely to walk on the school journey (OR=5.85, 95% CI=2.56-13.32).

Figure 1. Number of GPS tracks as a function of straight line distance between home-school
In the multivariate analysis, gender and parental education level remained associated with the odds of walking to school. Girls were less likely to walk to school than boys (OR=0.50, 95%CI=0.25-0.97), and children of parents with a lower level of education were more likely to walk to school (OR=4.90, 95%CI=2.11-11.3). None of the individual or family characteristics remained associated with cycling on the school journey in the multivariate analysis.

As shown in Table 2, univariate mixed model analysis showed a positive association of walking between home and school with the perceived presence of zebra crossings and pedestrian signals around school (OR=1.38, 95%CI=1.07-1.78), perceived low traffic speed in the school environment (OR=1.31, 95%CI=1.01-1.70) and perceived car parking availability in the school environment (OR=1.32, 95%CI=1.02-1.70). A negative association was found between parental perceptions of personal safety and walking to school (OR=0.52, 95%CI=0.30-0.90). In the multivariate analysis, low traffic speed in the school environment was the only factor to remain positively associated with walking (OR=1.48, 95%CI=1.11-1.96) and parental perceptions of personal safety were still negatively associated with walking to school (OR=0.43, 95%CI=0.24-0.78).

The univariate mixed model analysis for cycling between home and school showed a positive association of cycling with personal safety in the home environment (OR=1.78, 95%CI=1.16-2.73) (see also Table 3). A negative association was found with parental perception of car parking availability in the school environment (OR=0.78, 95%CI=0.64-0.96) and car availability in the household (OR=0.37, 95%CI=0.17-0.83). In the multivariate model, parental perception of car parking availability remained inversely associated with cycling between home and school (OR=0.73, 95%CI=0.59-0.89), whereas perceived personal safety was associated positively with cycling (OR=1.88, 95%CI=1.21-2.90).
## Table 2. Univariate analysis for neighborhood perception and children's transportation mode to school (walking)

<table>
<thead>
<tr>
<th>Attribute of the home-school route</th>
<th>OR (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall walking and cycling influence</td>
<td>1.26 (0.78-2.07)</td>
<td>0.35</td>
</tr>
<tr>
<td>Quality of walking and cycling influence</td>
<td>0.93 (0.27-3.23)</td>
<td>0.85</td>
</tr>
<tr>
<td>Physical environmental characteristics</td>
<td>0.95 (0.50-1.80)</td>
<td>0.88</td>
</tr>
<tr>
<td>Parental attitudes on physical activity</td>
<td>1.04 (0.97-1.11)</td>
<td>0.30</td>
</tr>
<tr>
<td>Distance to school (miles)</td>
<td>0.92 (0.68-1.25)</td>
<td>0.64</td>
</tr>
<tr>
<td>Perceived education (at school)</td>
<td>0.95 (0.61-1.52)</td>
<td>0.83</td>
</tr>
<tr>
<td>Exposed to violence (yes)</td>
<td>1.14 (0.67-1.94)</td>
<td>0.64</td>
</tr>
<tr>
<td>Exposed to violence (no)</td>
<td>0.88 (0.54-1.45)</td>
<td>0.65</td>
</tr>
<tr>
<td>Ethnicity (White)</td>
<td>0.92 (0.56-1.53)</td>
<td>0.76</td>
</tr>
<tr>
<td>Age (years)</td>
<td>0.99 (0.60-1.60)</td>
<td>0.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Attribute of the home neighborhood</th>
<th>OR (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social cohesion</td>
<td>1.25 (0.72-2.17)</td>
<td>0.40</td>
</tr>
<tr>
<td>Personal safety</td>
<td>0.95 (0.40-2.25)</td>
<td>0.91</td>
</tr>
<tr>
<td>Presence of noise</td>
<td>1.00 (0.72-1.37)</td>
<td>1.00</td>
</tr>
<tr>
<td>Presence of trees</td>
<td>0.98 (0.65-1.48)</td>
<td>0.98</td>
</tr>
<tr>
<td>Attractive buildings</td>
<td>1.00 (0.57-1.73)</td>
<td>1.00</td>
</tr>
<tr>
<td>Attributes of the home neighborhood</td>
<td>0.98 (0.40-2.25)</td>
<td>0.98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Attribute of the home-school route</th>
<th>OR (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall walking and cycling influence</td>
<td>1.26 (0.78-2.07)</td>
<td>0.35</td>
</tr>
<tr>
<td>Quality of walking and cycling influence</td>
<td>0.93 (0.27-3.23)</td>
<td>0.85</td>
</tr>
<tr>
<td>Physical environmental characteristics</td>
<td>0.95 (0.50-1.80)</td>
<td>0.88</td>
</tr>
<tr>
<td>Parental attitudes on physical activity</td>
<td>1.04 (0.97-1.11)</td>
<td>0.30</td>
</tr>
<tr>
<td>Distance to school (miles)</td>
<td>0.92 (0.68-1.25)</td>
<td>0.64</td>
</tr>
<tr>
<td>Perceived education (at school)</td>
<td>0.95 (0.61-1.52)</td>
<td>0.83</td>
</tr>
<tr>
<td>Exposed to violence (yes)</td>
<td>1.14 (0.67-1.94)</td>
<td>0.64</td>
</tr>
<tr>
<td>Exposed to violence (no)</td>
<td>0.88 (0.54-1.45)</td>
<td>0.65</td>
</tr>
<tr>
<td>Ethnicity (White)</td>
<td>0.92 (0.56-1.53)</td>
<td>0.76</td>
</tr>
<tr>
<td>Age (years)</td>
<td>0.99 (0.60-1.60)</td>
<td>0.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Attribute of the home neighborhood</th>
<th>OR (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social cohesion</td>
<td>1.25 (0.72-2.17)</td>
<td>0.40</td>
</tr>
<tr>
<td>Personal safety</td>
<td>0.95 (0.40-2.25)</td>
<td>0.91</td>
</tr>
<tr>
<td>Presence of noise</td>
<td>1.00 (0.72-1.37)</td>
<td>1.00</td>
</tr>
<tr>
<td>Presence of trees</td>
<td>0.98 (0.65-1.48)</td>
<td>0.98</td>
</tr>
<tr>
<td>Attractive buildings</td>
<td>1.00 (0.57-1.73)</td>
<td>1.00</td>
</tr>
<tr>
<td>Attributes of the home neighborhood</td>
<td>0.98 (0.40-2.25)</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Table 2. Univariate analysis for neighborhood perception and children's transportation mode to school (walking).
### Table 3. Univariate analysis for neighborhood perception and children's transportation mode to school (cycling).

<table>
<thead>
<tr>
<th>Attribute</th>
<th>OR</th>
<th>95% CI</th>
<th>p</th>
<th>OR</th>
<th>95% CI</th>
<th>p</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parental neighborhood perception</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of noise</td>
<td>0.78</td>
<td>(0.64-0.98)</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of traffic</td>
<td>1.00</td>
<td>(0.86-1.13)</td>
<td>0.97</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Presence of trees</td>
<td>1.05</td>
<td>(0.88-1.26)</td>
<td>0.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Attractions buildings</td>
<td>1.12</td>
<td>(0.91-1.40)</td>
<td>0.30</td>
<td></td>
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</tr>
<tr>
<td>Streets are free of litter</td>
<td>0.84</td>
<td>(0.63-1.11)</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attributes of the home neighborhood</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Quality of walking and cycling infrastructure</td>
<td>0.89</td>
<td>(0.65-1.22)</td>
<td>0.54</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Attributes of school route</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amenities of school environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car parking availability</td>
<td>0.73</td>
<td>(0.59-0.89)</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Bicycle parking availability</td>
<td>1.44</td>
<td>(1.23-1.67)</td>
<td>0.04</td>
<td></td>
<td></td>
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<tr>
<td>Drivers exceeding speed limit</td>
<td>1.12</td>
<td>(0.93-1.33)</td>
<td>0.16</td>
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<tr>
<td>Presence of traffic</td>
<td>0.90</td>
<td>(0.74-1.08)</td>
<td>0.25</td>
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<tr>
<td>Low traffic speed</td>
<td>2.60</td>
<td>(1.73-3.92)</td>
<td>0.01</td>
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<tr>
<td>Access crossings and pedestrian signals around school</td>
<td>0.83</td>
<td>(0.58-1.20)</td>
<td>0.39</td>
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<td></td>
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</tr>
<tr>
<td>Physical environmental characteristics</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical activity of parent (yes)</td>
<td>1.28</td>
<td>(0.92-1.83)</td>
<td>0.17</td>
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<tr>
<td>Distance to school (meters)</td>
<td>1.00</td>
<td>(0.84-1.18)</td>
<td>0.99</td>
<td></td>
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<td>Car available in household (0=no, 1=Yes)</td>
<td>0.27</td>
<td>(0.17-0.42)</td>
<td>0.01</td>
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<tr>
<td>Parental Education (Low)</td>
<td>0.80</td>
<td>(0.55-1.14)</td>
<td>0.23</td>
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</tr>
<tr>
<td>Parental Education (High)</td>
<td>0.80</td>
<td>(0.55-1.14)</td>
<td>0.23</td>
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<td></td>
</tr>
<tr>
<td>Gender (Female)</td>
<td>1.49</td>
<td>(1.25-1.78)</td>
<td>0.01</td>
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</tr>
<tr>
<td>BMI (Body Mass Index)</td>
<td>1.02</td>
<td>(0.80-1.33)</td>
<td>0.86</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Age (years)</td>
<td>1.07</td>
<td>(0.99-1.16)</td>
<td>0.10</td>
<td></td>
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<tr>
<td>Multivariate analysis</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: OR = Odds Ratio, CI = Confidence Interval.
Discussion

The aim of this study was to investigate children’s transport mode to school and its relationship with parental perceptions of the neighborhood. The large majority of trips recorded between home and school were undertaken actively (i.e., 83% of the trips; 65.5% cycling and 17.4% walking). This is much higher than numbers found in studies in the US, where combined walking and cycling to school frequency estimates ranged from 5% to 42.3% [31]. Also, compared to other European countries (i.e. Belgium, Denmark, England), the proportion of active transportation to school is relatively high in this study. In these countries, the estimates for walking ranged from approximately 16% to 91.6%, whereas those for cycling ranged from 0.2% to 65% [31,32]. Part of the reason for the high proportion of active transportation in the current study is the small distance between home and school. Children in the study sample lived relatively close to the school building (median straight line distance to school 477.8 meter, interquartile range:306.0-691.7). Therefore, most of the trips recorded were less than 1 km in length (see Figure 1). Since distance is an important determinant for active transportation [33], it is not surprising that a high proportion of the population used an active transportation mode. In the Netherlands, the average distance to the closest primary school is around 700 meters and even in the least densely populated areas the average distance to the closest school is <2 kilometers [34]. In addition, the Netherlands, a very densely populated country with high street connectivity, also has a strong cycling tradition [35].

This study also showed that, in this sample of children, perceived traffic safety in the school environment was linked to an increased odds of active transportation on the journey to school. More specific, when the traffic speed around school was perceived to be low, this was associated with higher odds of walking to school. This finding is in line with a recent systematic review that looked at perceived barriers to children’s active transportation to school and that showed that concerns of traffic safety (e.g., speed, intensity) was one of the most commonly found physical environmental barriers to active transportation to school [20]. Alleviating parental concerns about traffic safety through education might be a way to increase children’s active transportation. However, it is important to realize that parental concerns might be related to actual safety issues that also need to be addressed [17]. In general, improving school and neighborhood design is advocated when promoting walking to school, for example by creating infrastructural changes such as zebra crossings, pedestrian signals, traffic calming measures, perhaps in combination with other active transportation promotion interventions, such as the walking school bus [36]. On the other hand, whereas traffic speed in the direct vicinity of the school building increased the odds of walking, the quality and safety of walking and cycling infrastructure on the remaining route to school could not be linked to increased odds of walking or cycling. The questions in the questionnaire mainly focused on sidewalk/bicycle path availability and maintenance, thus, a possible explanation might be that walking and cycling infrastructure in the Netherlands are mostly of a high standard, e.g., sidewalks are available on almost all of the routes to school [30],
and may thus not be perceived as a barrier or facilitator for active transportation. Previous studies also reported social environmental factors such as neighborhood social cohesion to be related with children’s transport mode to school [14,18,19], but this could not be confirmed in the current study. The current study showed mixed results regarding parental concerns about personal safety in the home neighborhood and its association with children’s transport mode between home and school. Children from parents who rated the neighborhood favorably regarding personal safety were more likely to use their bike (OR=1.88, 95%CI=1.21-2.90) and less likely to walk to school (OR: 0.52, 95%CI: 0.30-0.90). Other studies showed that neighborhood safety was mostly perceived as a barrier for active transportation to school [20], e.g., a comparable Dutch study [19] found a small positive effect for social safety on both walking and cycling to school. Lastly, for the odds of a track being defined as cycling to school, a negative association with the perceived availability of car parking facilities was observed. This suggests that schools should be careful not to facilitate car travel by creating extra car parking areas, and the associated car traffic may be perceived as a barrier for children to cycle to school.

**Strengths & Limitations**

This study had specific strengths, but also faced some limitations. A strength is that the study conducted separate analyses for cycling and walking to school. This in contrast with most previous studies that have grouped walking and cycling together, and which might have obscured their association with certain specific environmental characteristics [21]. Also, given the fact that there was a need for research in a greater diversity of European countries [20], this is one of the first studies in which most of the children lived relatively close to the school building (<1 km) and where cycling was the dominant mode of transportation. In addition, contrary to previous studies that mostly relied on self-reported data, this study used GPS data to define the actual transport mode of the children. Using GPS to define mode of transport is a more objective and accurate measurement of day-to-day trips and transport mode to school, than using the usual mode of transport [37]. On the other hand, although the use of GPS had its advantages, it was difficult to assess reasons why some children did not record any trip between home and school during the assessment period or to assess reasons why specific trips were undertaken using active transportation, as no participant diaries were available and trips were derived using a completely automatic procedure. It is also important to note that the study used a cross-sectional design, which limits causal inference. Longitudinal studies investigating interventions on parental perception are still warranted.
Conclusions

The current study showed a positive association between parental perceptions of slow traffic speed in the school environment and walking between home and school. Also, children were less likely to cycle on the school journey with increased perceived amounts of car parking facilities in the school environment. Mixed results were found for perceived safety for personal and active transportation between home and school. Prospective intervention studies are warranted to confirm the findings of this study. Based on our findings, such studies should focus on alleviating negative parental perceptions about personal and traffic safety in the school and home environment. This can be done through infrastructural changes in the school environment (e.g. zebra crossings, pedestrian signals, traffic calming measures) or with other type of interventions, such as the walking school bus [36]. In the meantime, urban planners should focus on increasing traffic safety in the school environment and be careful not to invest in extra facilities that stimulate motorized travel to school.
<table>
<thead>
<tr>
<th>Questionnaires</th>
<th>Mean (SD)</th>
<th>Number</th>
<th>Question used</th>
<th>Coding answer categories</th>
<th>Varible name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of walking and cycling</td>
<td>5.2 (0.7)</td>
<td>430</td>
<td>1</td>
<td>Strongly agree, agree, disagree, strongly disagree</td>
<td>67</td>
</tr>
</tbody>
</table>

### Attributes of home-school route

<table>
<thead>
<tr>
<th>Questionnaires</th>
<th>Mean (SD)</th>
<th>Number</th>
<th>Question used</th>
<th>Coding answer categories</th>
<th>Varible name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parental attitude towards physical activity</td>
<td>4.9 (0.7)</td>
<td>430</td>
<td>2</td>
<td>Strongly agree, agree, disagree, strongly disagree</td>
<td>67</td>
</tr>
</tbody>
</table>

### Description of questionnaire items, answer categories and descriptive statistics

- **Quality of walking and cycling**
  - 1. The streets on the way to school are well maintained
  - 2. The sidewalks or crosswalks on the way to school are well maintained

- **Attributes of home-school route**
  - 1. Other ways to get my child to school: by car, by bike, by foot, etc.
  - 2. Other things that make my child feel safe on the way to school
  - 3. Other activities that my child enjoys doing outside of school
  - 4. Other things that encourage my child to play sports or do exercise

- **Parental attitude towards physical activity**
  - 1. When my child says, do not want to walk
  - 2. My child gets enough exercise
  - 3. I make sure my child eats healthy food
  - 4. My child eats healthy food

---

Appendix 1. Description of questionnaire items, answer categories and descriptive statistics
<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Agree</th>
<th>Strongly Disagree</th>
<th>3.56 (0.59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To leave a bicycle unlocked on the streets in my neighborhood, it is safe</td>
<td>Strongly Agree</td>
<td>Strongly Disagree</td>
<td>3.56 (0.59)</td>
</tr>
<tr>
<td>For my child to play/walk unsupervised in the neighborhood, it is safe</td>
<td>Strongly Agree</td>
<td>Strongly Disagree</td>
<td>3.56 (0.59)</td>
</tr>
<tr>
<td>My child doesn't have to run the risk of being hit by a vehicle when crossing the street</td>
<td>Strongly Agree</td>
<td>Strongly Disagree</td>
<td>3.56 (0.59)</td>
</tr>
<tr>
<td>My child can go outside and play with neighborhood children at night</td>
<td>Strongly Agree</td>
<td>Strongly Disagree</td>
<td>3.56 (0.59)</td>
</tr>
<tr>
<td>Pedestrians and cyclists on the streets are well at night</td>
<td>Strongly Agree</td>
<td>Strongly Disagree</td>
<td>3.56 (0.59)</td>
</tr>
<tr>
<td>Personal safety</td>
<td>Strongly Agree</td>
<td>Strongly Disagree</td>
<td>3.56 (0.59)</td>
</tr>
</tbody>
</table>
Parental neighborhood perception

### Appendix 1. Description of questionnaire items, answer categories and descriptive statistics (cont)

<table>
<thead>
<tr>
<th>Item</th>
<th>Answer Categories</th>
<th>Mean (SD)</th>
<th>Cronbach's α</th>
</tr>
</thead>
<tbody>
<tr>
<td>People in my neighborhood have similar age</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.85 (0.65)</td>
<td></td>
</tr>
<tr>
<td>My neighborhood is a cohesive community</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.60 (0.90)</td>
<td></td>
</tr>
<tr>
<td>There are a lot of noise in my neighborhood</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.10 (1.35)</td>
<td></td>
</tr>
<tr>
<td>My neighborhood is generally free from litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.00 (0.90)</td>
<td></td>
</tr>
<tr>
<td>There are trees along the streets in my neighborhood</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.00 (0.90)</td>
<td></td>
</tr>
<tr>
<td>My neighborhood is generally free from litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>3.50 (0.90)</td>
<td></td>
</tr>
<tr>
<td>There are electricity billboards in my neighborhood</td>
<td>Strongly agree, Strongly disagree</td>
<td>3.50 (0.90)</td>
<td></td>
</tr>
<tr>
<td>My neighborhood is generally free from litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>3.27 (0.90)</td>
<td></td>
</tr>
</tbody>
</table>

### Social cohesion

<table>
<thead>
<tr>
<th>Item</th>
<th>Answer Categories</th>
<th>Mean (SD)</th>
<th>Cronbach's α</th>
</tr>
</thead>
<tbody>
<tr>
<td>My neighbors are willing to help each other</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.85 (0.65)</td>
<td></td>
</tr>
<tr>
<td>There are trees along the streets in my neighborhood</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.00 (0.90)</td>
<td></td>
</tr>
<tr>
<td>My neighborhood is generally free from litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.00 (0.90)</td>
<td></td>
</tr>
<tr>
<td>There are electricity billboards in my neighborhood</td>
<td>Strongly agree, Strongly disagree</td>
<td>3.50 (0.90)</td>
<td></td>
</tr>
<tr>
<td>My neighborhood is generally free from litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>3.27 (0.90)</td>
<td></td>
</tr>
</tbody>
</table>

### Presence of noise

<table>
<thead>
<tr>
<th>Item</th>
<th>Answer Categories</th>
<th>Mean (SD)</th>
<th>Cronbach's α</th>
</tr>
</thead>
<tbody>
<tr>
<td>My neighborhood is a cohesive community</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.60 (0.90)</td>
<td></td>
</tr>
<tr>
<td>Presence of noise</td>
<td>Strongly agree, Strongly disagree</td>
<td>1.00 (1.00)</td>
<td></td>
</tr>
<tr>
<td>Presence of noise</td>
<td>Strongly agree, Strongly disagree</td>
<td>1.00 (1.00)</td>
<td></td>
</tr>
</tbody>
</table>

### Presence of trees

<table>
<thead>
<tr>
<th>Item</th>
<th>Answer Categories</th>
<th>Mean (SD)</th>
<th>Cronbach's α</th>
</tr>
</thead>
<tbody>
<tr>
<td>My neighborhood is generally free from litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>4.00 (0.90)</td>
<td></td>
</tr>
<tr>
<td>Trees are free of litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>1.00 (1.00)</td>
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</table>

### Presence of electricity billboards

<table>
<thead>
<tr>
<th>Item</th>
<th>Answer Categories</th>
<th>Mean (SD)</th>
<th>Cronbach's α</th>
</tr>
</thead>
<tbody>
<tr>
<td>My neighborhood is generally free from litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>3.50 (0.90)</td>
<td></td>
</tr>
<tr>
<td>Electricity billboards</td>
<td>Strongly agree, Strongly disagree</td>
<td>1.00 (1.00)</td>
<td></td>
</tr>
</tbody>
</table>

### Presence of litter

<table>
<thead>
<tr>
<th>Item</th>
<th>Answer Categories</th>
<th>Mean (SD)</th>
<th>Cronbach's α</th>
</tr>
</thead>
<tbody>
<tr>
<td>My neighborhood is generally free from litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>3.27 (0.90)</td>
<td></td>
</tr>
<tr>
<td>Presence of litter</td>
<td>Strongly agree, Strongly disagree</td>
<td>1.00 (1.00)</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix 1. Description of questionnaire items, answer categories and descriptive statistics (continuation)

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Coding Answer Categories</th>
<th>Mean (SD)</th>
<th>Number of Questions used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car parking availability</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Bike parking availability</td>
<td>2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Drivers exceeding speed limit</td>
<td>3</td>
<td>2.7 (1.0)</td>
<td>1</td>
</tr>
<tr>
<td>Presence of traffic</td>
<td>4</td>
<td>2.9 (1.0)</td>
<td>1</td>
</tr>
<tr>
<td>Slow drivers in the streets around school</td>
<td>5</td>
<td>3.4 (1.2)</td>
<td>1</td>
</tr>
<tr>
<td>To help pedestrians cross the streets near school</td>
<td>6</td>
<td>3.6 (1.2)</td>
<td>1</td>
</tr>
<tr>
<td>Location of school, census and pedestrian signals</td>
<td>7</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Additional variables: School environment, References, Literature Review, Methodology, Results, Discussion, Conclusion.
References


[29] TNO. URBIS. Available at: https://www.tno.nl/urbis.


[34] Statistics Netherlands C. Closeness facilities; distance locations, regional numbers. 2015; Available at: http://statline.cbs.nl/.


Children’s route choice during active transportation to school: difference between shortest and actual route

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Chapter 5

Abstract

Background
The purpose of this study is to increase our understanding of environmental correlates that are associated with route choice during active transportation to school (ATS) by comparing characteristics of actual walking and cycling routes between home and school with the shortest possible route to school.

Methods
Children (n=184; 86 boys, 98 girls; age range: 8-12 years) from seven schools in suburban municipalities in the Netherlands participated in the study. Actual walking and cycling routes to school were measured with a GPS-device that children wore during an entire school week. Measurements were conducted in the period April-June 2014. Route characteristics for both actual and shortest routes between home and school were determined for a buffer of 25 meters from the routes and divided into four categories: Land use (residential, commercial, recreational, traffic areas), Aesthetics (presence of greenery/natural water ways along route), Traffic (safety measures such as traffic lights, zebra crossings, speed bumps) and Type of street (pedestrian, cycling, residential streets, arterial roads). Comparison of characteristics of shortest and actual routes was performed with conditional logistic regression models.

Results
Median distance of the actual walking routes was 390.1 meters, whereas median distance of actual cycling routes was 673.9 meters. Actual walking and cycling routes were not significantly longer than the shortest possible routes. Children mainly traveled through residential areas on their way to school (>80% of the route). Traffic lights were found to be positively associated with route choice during ATS. Zebra crossings were less often present along the actual routes (walking: OR=0.17, 95%CI=0.05-0.58; cycling: OR=0.31, 95%CI=0.14-0.67), and streets with a high occurrence of accidents were less often used during cycling to school (OR=0.57, 95% CI=0.43-0.76). Moreover, percentage of visible surface water along the actual route was higher compared to the shortest routes (walking: OR=1.04, 95%CI=1.01-1.07; cycling: OR=1.03, 95%CI=1.01-1.05).

Conclusion
This study showed a novel approach to examine built environmental exposure during active transport to school. Most of the results of the study suggest that children avoid to walk or cycle along busy roads on their way to school.
Background

Stimulating children to be physically active is an important public health promotion and disease prevention strategy [1,2]. The majority of children in the Netherlands currently do not comply with the latest physical activity guidelines [3,4]. A promising way to increase children’s habitual daily physical activity is to stimulate active transportation (i.e. walking or cycling) to and from school [5,6]. Children who use active transportation to school have higher overall levels of physical activity compared to children who rely on motorized transport [7,8]. Moreover, engaging in active transport is associated with increased levels of physical fitness in children [9].

To further promote physical activity in primary school children, determinants associated with active transportation need to be investigated. Socio-ecological frameworks suggest that certain characteristics of the built environment are important for stimulating active transportation [10,11]. However, consistent evidence for such associations appears to be lacking. The only environmental characteristic that has been consistently found to be negatively associated with children’s active transportation is the distance between home and school [12]. Most of the literature on determinants of active transportation has focused on environmental characteristics that are related to the transportation mode, i.e. active versus motorized transportation. Another approach to further examine which environmental characteristics stimulate active transportation, is to look at the routes that are used for active transportation. For instance, by comparing characteristics of the actually traveled route with characteristics of the shortest route: exposure to environmental characteristics during actually traveled routes can be significantly different from GIS-modeled routes [13].

Recently, Krenn et al. [14] have performed such an analysis among an adult population of cyclists in Austria. Within this population, environmental characteristics that were associated with the actual cycled route included the presence of bicycle paths, traffic lights, water and greenery, and the absence of dangerous intersections, busy roads, shops, and inclination of the route. Whether the environmental characteristics related to the route choice of adult cyclists also affect the route choice of school children has not been studied yet. It is also unknown to what extent there is a difference between environmental characteristics that are associated with walking routes versus cycling routes to school, but it is likely that different correlates are relevant for walking than for cycling [15].

Apart from a focus on transportation mode rather than route choice, and the lack of discrimination between walking and cycling, another limitation of previous studies is the methodology. This might explain the lack of consistency in observed associations between the built environment and active transportation. Methodological issues include: 1) inaccurate geocoding of the home and school address, 2) different ways to measure the environment, i.e., buffer method, 3) inaccurate estimation of the route to school, and 4) poor quality data of the pedestrian street network [12]. Some of these issues can be addressed by using Global Positioning Systems (GPS) to map the school journey [16].
Firstly, most studies that examined active transportation to school used postal codes for geocoding the location of the home and school address. This method leads to misrepresentations of the environment that children are exposed to. For example, Bow showed that >10% of the addresses they geocoded based on postal code were further than 200 meters from the true address location [17], with GPS the home address can be more accurately determined through clustering of data points collected during the night, when children are at home [18]. Secondly, in a traditional circular neighborhood buffer approach [19], where a circle is drawn around the home and school address to assess the home/school environment within a certain range, it is arbitrary what buffer size best represents the environment of the children. Changes in buffer size, e.g., using a 400 meter buffer instead of 800 meter buffer, can result in very different determinants. A small buffer along the GPS route gives a more precise indication of the actual exposure to the built environment, compared to large circular buffers around the home or school. [20,21].

Third, previous studies have mostly used a Geographic Information Systems (GIS) derived path on the network to represent the actual route traveled. Duncan and others [22] have shown that these GIS derived routes are very similar in distance, but not always representative of the actually traveled route, because different routes were used. Thus, with the use of GPS, several methodological constraints of previous studies can be avoided and characteristics of the actually travelled route can be mapped more precisely[8,23].

Fourth, in previous studies poor quality data of the pedestrian street network made it difficult to accurately calculate certain characteristics that are believed to be relevant for active transportation, such as network connectivity [24]. Fortunately, a more detailed pedestrian network is increasingly available through satellite imagery and open source websites such as Open Street Map (OSM).

In sum, the aim of this study is to gain a better understanding of the built environmental characteristics that are associated with route choice in both walking and cycling to school as measured by GPS. This study tries to clarify which characteristics of the built environment are associated with children’s active transport to school. The results of this study can support public health professionals and urban planners to create more effective environmental interventions to promote active transportation to school among children.

**Methods**

**Participants and setting**

This cross-sectional study was conducted in a convenience sample of seven schools participating in the Schoolzone project. The Schoolzone project is a natural experiment in the Netherlands that investigates the effect of increasing traffic safety around primary schools on daily physical activity levels of schoolchildren (ZonMW, project number 525001001). The schools participating in the current study were located in three suburban municipalities in the Amsterdam region: i.e, Zaanstad (n=3), Haarlemmermeer (n=2) and Edam-Volendam (n=2). The neighborhoods in which the seven schools were located were all constructed
Children’s route choice during active transportation to school

post-WWII. A total of 342 children attending these schools (grade 6-7, age 8 to 12 years) were invited to participate in the study. Their parents received written information through the school about study goals and procedures. Subsequently, parents provided informed consent for their children. This procedure resulted in a group of 213 (63.8%) children that were included in the study. The study design and procedures were approved by the medical ethical committee of the VU University Medical Centre, Amsterdam, The Netherlands.

Instrumentation / Measures
All children were requested to wear a GPS receiver (Travel recorder X, BT-Q1000X, QStarz International Co) during waking hours, for eight consecutive days. The GPS receivers were set to record the geographical position of the children, with a sampling frequency of 5 seconds. The GPS device was attached to the children’s waist with an elastic belt. The GPS device and belt were handed out during school hours, during which children were personally instructed on how to wear the device. During activities that could damage the device, or could be uncomfortable to wear, the children were asked to temporarily remove the device (e.g., during swimming, showering). Written instructions for children and their parents were handed out together with the device. Furthermore, after receiving the device, children completed a short questionnaire to provide information on their age, gender and habitual daily physical activity behavior. All measurements were conducted between April and June 2014. Out of the 213 children wearing the GPS device, the 184 children that recorded at least one track between home and school were included in the current analysis.

Data handling (I): GPS data
GPS data were downloaded to a computer with Q-Travel v1.48, a travel data management software package from Qstarz. Data was then converted to a csv format for further processing within the URBIS III software package [25]. First, locations of the home address of the children were determined based on clusters in the GPS data recorded during the night time (12 p.m.- 6 a.m.) [18]. Location of the school building was determined based on TOP10NL. Next, each GPS track between the home address and the school building was identified with an automatic procedure in URBIS [23], this procedure also includes the tracks that have intermediate stops between home and school, i.e., multi-destination trips. Trips going in both directions (i.e. home or school) were eligible to be included in the analysis. For each track, the calculated speed was used to determine the mode of transport at each individual GPS point. GPS points with a calculated speed below 10 km/h were categorized as ‘walking’. Points were categorized as ‘cycling’ if the speed was between 10 and 25 km/h. The remainder of the GPS points (with a speed below 150 km/h) was categorized as ‘motorized transport’ [23]. To correct for sudden changes in speed due to bad satellite reception, a track was defined as cycling or motorized if there was a period of at least one minute within that transportation mode, i.e. motorized travel, cycling. Tracks that contained both a 1 minute period of cycling and a period of motorized travel were categorized as motorized transport. All remaining tracks that were not classified either cycling or motorized were defined as walking tracks. Then, descriptive
characteristics, i.e., distance, duration, average speed, and maximum speed were calculated for all recorded tracks. For each child, the shortest actual walking and cycling track were selected to be used in the subsequent analysis of active transportation which compared the actual route with the shortest route via the street network.

Data handling (II): Street Network
The street network was constructed using the road centerlines available in the TOP10NL database (topographic map of the Netherlands, scale 1: 10,000 provided by the Dutch Land use register Kadaster). To complete the network, centerlines of missing streets were manually added by the first author based on Open Street Map (OSM) data and satellite images from LuchtfotoNL (2014). Shortest routes between home and school were generated based on this street network, using the home address, as determined with the above mentioned cluster detection method, and the x and y coordinates of the center of the polygon of the school buildings. Shortest routes were calculated with the Network Analyst tool in ArcGis 10.2. Differences in distance between GIS derived shortest routes and the actual walking and cycling routes were calculated as a detour ratio.

Data handling (III): Characteristics of the built environment
For both the shortest and the actual traveled routes, four categories of built environmental characteristics were determined within a buffer distance of 25 meters along the routes: land use, traffic, aesthetics, and type of street (see also Figure 1). Land use mix was calculated using CBS Land use data, and based on a 4-category entropy index [26]. A distinction was made between the following entropy categories: residential areas, commercial areas, traffic areas, and recreational areas. In this entropy index, 0 stands for no diversity, while 1 means that there is an equal distribution of land use. The number of residents was reported per square kilometer using CBS squares, derived from the Dutch Statistics Center, in 100 by 100 meter cells [27]. The residential density was calculated proportionally for the buffer areas that intersected with the cells.

Traffic junctions, traffic accidents, zebra crossings, street lights, traffic lights and speed bumps were all represented by point data. The number of junctions was determined based on the street network from the TOP10NL dataset provided by the Dutch land use registry Kadaster [28]. The number of traffic accidents was derived from BRON, a national database in which traffic related accidents are recorded through official reports or registration sets from the police. Around 84% of accidents are represented in this database [29]. All other point data were collected using local land use registry data (GBKN) from participating municipalities. The amount of points found within the 25 meter buffer along the routes were reported as the number of points per km of route.

The percentage water along the route was determined as a measure of aesthetics of visible surface water (e.g. ponds, rivers, lakes). This percentage was calculated based on polygons of aquatic areas from the TOP10NL database. Similarly, the percentage of green along the route was calculated based on polygons of green
Children’s route choice during active transportation to school

from TOP10NL, these represent neighborhood green spaces (e.g. bushes, grass plots, woods). Both percentage of green and water along the route were reported as average percentage per kilometer of route. Number of trees along the route are also reported and are represented by point data.

The type of street was determined based on attributes of the street network from the TOP10NL data. The percentage of street type along the route within a buffer of 25 meters was calculated for four street types: residential streets, pedestrian path, separate bicycle path, and arterial roads with a bicycle lane. Residential streets are located in residential areas, but other types of streets are also present in these areas, i.e., cycling paths and pedestrian paths. Separate pedestrian and cycling paths in the Netherlands are usually not accessible to motorized traffic (sometimes with the exception of motor scooters). Residential streets are used by all modes of transportation, thus motorized traffic shares the streets with cyclists while pedestrians are directed to the sidewalk. Maximum speed of motorized traffic on residential streets is usually low, with a maximum of 30 km/h. Arterial roads on the other hand, have a speed limit of 50 km/h. When cyclists travel along these arterial roads, they are directed to a separately marked cycling lane. Pedestrians can use

Figure 1. Comparison of shortest route and actual route.
the sidewalk when these are available. A more detailed description of all GIS-variables used in the analysis can be viewed in Supplementary table 1.

**Statistical analysis**

Characteristics that showed a non-normal distribution are summarized by their median and interquartile range reported as the 25th percentile and the 75th percentile. Conditional logistic regression analysis was used to examine the difference between environmental characteristics of the actual route and environmental characteristics of the GIS derived shortest route. Table 1 shows an example of the dataset that was used in the regression analysis. In this table, ID represents the participant, route 0 stands for the shortest route and route 1 for the actual route. Var1 represents the number of trees, Var2 the percentage of sidewalk along the route, etc. First, each environmental characteristic (e.g. Var1) was tested separately using univariate conditional logistic regression. Conditional logistic regression was used because shortest and actual route are not independent within a child. Then, after selection of candidate variables that had a significance level below 0.20, a backward selection process was used to construct a multivariate final model both for environmental characteristics of the walking routes, and for environmental characteristics of the cycling routes. All statistical analyses were performed in SPSS version 22.0.

<table>
<thead>
<tr>
<th>ID</th>
<th>Route</th>
<th>var1 Distance</th>
<th>var2 Trees</th>
<th>var3 %Sidewalk</th>
<th>var...</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>623</td>
<td>22</td>
<td>87</td>
<td>...</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>519</td>
<td>12</td>
<td>95</td>
<td>...</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>432</td>
<td>20</td>
<td>86</td>
<td>...</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>316</td>
<td>19</td>
<td>87</td>
<td>...</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1023</td>
<td>50</td>
<td>75</td>
<td>...</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>939</td>
<td>32</td>
<td>78</td>
<td>...</td>
</tr>
<tr>
<td>ID</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Table 1. Example of dataset used in the conditional regression analysis
Table 2. General characteristics of the final study population.

<table>
<thead>
<tr>
<th>Participant characteristics</th>
<th>n</th>
<th>Mean (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>184</td>
<td>10.5 (±0.9)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boy</td>
<td>86</td>
<td>46.7</td>
</tr>
<tr>
<td>Girl</td>
<td>98</td>
<td>53.3</td>
</tr>
<tr>
<td>City</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volendam</td>
<td>63</td>
<td>34.2</td>
</tr>
<tr>
<td>School A</td>
<td>38</td>
<td>20.7</td>
</tr>
<tr>
<td>School B</td>
<td>25</td>
<td>13.6</td>
</tr>
<tr>
<td>Zaandam</td>
<td>63</td>
<td>34.2</td>
</tr>
<tr>
<td>School C</td>
<td>28</td>
<td>15.2</td>
</tr>
<tr>
<td>School D</td>
<td>14</td>
<td>7.6</td>
</tr>
<tr>
<td>School E</td>
<td>21</td>
<td>11.4</td>
</tr>
<tr>
<td>Hoofddorp</td>
<td>56</td>
<td>31.5</td>
</tr>
<tr>
<td>School F</td>
<td>32</td>
<td>18.2</td>
</tr>
<tr>
<td>School G</td>
<td>26</td>
<td>14.1</td>
</tr>
<tr>
<td>Journey to school</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of children with at least one walking track</td>
<td>67</td>
<td>36.4</td>
</tr>
<tr>
<td>Number of children with at least one cycling track</td>
<td>162</td>
<td>88.0</td>
</tr>
<tr>
<td>Number of children with at least one motorized track</td>
<td>70</td>
<td>38.0</td>
</tr>
</tbody>
</table>

Results

In total, a group of 184 children (86 boys, 98 girls, age 8-12 years) recorded 1,249 GPS tracks between home and school. General characteristics of the final study population are shown in Table 2. Out of all children, 67 recorded one or more walking tracks to school, and 162 children recorded one or more tracks that were classified as cycling. Eight children did not record any walking or cycling tracks between home and school. Characteristics of the shortest GPS tracks used in the comparison with the shortest GIS routes are shown in Table 3. Characteristics of all 1,249 GPS tracks are shown in Supplementary table 2. The median distance of the recorded walking routes was 390.0 (interquartile range: 248.8-606.7) meters with a median duration of 6.1 (interquartile range: 3.8-9.3) minutes. Recorded routes were on average 5.6% longer than the shortest routes, but this difference was not significant (p=0.38). The median distance of the actual traveled cycling route was 673.9 (interquartile range:459.4-1008.3) meters, with a median duration of 5.0 (interquartile range:3.5-7.6) minutes. On average, actual cycling routes were 10.9%, but not significantly, longer than the shortest routes over the network (p=0.11). With the current buffer size of 25 meters, median overlap between the two buffered routes was 69.3% (interquartile range: 48.8%-86.2%) for cycling routes, and 64% (interquartile range: 33.4%-81.7%) for walking routes.
Environmental characteristics of walking routes

Results of the conditional logistic regression analyses of walking routes are shown in Table 4, in which environmental characteristics are divided into four categories: land use, traffic, aesthetics and type of street. The majority of the actual walking routes to school passed through residential areas (88.9% of the route). On average, actual walking routes were going through a significantly smaller amount of transport areas (OR = 0.76, 95% CI= 0.6-0.96) compared to the shortest route. Moreover, there were significantly fewer street lights (OR = 0.97, 95% CI= 0.95-.99) and zebra crossings (OR = 0.55, 95% CI= 0.35-0.87) within the 25 meter buffer of the actual walking route, compared to the shortest walking route. The percentage of sidewalks was lower along the actually traveled routes, compared to the shortest routes (OR = 0.94, CI= 0.90-0.98). Furthermore, around half of the walks to school was conducted on residential streets (49.6%), which is significantly more than on the shortest route (OR=1.04, 95% CI=1.01-1.08). Shortcuts between houses (%pedestrian paths) were used less (OR=0.93, 95% CI=0.89-0.98) on the actual walked routes, compared to the shortest ones. Also, percentage of water was higher along actually walked routes (OR=1.04, 95% CI=1.01-1.07). After the backward selection process, the final model for the walking route (see Table 6) showed significant differences between actual and shortest routes. There were more traffic lights, less zebra crossings and a lower percentage of sidewalks along the actual walking routes compared to the shortest routes.

Table 3. Descriptive statistics of the shortest traveled walking and cycling routes of 176 children.

<table>
<thead>
<tr>
<th>Mode of transport</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Median</th>
<th>25th percentile</th>
<th>75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking (N=67, n=67)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (meters)</td>
<td>462.1</td>
<td>360.5</td>
<td>390.1</td>
<td>248.8</td>
<td>606.7</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>8.0</td>
<td>7.2</td>
<td>6.1</td>
<td>3.8</td>
<td>9.3</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>3.8</td>
<td>1.2</td>
<td>3.9</td>
<td>3.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Max Speed (km/h)</td>
<td>12.0</td>
<td>12.1</td>
<td>9.4</td>
<td>7.0</td>
<td>11.2</td>
</tr>
<tr>
<td>Cycling (N=162, n= 162)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (meters)</td>
<td>894.4</td>
<td>891.1</td>
<td>673.9</td>
<td>459.4</td>
<td>1008.3</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>9.3</td>
<td>19.6</td>
<td>5.0</td>
<td>3.5</td>
<td>7.6</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>8.2</td>
<td>3.6</td>
<td>8.0</td>
<td>5.5</td>
<td>10.6</td>
</tr>
<tr>
<td>Max Speed (km/h)</td>
<td>18.6</td>
<td>8.4</td>
<td>17.8</td>
<td>15.1</td>
<td>20.9</td>
</tr>
</tbody>
</table>

N=number of tracks used in the analysis, n=number of children.
Table 4. Characteristics of shortest walking routes compared to characteristics of actual walking routes.

<table>
<thead>
<tr>
<th>Route characteristics</th>
<th>Shortest GIS-Route (reference route)</th>
<th>Actual GPS-Route</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean and ±SD or Median and interquartile range (25-75)</td>
<td></td>
<td>OR</td>
</tr>
<tr>
<td><strong>Length of route (meter)</strong></td>
<td>382.8 (270.8-579.4)</td>
<td>390.0 (248.8-606.7)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Land-use</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entropy</td>
<td>0.40 (0.26-0.56)</td>
<td>0.38 (0.17-0.55)</td>
<td>0.11</td>
</tr>
<tr>
<td>Commercial area (%)</td>
<td>0.0 (0.0-0.0)</td>
<td>0.0 (0.0-0.0)</td>
<td>1.23</td>
</tr>
<tr>
<td>Residential area (%)</td>
<td>88.9 (82.5-95.4)</td>
<td>90.3 (81.8-97.5)</td>
<td>1.03</td>
</tr>
<tr>
<td>Recreational area (%)</td>
<td>2.1 (2.1-11.6)</td>
<td>5.3 (0.0-12.4)</td>
<td>1.07</td>
</tr>
<tr>
<td>Traffic area (%)</td>
<td>0.0 (0.0-8.5)</td>
<td>0.0 (0.0-5.5)</td>
<td>0.76</td>
</tr>
<tr>
<td>Residents (n per km)</td>
<td>77.2 (57.2-94.5)</td>
<td>71.3 (59.3-93.5)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Aesthetics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Green along route</td>
<td>38.7 (18.3-52.9)</td>
<td>43.9 (19.2-62.6)</td>
<td>1.01</td>
</tr>
<tr>
<td>% Water along route</td>
<td>12.8 (0.0-42.2)</td>
<td>20.1 (0.0-46.8)</td>
<td>1.04</td>
</tr>
<tr>
<td>Trees (n per km)</td>
<td>147.5 (118.3-179.1)</td>
<td>156.3 (122.1-197.2)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Traffic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic lights (n per km)</td>
<td>0.00 (0.0-0.0)</td>
<td>0.00 (0.0-0.0)</td>
<td>1.23</td>
</tr>
<tr>
<td>Street lights (n per km)</td>
<td>70.0 (59.4-94.8)</td>
<td>65.8 (50.6-84.8)</td>
<td>0.97</td>
</tr>
<tr>
<td>Street bumps (n per km)</td>
<td>7.7 (1.7-14.6)</td>
<td>6.4 (0.0-14.9)</td>
<td>0.98</td>
</tr>
<tr>
<td>Accidents (n per km)</td>
<td>1.6 (0.0-3.3)</td>
<td>0.0 (0.0-2.5)</td>
<td>0.95</td>
</tr>
<tr>
<td>Zebra crossings (n per km)</td>
<td>1.7 (0.0-3.6)</td>
<td>0.0 (0.0-2.9)</td>
<td>0.55</td>
</tr>
<tr>
<td>Junctions (n per km)</td>
<td>37.8 ±13.2</td>
<td>37.1 ±16.4</td>
<td>1.00</td>
</tr>
<tr>
<td>% Sidewalk along route</td>
<td>98.9 (95.5-99.9)</td>
<td>93.7 (77.2-100.0)</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>Type of Street</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Road (%)</td>
<td>0.0 (0.0-16.9)</td>
<td>0.0 (0.0-12.7)</td>
<td>1.00</td>
</tr>
<tr>
<td>Residential Street (%)</td>
<td>44.0 ±14.9</td>
<td>49.8 ±19.0</td>
<td>1.04</td>
</tr>
<tr>
<td>Cycling path (%)</td>
<td>10.4 (10.4-26.8)</td>
<td>12.4 (0.0-30.2)</td>
<td>1.00</td>
</tr>
<tr>
<td>Pedestrian path (%)</td>
<td>30.0 (20.4-41.0)</td>
<td>24.6 (15.3-38.2)</td>
<td>0.93</td>
</tr>
</tbody>
</table>

SD=Standard deviation, OR=Odds Ratio, p-values below 0.05 are printed in bold type.
Table 5. Characteristics of shortest cycling routes compared to characteristics of actual cycling routes.

<table>
<thead>
<tr>
<th>Route characteristics</th>
<th>Shortest GiS-route (reference route)</th>
<th>Actual GPS-route</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean and ±SD or Median and interquartile range (25-75)</td>
<td>OR</td>
<td>Lower</td>
</tr>
<tr>
<td><strong>Length of route</strong> (meter)</td>
<td>675.6 (498.8-965.3)</td>
<td>673.9 (459.4-1008.3)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Land-use</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entropy</td>
<td>0.49 (0.33-0.69)</td>
<td>0.51 (0.35-0.67)</td>
<td>3.82</td>
</tr>
<tr>
<td>Commercial area (%)</td>
<td>0.00 (0.0-0.0)</td>
<td>0.00 (0.0-0.1)</td>
<td>0.88</td>
</tr>
<tr>
<td>Residential area (%)</td>
<td>86.5 (73.3-91.9)</td>
<td>84.0 (75.5-91.4)</td>
<td>0.98</td>
</tr>
<tr>
<td>Recreational area (%)</td>
<td>9.8 (2.0-20.2)</td>
<td>11.9 (5.5-19.2)</td>
<td>1.06</td>
</tr>
<tr>
<td>Traffic area (%)</td>
<td>2.0 (0.0-8.7)</td>
<td>1.4 (0.0-6.9)</td>
<td>0.90</td>
</tr>
<tr>
<td>Residents (n per km)</td>
<td>65.4 (45.0-84.8)</td>
<td>63.1 (46.5-80.7)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Aesthetics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Green along route</td>
<td>49.9 (34.0-71.5)</td>
<td>55.7 (32.5-72.4)</td>
<td>1.00</td>
</tr>
<tr>
<td>% Water along route</td>
<td>37.7 (10.2-61.3)</td>
<td>44.6 (15.4-68.5)</td>
<td>1.03</td>
</tr>
<tr>
<td>Trees (n per km)</td>
<td>145.6 (102.9-174.2)</td>
<td>140.7 (103.5-167.8)</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>Traffic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic lights (n per km)</td>
<td>0.00 (0.0-0.0)</td>
<td>0.00 (0.0-0.0)</td>
<td>1.29</td>
</tr>
<tr>
<td>Street lights (n per km)</td>
<td>67.7 ±21.6</td>
<td>62.3 ±21.0</td>
<td>0.95</td>
</tr>
<tr>
<td>Street bumps (n per km)</td>
<td>3.7 (1.5-9.8)</td>
<td>3.4 (0.8-8.3)</td>
<td>0.96</td>
</tr>
<tr>
<td>Accidents (n per km)</td>
<td>1.8 (0.0-3.6)</td>
<td>1.1 (0.0-2.9)</td>
<td>0.57</td>
</tr>
<tr>
<td>Zebra crossings (n per km)</td>
<td>1.6 (0.0-2.3)</td>
<td>0.8 (0.0-2.3)</td>
<td>0.56</td>
</tr>
<tr>
<td>Junctions (n per km)</td>
<td>33.2 ±13.4</td>
<td>35.3 ±12.8</td>
<td>1.03</td>
</tr>
<tr>
<td>% Sidewalk along route</td>
<td>98.7 (33.0-99.9)</td>
<td>93.2 (78.1-100.0)</td>
<td>0.96</td>
</tr>
<tr>
<td><strong>Type of Street</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Road (%)</td>
<td>3.4 (0.0-17.0)</td>
<td>7.9 (0.0-14.5)</td>
<td>0.99</td>
</tr>
<tr>
<td>Residential Street (%)</td>
<td>40.8 ±16.5</td>
<td>43.9 ±15.2</td>
<td>1.03</td>
</tr>
<tr>
<td>Cycling path (%)</td>
<td>22.3 (6.0-34.4)</td>
<td>24.1 (11.5-35.9)</td>
<td>1.01</td>
</tr>
<tr>
<td>Pedestrian path (%)</td>
<td>22.8 (14.7-35.1)</td>
<td>22.0 (15.7-28.8)</td>
<td>0.95</td>
</tr>
</tbody>
</table>

SD=Standard deviation, OR=Odds Ratio, p-values below 0.05 are printed in bold type.
Environmental characteristics of cycling routes
Results of the conditional regression analysis on differences between environmental characteristics of actually cycled routes and shortest cycling route are shown in Table 5. Similar to walking routes, cycling routes were located mostly in residential areas (80.7%). Compared to the shortest route, a larger part of the actual cycling route travelled through recreational areas (OR=1.06, 95% CI=1.01-1.11). The percentage of water (42.7%) along the actual route was also significantly higher compared to the shortest route (OR=1.03, 95%CI=1.01-1.05). Moreover, actually cycled routes differed from the shortest routes on all of the variables in the traffic category, i.e. more traffic lights and junctions, less street lighting, speed bumps, accidents and zebra crossings. Most of the actual cycling routes passed through residential streets (43.9%). This is significantly more often compared to the shortest route (OR=1.03, 95%CI=1.01-1.06). Pedestrian paths were covered less on actual cycling routes compared to shortest routes (OR=0.95, 95%CI=0.92-0.98). After the backward selection process, the final model for cycling routes (see Table 6) showed differences between actual and shortest cycling routes. Compared to the shortest GIS routes, actual cycling routes had a smaller number of trees, accidents, zebra crossings, and percentage of sidewalks along the route compared to the shortest cycling routes. Moreover, actually cycled routes had more traffic lights, junctions and a higher chance of being on residential streets compared to the shortest GIS route.

Table 6. Final multivariate models for actual walking and cycling routes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Beta</th>
<th>OR</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Walking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic lights</td>
<td>.75</td>
<td>2.11</td>
<td>1.07</td>
</tr>
<tr>
<td>Zebra crossings</td>
<td>-1.77</td>
<td>.17</td>
<td>.05</td>
</tr>
<tr>
<td>% Residential Street</td>
<td>.12</td>
<td>1.12</td>
<td>1.04</td>
</tr>
<tr>
<td>% Sidewalk along route</td>
<td>-.09</td>
<td>.91</td>
<td>.85</td>
</tr>
<tr>
<td>Cycling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trees</td>
<td>-.02</td>
<td>.96</td>
<td>.96</td>
</tr>
<tr>
<td>Traffic lights</td>
<td>.56</td>
<td>1.75</td>
<td>1.04</td>
</tr>
<tr>
<td>Accidents</td>
<td>-.56</td>
<td>.57</td>
<td>.39</td>
</tr>
<tr>
<td>Zebra crossings</td>
<td>-1.19</td>
<td>.31</td>
<td>.14</td>
</tr>
<tr>
<td>Junctions</td>
<td>.12</td>
<td>1.13</td>
<td>1.05</td>
</tr>
<tr>
<td>% Residential streets</td>
<td>.06</td>
<td>1.06</td>
<td>1.01</td>
</tr>
<tr>
<td>% Pedestrian paths</td>
<td>-.09</td>
<td>.91</td>
<td>.85</td>
</tr>
<tr>
<td>% Sidewalk along route</td>
<td>-.10</td>
<td>.91</td>
<td>.85</td>
</tr>
</tbody>
</table>

SD=Standard deviation, OR=Odds Ratio
Discussion

This cross-sectional study investigated differences in environmental characteristics of the actual walking and cycling route between home and school, compared to the environmental characteristics of the shortest route. Examining these differences provides insight in Dutch children’s route choice during active transportation between home and school.

For children that walked, median distance of the actual journey to school was 343.3 meters. Actual routes for cyclists had a median distance of 673.9 meters. These covered cycling distances are very similar to the average distance to a primary school in the Netherlands, which is 700 meters [30]. As expected, mode of transportation between home and school was related to the distance of the route [23][31]. The actual routes were 5.6% and 10.9% longer than the shortest route for walking and cycling, respectively. These detour ratios are in line with a study of Krenn et al. [14] who found that adult cyclists in Graz detoured on average 7.6%.

In final multivariate models, there was a significant difference in the amount of zebra crossings on the actual route to school versus the shortest route. Both during their cycling and walking routes, children were less likely to cover routes with zebra crossings (walking route: OR=0.17, 95% CI=0.05-0.58; cycling route: OR = 0.31, 95% CI=0.14-0.67). On the other hand, children did seem to use crossings with traffic lights when they were available. Possibly, children avoided walking along the busy roads when going to school, and preferably used signalized intersections to cross the main roads. Earlier, other studies have shown that such signalized intersections were associated with active travel to school [32,33]. Most of the zebra crossings in the Netherlands are located on or near roads where speed and intensity of motorized traffic is higher. It is likely that children avoid these busy streets. This could also explain why actual routes had a lower record of accidents as measured through BRON [29] compared to the shortest route, since accidents more often occur on busier roads. Unfortunately, data on traffic intensity was only available for the arterial roads in the dataset, not for the other streets in the network and could thus not be used in the current analysis.

Moreover, on their route to school children mainly traveled through residential areas and used residential streets (49.8% of their walking route, 43.9% of their cycling route). This was significantly different from their shortest route to school (walking: 44.0%, cycling:40.8%). Typically, residential streets are spread across residential areas and have many corners, junctions and short cuts. Actual cycling routes also had significantly more junctions compared to shortest routes. It has been shown that a high connectivity is supportive of active transportation [34]. Moreover, in the Netherlands, speed and intensity of the motorized traffic is low in these residential areas. There is usually a speed limit of 30 km/h on these streets. Also, during the morning the phenomenon of ‘safety by numbers’ may play a role here. According to this theory motorists change their behavior when large numbers of cyclists or pedestrians are present [35]. Thus, these residential streets may be perceived as safe to use for cycling, despite the absence of separate bicycle paths.
Furthermore, although some studies have shown that aesthetics, or an enjoyable scenery, can be associated with active transportation [36,37] this study did not show that actual walking or cycling routes had more visible green than shortest routes between home and school. There was no significant difference between percentage of green along the children’s actual walking and cycling routes and the percentage of green along the shortest routes on the network. On the other hand, in the unadjusted models, there was a difference in the amount of water ways visible along the actual routes, compared to the shortest routes. Both cyclists and pedestrians seemed to prefer routes that had a higher percentage of visible surface water along the route. This could be due to aesthetics of the route [36,37], but another explanation could be that routes along the water are generally more safe because of the buffer that water ways offer from other traffic. Contrary to what would be expected, the percentage of sidewalks along the actual walking route was lower than the percentage of sidewalks along the shortest route. Previous studies have shown that sidewalk presence is positively associated with walking to school [32]. In the current study, large parts of the walking routes (87%) were located on or near a sidewalk, but not significantly different compared to the percentage of sidewalks along the shortest routes. Thus, these results may be explained by the incompleteness of the pedestrian street network, where still not every possible path could be mapped.

**Strengths & Limitations**

This study used a novel approach to investigate environmental characteristics of active transportation to school. In contrast to previous studies, analysis of walking and cycling routes were separated as both transportation modes require different street infrastructure. The current study investigated environmental characteristics of the actually traveled route by investigating environmental correlates within a range of 25 meters of the GPS signal. By using this relatively small buffer the actual exposure to the environment was much better represented than when using large circular buffers (e.g. 400 meters) around the house that are commonly used to represent environmental exposure during active transportation. It can be argued that people are not influenced by all of the features that are encompassed by these large circular buffers, e.g., because they never interact with these distant features [21]. Still, as buffers are used in the current study, the modifiable area unit problem may have played a role in this analysis as well. The modifiable area unit problem represents a phenomenon in geospatial analysis where observed aggregated values are different dependent on the boundaries that are drawn [32], in this case buffer size. This study used a 25 meter buffer to optimally discriminate between the GIS derived route and the GPS route. Larger buffers that are also commonly used, i.e., 100 meters or 250 meters, make it hard to find differences between the two routes because of the increasing overlap of the buffers. Moreover, two other comparable studies also used a similar buffer size of 25 meter [14,38]. Another study used buffers of 100 meters to identify food outlets and physical activity facilities, but used a similar buffer of 20 meter to join the GPS points to the road network [13].
Also, despite only using the shortest walking and cycling GPS route in the analysis, multi-destination tracks were still present in our sample. Moreover, the recorded GPS tracks were not matched to the street network during the data handling process. Instead, the recorded GPS routes were buffered. So, in the analysis the buffered ‘raw’ GPS signal of the actual route was compared with the buffered street network. This was done to resemble the actually walked or cycled routes as closely as possible. Sidewalks, for example, are generally aligned perfectly aside the buffered street network, whereas the actual GPS signal follows a more arbitrary path that can deviate from the street network. Thus, part of the sidewalks along the route are missed. This was partially solved by using a buffer, in this case 25 meters, which also compensated for the inaccuracy in the GPS signal. Schipperijn et al. [39] showed that with the BT Q1000XT-model of the GPS, median error for walking trips was 3.9 meters, and for cycling trips 2.0 meters, but still >20% of GPS points fell outside of 10 meters of the expected location. These methodological constraints may have influenced results of this study, underestimating the presence of certain characteristics along the actual active transportation routes.

Data collection took place in the more suburban parts of the Netherlands. Children who travel in more urban or more rural areas may use different routes to school. Although a similar analysis for rural routes would be less interesting because of the lack of alternative routes, it would be interesting to see if active transportation routes in the bigger cities are similar. Furthermore, most of the data collection took place around spring and the beginning of summer. This could have influenced transportation behavior of the children. It is well known that seasonal changes, e.g., hours of daylight, weather, can have a large impact on daily physical activity levels and mode of transportation [40]. In the winter when it is still dark during morning trips, for example street lighting may play a more significant role in route choice for walking and/or cycling. Thus, some of the results of the current study may be the consequence of methodological choices and challenges, e.g. cross-sectional study, size of the buffers, aligning GPS signals with the pedestrian street network, multi-destination trips.

**Conclusion**

In the current study, actual cycling routes had significantly more traffic lights and a higher connectivity than shortest routes. Moreover, children that cycled to school avoided streets with a high incidence of accidents. Both on their walking and cycling routes, children seemed to prefer residential streets over other type of streets, but avoided streets with zebra crossings. Most of the differences between actual and shortest routes may be explained by the preference of children (and their parents) to avoid walking or cycling along the busy roads on their way to school. Thus, this study seems to confirm the importance of traffic safety for active transportation to school.
### Supplementary table 1. Description of the GIS-variables used in the comparison of the shortest and actual route

<table>
<thead>
<tr>
<th>Routes</th>
<th>Source</th>
<th>Type of GIS-data*</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street Network</td>
<td>Top10NL, OpenStreetMap (OSM), satellite images</td>
<td>Polylines</td>
<td>Constructed using the road centerlines available in the TOP10NL database (topographic map of the Netherlands, scale 1: 10,000 provided by the Dutch Land use register Kadaster). To complete the street network, centerlines of missing streets were manually added based on Open Street Map (OSM) data and satellite images from LuchtfotoNL (2014).</td>
</tr>
<tr>
<td>Shortest route length (meter)</td>
<td>Street Network</td>
<td>Polylines</td>
<td>Shortest routes were calculated with the Network Analyst tool in ArcGis 10.2 and were based on the shortest routes on the street network between the x,y-location of the home and school building.</td>
</tr>
<tr>
<td>Actual Route length (meter)</td>
<td>GPS-tracks</td>
<td>Polylines</td>
<td>Locations of the home address and school building of the children were determined based on clusters in the GPS data. Next, each GPS track between the home address and the school building was identified with an automatic procedure. Trips going in both directions (i.e., home or school) were eligible to be included in the analysis.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land-use</th>
<th>Source</th>
<th>Type of GIS-data*</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entropy</td>
<td>CBS Land use data</td>
<td>Polylines</td>
<td>A four-category entropy index in which 0 stands for no diversity, while 1 means that there is an equal distribution of land use. A distinction was made between the following entropy categories: commercial areas, residential areas, recreational areas, and transport areas.</td>
</tr>
<tr>
<td>% Commercial area</td>
<td>CBS Land use data</td>
<td>Polylines</td>
<td>Public facilities, office space, industrial, retail, or construction areas as classified by the CBS Land use data. Reported as a percentage of the total surface area of the route.</td>
</tr>
<tr>
<td>% Residential area</td>
<td>CBS Land use data</td>
<td>Polylines</td>
<td>Areas classified as residential areas in the CBS land use data. Reported as a percentage of the total surface area of the route.</td>
</tr>
<tr>
<td>% Recreational area</td>
<td>CBS Land use data</td>
<td>Polylines</td>
<td>Areas classified as green, playgrounds, parks, water and sports facilities in the CBS Land use data. Reported as a percentage of the total surface area of the route.</td>
</tr>
<tr>
<td>% Transport area</td>
<td>CBS Land use data</td>
<td>Polylines</td>
<td>Areas classified as main roads, railways or airports in the CBS Land use data. Reported as a percentage of the total surface area of the route.</td>
</tr>
<tr>
<td>Residents (n per km)</td>
<td>CBS Squares</td>
<td>Polylines</td>
<td>CBS squares, derived from the Dutch Statistics Center, provided number of residents in 100 by 100 meter cells. Surface area within a 25 meter of the route . Reported as estimated number of residents per kilometer of route.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aesthetics</th>
<th>Source</th>
<th>Type of GIS-data*</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Green along route</td>
<td>TOP10NL</td>
<td>Polylines</td>
<td>Calculated based on the areas of green from TOP10NL, these surface areas represent neighborhood green spaces (e.g. bushes, grass plots, woods). Areas of green were buffered with 25 meter. Length of the route within these buffers where divided by the total route length and reported as a percentage of the route.</td>
</tr>
<tr>
<td>% Water along route</td>
<td>TOP10NL</td>
<td>Polylines</td>
<td>Calculated based on the surface areas of water from TOP10NL, these surface areas represent natural water ways (e.g. ponds, rivers, lakes). Areas of water were buffered with 25 meter. Length of the route within these buffers where divided by the total route length and reported as a percentage of the route.</td>
</tr>
<tr>
<td>Trees (n per km)</td>
<td>local land use registry data</td>
<td>Points</td>
<td>Number of trees within the buffer of 25 meter of the route. Reported as the number of points per km of route.</td>
</tr>
</tbody>
</table>
### Traffic

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Source</th>
<th>Type of GIS-data*</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic lights (n per km)</td>
<td>local land use registry data, OSM</td>
<td>Points</td>
<td>Number of traffic lights within the buffer of 25 meter of the route. Missing traffic lights were manually added based on Open Street Map data. Reported as the number of points per km of route.</td>
</tr>
<tr>
<td>Street lights (n per km)</td>
<td>local land use registry data</td>
<td>Points</td>
<td>Number of lampposts within the buffer of 25 meter of the route. Reported as the number of points per km of route.</td>
</tr>
<tr>
<td>Street bumps (n per km)</td>
<td>local land use registry data, OSM, satellite images</td>
<td>Points</td>
<td>Number of street bumps within the buffer of 25 meter of the route. Missing street bumps were manually added based on Open Street Map data and satellite images from LuchtfotoNL. Reported as the number of points per km of route.</td>
</tr>
<tr>
<td>Accidents (n per km)</td>
<td>BRON</td>
<td>Points</td>
<td>Number of traffic related accidents recorded in a national database through official reports or registration sets from the police.</td>
</tr>
<tr>
<td>Zebra crossings (n per km)</td>
<td>local land use registry data, OSM, satellite images</td>
<td>Points</td>
<td>Number of zebra crossings within the buffer of 25 meter of the route. Missing zebra crossings were manually added based on Open Street Map data and satellite images from LuchtfotoNL. Reported as the number of points per km of route.</td>
</tr>
<tr>
<td>Junctions (n per km)</td>
<td>Street network</td>
<td>Points</td>
<td>Number of junctions within the buffer of 25 meter of the route. Reported as the number of points per km of route.</td>
</tr>
<tr>
<td>% Sidewalk along route</td>
<td>local land use registry data</td>
<td>Polygons</td>
<td>Calculated based on the data on sidewalks provided by the local municipality. Sidewalk areas were buffered with 25 meter. Length of the route within these buffers where divided by the total route length and reported as a percentage of the route.</td>
</tr>
</tbody>
</table>

### Type of Street

<table>
<thead>
<tr>
<th>Type of Street</th>
<th>Source</th>
<th>Type of GIS-data*</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Main Road</td>
<td>Street Network</td>
<td>Polylines</td>
<td>All arterial roads, including highways within a buffer of 25 meter of the route. Speed limits on these roads are typically 50 km/h or higher. When cyclists travel along these roads, they are directed to a separately marked cycling lane. Pedestrians use the sidewalk when these are available. Reported as a percentage of total length of roads.</td>
</tr>
<tr>
<td>%Residential Street</td>
<td>Street Network</td>
<td>Polylines</td>
<td>Roads going through residential areas. Residential streets are used for all modes of transportation, thus motorized traffic shares the streets with cyclists while pedestrians are directed to the sidewalk. Maximum speed of motorized traffic on residential streets is usually low, with a maximum of 30 km/h. Reported as a percentage of total length of roads.</td>
</tr>
<tr>
<td>%Cycling path</td>
<td>Street Network</td>
<td>Polylines</td>
<td>Separate cycling paths designed for use by cyclists. Bike lanes marked by a line on the main road were not included in this category. Reported as a percentage of total length of roads.</td>
</tr>
<tr>
<td>%Pedestrian path</td>
<td>Street Network</td>
<td>Polylines</td>
<td>Separate paths designed for use by pedestrians, e.g., pathways through parks or other recreational facilities, shortcuts between houses. Reported as a percentage of total length of roads.</td>
</tr>
</tbody>
</table>

* Type of GIS-data: a) Points: represented by a x,y -coordinate b) Polylines: a sequence of points defining a connected series of line segments c) Polygons: a closed chain of line segments forming a plane.
Supplementary table 2. Descriptive statistics of GPS tracks (N=1,249) between home and school of 184 children.

<table>
<thead>
<tr>
<th>Mode of transport</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Median</th>
<th>25th percentile</th>
<th>75th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking (N=211, n=67)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (meters)</td>
<td>405.3</td>
<td>310.9</td>
<td>343.3</td>
<td>213.0</td>
<td>549.8</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>7.7</td>
<td>10.4</td>
<td>5.3</td>
<td>3.0</td>
<td>8.8</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>3.7</td>
<td>1.2</td>
<td>3.8</td>
<td>3.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Max Speed (km/h)</td>
<td>10.5</td>
<td>7.9</td>
<td>9.2</td>
<td>6.8</td>
<td>11.2</td>
</tr>
<tr>
<td>Cycling (N=831, n=162)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (meters)</td>
<td>1066.3</td>
<td>1142.1</td>
<td>817.4</td>
<td>563.6</td>
<td>1186.0</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>14.1</td>
<td>29.7</td>
<td>6.3</td>
<td>4.1</td>
<td>10.5</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>7.7</td>
<td>3.5</td>
<td>7.4</td>
<td>4.9</td>
<td>10.4</td>
</tr>
<tr>
<td>Max Speed (km/h)</td>
<td>19.7</td>
<td>24.0</td>
<td>18.3</td>
<td>15.9</td>
<td>20.8</td>
</tr>
<tr>
<td>Motorized transport (N=207, n=70)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance (meters)</td>
<td>4900.0</td>
<td>6734.9</td>
<td>2082.0</td>
<td>1076.8</td>
<td>5770.3</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>75.3</td>
<td>199.8</td>
<td>8.2</td>
<td>4.9</td>
<td>53.5</td>
</tr>
<tr>
<td>Average speed (km/h)</td>
<td>12.6</td>
<td>7.3</td>
<td>12.6</td>
<td>6.7</td>
<td>17.4</td>
</tr>
<tr>
<td>Max Speed (km/h)</td>
<td>56.8</td>
<td>30.5</td>
<td>52.2</td>
<td>40.1</td>
<td>63.2</td>
</tr>
</tbody>
</table>

N= number of tracks recorded for each transportation mode, n=number of children
Chapter 5

References


Chapter 6

Effect of improving traffic safety in the primary school environment on children’s physical activity levels

Submitted

Dirk Dessing
Frank H Pierik
Geertje Hegeman
Evert Verhagen
Willem van Mechelen
Sanne I de Vries
Abstract

Introduction
Traffic safety problems in the school environment have been linked to lower rates of physical activity (PA) and higher adiposity rates in children in previous research. This study is a natural experiment in the Netherlands, which aims to investigate the longitudinal effect of infrastructural changes to increase traffic safety around primary schools (‘Schoolzone’) on children’s daily PA levels.

Methods
Using a pretest-posttest design with two follow-up measurements, the PA level of children attending a school where a ‘Schoolzone’ was constructed (intervention group) was compared to the PA level of children at a school where the built environment remained unchanged (control group). PA was assessed among 251 children, aged 8-11 years, with a combination of accelerometry and Global Positioning System (GPS) devices. Baseline measurements (T0) started in April-June 2014; follow-up measurements were conducted six months (T1) and one year after baseline (T2). The effect of a ‘Schoolzone” construction was examined with linear mixed effect models, using the number of minutes of moderate-to-vigorous intensity physical activity (MVPA) children per entire school day and the number of minutes of MVPA accumulated in the school environment (<100 meters from school) as outcome measures.

Results
At baseline children accumulated an average of 50.3 (±19.5) minutes of MVPA per school day, of which 17.9 ± 10.6 minutes were spent in the school environment. Overall, children were less active during both follow-up measurements, compared to baseline (ΔT0-T1: β=6.93, Std. Error=1.87, p<0.01, ΔT0-T2: β=6.38, Std. Error=1.56, p<0.01). No significant effect was found of the ‘Schoolzone’ on total day MVPA (T1: β= -0.19, Std. Error=2.27, p=0.93; T2: β= 3.51, Std. Error=2.07, p=0.09), nor on MVPA recorded in the school environment (T1: β= 0.42, Std. Error=1.29, p=0.74; T2: β=1.27, Std. Error=1.19, p=0.28).

Conclusion
This study did not confirm that infrastructural changes to increase traffic safety around schools (i.e. the construction of ‘Schoolzones’) had an effect on PA levels of primary school children.
Introduction

Increasing the level of habitual moderate to vigorous intensity physical activity (MVPA) in youth is an important health promotion and disease prevention strategy [1,2]. Making structural changes in the environment in which children live and play has been recognized as a vital component of such a strategy [3]. In this regard, the school environment is an interesting setting for intervention developers and researchers. Children spend a large proportion of their time within the school environment [4,5]. In addition, this setting provides the opportunity to reach children with diverse backgrounds (e.g. ethnicity, socioeconomic status) [6,7]. At the same time, traffic safety problems in the school environment have been linked to lower rates of physical activity (PA) and higher adiposity rates in children [8]; e.g. a recent South African study showed that objective traffic safety could be associated with higher PA levels [9]. Furthermore, other studies have also found associations of parental perception of traffic safety with children’s PA level [10-12]. A possible explanation might be that parental concerns about road safety are related with children being allowed to use active transportation between home and school [3]. Children who use active transportation (i.e. walking or cycling) on their trip between home and school have higher overall levels of PA than those children who rely on motorized transport [13,14]. Moreover, a recent study has also established that parental concerns regarding safety are a major barrier to children’s active free play, as this leads to restrictions in children’s independent mobility [15]. A systematic review showed that children who have the freedom to play outdoors have higher PA levels than those who are more restricted in their mobility [16]. Unfortunately, longitudinal research on this topic is scarce; i.e., most of the studies on traffic safety in relation to children’s PA level are cross-sectional.

A study by Yang et al. [17] used mathematical models to quantify the effect of traffic safety on the PA level of school children. This study revealed that it is most effective to focus on safety measures within a small concentrated area around the school, instead of making changes in the entire neighborhood. In recent years, Dutch municipalities have started interventions that are very similar to the approach Yang et al. [17] suggested. In the Netherlands, so called “Schoolzones” are created consisting of a set of traffic safety measures around the primary school building. Depending on the local situation, a set of infrastructural changes (e.g. school markings on the road, sidewalk improvements, pedestrian or bicycle crossings, bicycle facilities, traffic signals, see Figure 1) is made in the school environment. The objective of this study was to investigate the effect of such traffic safety measures in the primary school environment on the PA level of the attending schoolchildren.
Methods

This study is a natural experiment using a pretest-posttest design with two follow-up measurements in which the effect was investigated of measures to increase traffic safety around primary schools on daily PA levels of schoolchildren in the Netherlands. The study compared the PA level of children that were either attending a school where a Schoolzone was constructed (intervention group) with the PA level of children attending a school where no infrastructural changes were made (control group). The study was approved by the ethics committee of the VU University Medical Center (VUmc, Amsterdam, The Netherlands).

Recruitment and setting
Recruitment of primary schools took place in 5 suburban municipalities (i.e., Zaanstad, Haarlemmermeer, Edam-Volendam, Hilversum and The Hague) that were all located in the urban agglomeration in the western part of the Netherlands. Schools that were selected by the municipalities to construct a Schoolzone and that were designated to receive this intervention during the Spring or Summer of 2014 were invited to participate in the present study. School principals of these schools were contacted by e-mail and telephone, and invited for a face-to-face explanatory meeting. When school principals agreed to participate, control schools were matched to the intervention schools based on geographical location, degree of urbanization, pupil demographics, and neighborhood characteristics. The recruitment resulted in 11 participating schools (5 intervention schools and 6 control schools): 3 schools were located in Zaanstad, 2 in the Haarlemmermeer, 2 in Edam-Volendam, 2 in Hilversum and 2 in The Hague.
All 463 children in grades 5, 6 or 7 (~8-11 years old) attending either the participating intervention schools or the control schools were eligible to take part in the study. Children and their parents were informed about the study through letters and pamphlets that were handed out by their teacher. Written informed consent was obtained from the parent or guardian of the participating children. Baseline measurements took place in the period of April-June. Two follow-up measurements (T1, T2) took place after the construction of the Schoolzone, respectively 6 months after baseline (T1: September-November) and around 1 year after baseline (T2: April-June) with intervention and matched control schools always being measured during the same week. For schools in Zaanstad, Haarlemmermeer, and Edam-Volendam, measurements started in 2014. Measurements at schools in Hilversum and The Hague started in 2015.

Schoolzone intervention
The main goal of a Schoolzone is to increase traffic safety in the streets adjacent to the primary school building. All access roads for cars into the area were marked with the text ‘SCHOOL’ (See Figure 1) and were accompanied by traffic signs, indicating that car drivers are approaching a primary school. The other infrastructural changes that were made in the Schoolzone depended on the local situation and varied between schools. Changes included traffic calming measures (e.g. speed bumps), sidewalk improvements, pedestrian or bicycle crossings, bicycle facilities and traffic signs. Table 1 shows the infrastructural changes for each school. The decision on which infrastructural adaptations were made in each Schoolzone, was executed by the municipality after consultation with other stakeholders. Next, the infrastructural changes were implemented by local contractors. All Schoolzones were constructed during school holidays in 2014 or 2015.

Table 1. Elements of Schoolzone design at the intervention schools

<table>
<thead>
<tr>
<th>Elements of Schoolzone design</th>
<th>Zaanstad</th>
<th>Haarlemmermeer</th>
<th>Edam-Volendam</th>
<th>The Hague</th>
<th>Hilversum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry roads marked with the text ‘SCHOOL’</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Traffic speed calming infrastructure (e.g. speed humps, road narrowing)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sidewalk improvements</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cycling path</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Facilities for crossing busy road (e.g. zebra-striped crossing, traffic light)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Educational program at school</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Kiss&amp;Ride zone</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Playground markings on sidewalks</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Outcome measures

Primary outcome measure of this study was the number of minutes of MVPA children accumulated during an entire school day. Secondary outcome measure was the number of minutes of MVPA accumulated in the school environment, defined as a buffer area with a boundary at 100 meters from the center point of the school building.

Instrumentation

MVPA during an entire school day and MVPA in the school environment were objectively measured through the combination of accelerometry (Actigraph, GT3X) and a Global Positioning System (GPS) device (Travel Recorder X, BT-Q1000X, Qstarz International co). After a classroom instruction, children were asked to wear an elastic belt with both devices during waking hours, for 8 consecutive days. Written instructions for children and their parents were handed out together with the device. Furthermore, after receiving the devices, children completed a short questionnaire to provide information on their age, gender and habitual daily physical activity behavior. Accelerometers were initialized to record with a sample rate of 30hz, and afterwards aggregated to 1 second epochs with the Actilife Software (v6.11.9). Because of the limited available memory, GPS devices were set to record the geographical location with a sample frequency of 5 seconds.

Data processing

The data management software from Qstarz, Qtravel v1.48, was used to download the GPS data and to convert the data to the csv format for further processing in URBIS [18]. A cluster detection method was then used to determine the location of the school building and home address and calculate the distance between home and school [19]. Mode of transport between home and school was then determined based on a trip detection algorithm [20]. GPS points were classified as ‘in the school environment’ when they were located within the 100 meter buffer of the school location. School hours reported by the school were then used to divide these points into three categories: before, during and after school. Accelerometer output of 1 second intervals was also first converted to the csv format. Periods of 20 minutes of consecutive zeros were considered to be non-wear periods [21,22]. Accelerometer and GPS data were date and time matched to create a measure of location and activity for each 5 seconds GPS epoch.

After matching the data, Evenson’s cut-points [23,24] were used to define each epoch as either sedentary (≤100 counts per minute), light PA (101 to 2295 counts per minute) or MVPA (≥2296 counts per minute). Each 5 second epoch defined as MVPA was considered to contribute to reaching the daily PA requirement. Total amount of sedentary, light PA and MVPA during the entire day was calculated by aggregating per participant the respectively classified epochs for each individual day. Equivalently, the amount of time spent in the school environment was calculated separately for three PA categories. In order to be included in the analysis, children had to record at least 1 weekday with ≥360 minutes of combined GPS and accelerometer data during the baseline measurement. Only weekdays were included in the analysis.
Data analysis and statistical methods
Statistical analyses were performed using R [25] using the lme package [26]. First, differences between intervention and control group on background characteristics (age, gender and distance between home and school) were compared with a t-test or Pearson’s chi-square test. Linear mixed effect models were then used to investigate if there were differences in total day MVPA and minutes of MVPA in the school environment between intervention and control group during the three measurement periods (i.e. baseline, T1, T2). For random effects, an intercept-only model was used with intercepts for school, participant and day of the week. As fixed effects, the measurement period was entered as a categorical variable, together with group (control used as reference and coded as 0, intervention coded as 1). To investigate if there were differences in effect between intervention and control group during the two follow-up measurements the interaction of group and measurement was added to the models. A linear mixed model analysis was also used to check if wear time decreased significantly over the 3 measurement periods. For these models, the same random and fixed effects were entered. Final models used for the analysis of minutes of MVPA were adjusted for gender, average minutes of MVPA/day recorded at baseline, and for wear time.
Chapter 6

Results

Participants and combined GPS and accelerometer wear time
In total, 299 children had received consent of their parents to participate in the study. Of this group, 251 children (122 boys, 129 girls) provided at least one valid weekday of PA data during baseline measurements. The age of these children ranged between 8 and 11 years, with an average of 10.2 (±0.9) years. Average distance to school was 615.6 (interquartile range: 394.5-910.5) meters, with most of the children using active transportation to school (walking trips: 26.4%, cycling trips: 60.9%). No significant differences between intervention and control schools were found for the background characteristics age, gender and distance between home and school. Out of the 251 children, 202 children also provided sufficient valid PA data during at least one of the follow-up measurement periods. Figure 2 shows the flow of the participants during the study.

Mean amount of wear time during baseline measurements was 624.6 (±88.5) minutes per day, with a median of 4 valid weekdays per child (see also Table 2). Wear time significantly decreased during both follow-up measurements compared to wear time at the baseline measurement (ΔT0-T1: β=-73.8 minutes, Std. Error = 12.2, p<0.01; ΔT0-T2: β=-38.8 minutes, Std. Error=10.3, p<0.01), but remained well above the boundary of 360 minutes for a valid weekday. Also, an interaction effect was found for group and the first follow-up (T1) measurement (ΔControlT1-InterventionT1: β=46.1, Std. Error=14.9, p<0.01), indicating that wear time in the intervention group was higher than wear time in the control group at T1.
Table 2. Participant characteristics and summary of accelerometer recordings at baseline measurements.

<table>
<thead>
<tr>
<th></th>
<th>Intervention group</th>
<th>Control group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>n (%)</td>
<td>n (%)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>66 (52.0%)</td>
<td>56 (45.2%)</td>
<td>122 (48.6%)</td>
</tr>
<tr>
<td>Girls</td>
<td>61 (48.0%)</td>
<td>68 (54.8%)</td>
<td>129 (51.4%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at baseline (years)</td>
<td>10.2 (±1.0)</td>
<td>10.1 (±0.9)</td>
<td>10.2 (±0.9)</td>
</tr>
<tr>
<td>Distance from home to school (m)</td>
<td>576.9 (369.6-910.0)</td>
<td>636.5 (408.7-942.3)</td>
<td>615.6 (394.5-910.5)</td>
</tr>
<tr>
<td>Mode of transport of trips recorded between home and school</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>219 (26.5%)</td>
<td>112 (26.2%)</td>
<td>331 (26.4%)</td>
</tr>
<tr>
<td>Cycle</td>
<td>528 (63.9%)</td>
<td>235 (55.0%)</td>
<td>763 (60.9%)</td>
</tr>
<tr>
<td>Motorized</td>
<td>79 (9.6%)</td>
<td>80 (18.7%)</td>
<td>159 (12.7%)</td>
</tr>
<tr>
<td>Daily wear time (minutes)</td>
<td>627.3 (±85.1)</td>
<td>621.8 (±92.2)</td>
<td>624.6 (±88.5)</td>
</tr>
<tr>
<td>Number of valid weekdays (n)</td>
<td>3.9 (±1.2)</td>
<td>3.7 (±1.2)</td>
<td>3.8 (±1.2)</td>
</tr>
<tr>
<td>Number of days reached PA guideline* (n)</td>
<td>1.4 (±1.5)</td>
<td>1.1 (±1.2)</td>
<td>1.2 (±1.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVPA/day (minutes)</td>
<td>50.4 (±20.1)</td>
<td>50.1 (±18.9)</td>
<td>50.3 (±19.5)</td>
</tr>
<tr>
<td>MVPA in school environment (minutes)</td>
<td>1.3 (±1.0)</td>
<td>1.0 (±0.9)</td>
<td>1.1 (±0.9)</td>
</tr>
<tr>
<td>Before school</td>
<td>16.7 (±11.3)</td>
<td>11.8 (±6.1)</td>
<td>14.3 (±9.4)</td>
</tr>
<tr>
<td>During School</td>
<td>3.4 (±5.1)</td>
<td>3.6 (±4.4)</td>
<td>3.5 (±4.8)</td>
</tr>
<tr>
<td>After school</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Accumulated more than 60 minutes of MVPA during the day

Numbers are given as n (%), mean (±SD), or median (interquartile range (IQR)).
Figure 2. Flow chart of participants during the study.

5 municipalities

11 schools agreed to participate

11 schools
463 children invited to participate

5 Intervention schools
208 children

6 Control schools
255 children

Request for parents and children’s informed consent

Consent given and participated in baseline measurements
299/463 children (64.6%)

Intervention group
147/208 children (70.6%)

Control group
152/255 children (59.6%)

Recorded enough accelerometer data during baseline measurements (T0)
251/299 children (83.9%)

Intervention group
127/147 (86.3%)

Control group
124/152 (81.6%)

Children who recorded enough accelerometer data during follow-up (T1 or T2)
202/251 children (80.5%)

Intervention group
114/127 (89.8%)

Control group
88/124 (70.9%)
**Total weekday physical activity**

During baseline measurements, children accumulated an average of 50.3 (SD ±19.5) minutes of MVPA per day. There were no significant differences between intervention and control group in the number of minutes of MVPA/day at baseline. Out of the participating children, 60.6% recorded at least one day on which they reached the guideline of 60 minutes/day (Control group: 58.1%, Intervention group: 63.0%). Table 2 presents a further description of combined GPS and accelerometry data from baseline measurements. In the adjusted model, corrected for the confounders gender, wear time and baseline MVPA, the number of minutes of MVPA/day during both follow-up measurements was significantly lower, compared to the baseline measurement (ΔT0-T1: β=−6.93 minutes, Std. Error=1.87, p<0.01; ΔT0-T2: β=−6.38 minutes, Std. Error=1.56, p<0.01), further details are presented in Table 3. The interaction effect for group*measurement period that was present in the crude analysis (β=4.68, Std. Error=2.40, p<0.05) disappeared after adjusting for confounders (β= 3.51, Std. Error=2.07, p=0.09).

Figure 3 shows the adjusted means of the number of minutes of MVPA/day for both intervention and control group at the three measurement periods.

Figure 3. Adjusted means and standard error of total weekday minutes of MVPA. Results of mixed model analysis were corrected for gender, average wear time, and number of minutes of MVPA at baseline.
Table 3. Summary table for mixed model analysis of total weekday minutes of MVPA/day and minutes of MVPA/day in the school environment.

<table>
<thead>
<tr>
<th></th>
<th>Total weekday MVPA (Crude Model)</th>
<th>Total weekday MVPA (Adjusted Model)</th>
<th>School Environment MVPA (Crude Model)</th>
<th>School Environment MVPA (Adjusted Model)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E  95% CI  p</td>
<td>E  95% CI  p</td>
<td>E  95% CI  p</td>
<td>E  95% CI  p</td>
</tr>
<tr>
<td><strong>Fixed Parts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Intercept)</td>
<td>51.1 45.6–56.6  &lt;.001</td>
<td>-19.5 14.4–34.3  &lt;.001</td>
<td>15.9 11.5–20.4  &lt;.001</td>
<td>5.2 2.4–8.0 0.003</td>
</tr>
<tr>
<td>Intervention</td>
<td>0.6  -7.0–8.1  0.887</td>
<td>0.0  -4.3–3.3  0.989</td>
<td>5.9  -0.9–11.6  0.78</td>
<td>2.0  -0.6–4.5 0.146</td>
</tr>
<tr>
<td>Follow-up (T1)</td>
<td>-10.7  -15.1–6.4  &lt;.001</td>
<td>-6.9  -10.6–3.3  &lt;.001</td>
<td>-2.6  -4.9–0.4  0.023</td>
<td>-2.7  -4.8–0.7 0.010</td>
</tr>
<tr>
<td>Follow-up (T2)</td>
<td>-8.9  -12.5–5.4  &lt;.001</td>
<td>-6.4  -9.5–3.3  &lt;.001</td>
<td>-0.5  -2.4–1.3  0.50</td>
<td>-0.3  -2.0–1.5 0.777</td>
</tr>
<tr>
<td>Intervention *Follow-up (T1)</td>
<td>1.5  0.3–2.8  0.587</td>
<td>-0.2  -4.6–3.3  0.932</td>
<td>0.5  -2.3–3.2  0.747</td>
<td>0.4  -2.1–2.9 0.744</td>
</tr>
<tr>
<td>Intervention *Follow-up (T2)</td>
<td>4.9  0.2–9.6  0.043</td>
<td>3.5  -0.7–7.6  0.091</td>
<td>-1.3  -3.4–1.5  0.48</td>
<td>-1.3  -3.6–1.1 0.285</td>
</tr>
<tr>
<td>BaselineMVPA</td>
<td>0.6  0.6–3.7  &lt;.001</td>
<td>0.6  0.6–3.7  &lt;.001</td>
<td>0.6  0.6–3.7  &lt;.001</td>
<td>0.6  0.6–3.7  &lt;.001</td>
</tr>
<tr>
<td>Gender</td>
<td>2.6  0.7–4.5  0.006</td>
<td>1.5  0.5–2.6  0.004</td>
<td>1.5  0.5–2.6  0.004</td>
<td>1.5  0.5–2.6  0.004</td>
</tr>
<tr>
<td>Wear time</td>
<td>0.06  0.05–0.07  &lt;.001</td>
<td>0.06  0.05–0.07  &lt;.001</td>
<td>0.06  0.05–0.07  &lt;.001</td>
<td>0.06  0.05–0.07  &lt;.001</td>
</tr>
</tbody>
</table>

| **Random Parts**        |                                  |                                     |                                      |                                          |
| Nppm                   | 251                               | 251                                 | 251                                  | 251                                      |
| Nschool                 | 11                                | 11                                  | 11                                   | 11                                       |
| NWday                   | 5                                 | 5                                   | 5                                    | 5                                        |
| IOCppm                 | 0.258                             | 0.024                               | 0.175                                | 0.004                                    |
| IOCSchool               | 0.046                             | 0.012                               | 0.126                                | 0.027                                    |
| IOCWday                 | 0.007                             | 0.006                               | 0.035                                | 0.044                                    |
| Observations           | 1933                              | 1933                                | 1905                                 | 1905                                     |

E Crude analysis for total day MVPA, a Crude analysis corrected for gender, wear time, and average number of minutes MVPA at baseline. b Crude analysis for total day MVPA. c Minutes of MVPA in school environment, corrected for gender, and average number of minutes MVPA recorded at baseline. ICC: Intra Class Correlation.
Physical activity in the school environment
During the day, children recorded an average of 294.0 (±61.2) minutes/day in the school environment at baseline, of which 17.9 ± 10.6 minutes were spent in MVPA. The number of minutes of MVPA/day in the school environment at the first follow-up was significantly lower compared to baseline, but the difference between control and intervention group at T1 was not significant (ΔT0-T1: β= -2.72 minutes, Std. Error=1.06, p<0.05; ΔControlT1-InterventionT1: β= 0.42, Std. Error=1.29, p=0.74). At T2, the difference between intervention and control group in total minutes of MVPA in the school environment was not significant as well (ΔT0-T2: β=0.25 minutes, Std. Error= 0.89, p=0.77; ΔControlT2-InterventionT2: β=-1.27, Std. Error=1.19, p=0.28). Results of the adjusted analysis for MVPA in the school environment are presented in Table 3 and adjusted means are visualized in Figure 4.

Figure 4. Adjusted means and standard error of minutes of MVPA/day recorded in the school environment. Results of mixed model analysis were corrected for gender, and number of minutes of MVPA at baseline.
Discussion

The aim of this controlled natural experiment was to examine the longitudinal effect of traffic safety measures in the primary school environment on children’s PA levels. The crude analysis seemed to confirm this effect as there was a small difference between intervention and control schools in total minutes of MVPA accumulated during the day (4.86 minutes; 95% CI: 0.15-9.57) exactly one year after baseline. However, this effect was not significant after controlling for gender, wear time, and average number of minutes of MVPA at baseline.

This is one of the first longitudinal studies using a combination of accelerometer and GPS data to examine changes in children’s PA after reconstructing the school environment. Previous research seemed to indicate that traffic safety could be associated with higher PA levels [8,12,27], for example by showing that features of the built environment (such as speed humps, intersection density) were associated with changes in MVPA of young children [11]. A possible explanation for the apparent lack of effects found in the current study is that the percentage of active transportation from and to school in the study population was already high at baseline measurements (i.e., 87%). Only around 13% of total detected trips between home and school was motorized. A recent review by Timperio et al. [28] showed that improved walking/cycling infrastructure and pedestrian safety structures, such as have been constructed in the current study, are mostly associated with increased transport-related PA. The high amount of active transportation found in the current study is not really surprising given the context in which the study was performed; despite parental concerns about traffic safety, cycling remains a popular mode of transport in The Netherlands [29,30]. Moreover, most of the participating children lived within walking distance to their school (median distance: 615.6 meters, IQR: 394.5-910.5) [31]. However, this makes comparability of the current study to other contexts difficult, e.g., the ratio of active transportation in other continents/countries is much lower: a recent review reported an average of around 20% of children who used active transportation to school in the US [32].

Furthermore, the average number of minutes of MVPA measured at baseline (50.3 ±19.5 minutes) was already relatively close to the guideline of 60 minutes/day, and 65% of children recorded at least one day on which they reached this guideline. Moreover, the amount of minutes of MVPA that was recorded, may be an underestimation of total MVPA as some of the children reported not wearing the devices during contact sports and other activities where the devices might get damaged (e.g. judo, soccer, swimming) [33]. Next, as this was a natural experiment, there was some heterogeneity in the manner the intervention was executed. There were notable differences between municipalities both in the decision process on which schools were appropriated to receive a Schoolzone, as well as differences in which elements were chosen as part of the Schoolzone design (see also Table 2). Some designs might have been more effective than others in increasing traffic safety, but these effects could not be quantified within the current study.
Furthermore, just like in previous studies [34,35], children in this study accumulated less minutes of MVPA/day at follow-up measurements than at baseline. On average, children spent 50 minutes in MVPA per weekday at baseline. At both follow-up time points this was around 7 minutes less, even when models were corrected for total daily wear time. This is most likely the effect of ageing, as children generally become less physically active when they get older [11,35]. Studies have also shown that there is strong seasonal variation in children’s PA levels [36,37] but this would only explain the lower PA levels at the first follow-up in autumn, but not during the second follow-up which was performed exactly 1 year after baseline and thus with comparable weather conditions.

Secondary aim of the study was to see whether there would be changes in children’s PA in the direct vicinity of the school. At baseline children accumulated around one third (17.9 ±10.6) of their total minutes of weekday MVPA in the school environment (<100 meters of school building). This was slightly lower at both follow-up time points, but did not change significantly exactly one year later. Before the study started, we hypothesized that the Schoolzone intervention could have an effect on the amount of outdoor play in the school environment as other studies showed that parental concerns about speeding traffic were negatively associated with children’s amount of outdoor play[38], but no differences were found in MVPA in the school environment between intervention and control schools at both follow-up time points. The amount of time spent in the school environment was very much comparable to numbers that were found in a previous study [4] which also showed that most of the time in the school environment was spent sedentary, and PA was predominantly taking place during recess, and much less outside school hours.

**Strengths & Limitations**

The major strength of the current study is its longitudinal design in combination with the use of objective measurements of location and PA. To the best of our knowledge, this has been one of the first studies to use GPS measurements in the evaluation of traffic safety measures in the primary school environment. At the same time, the combination of GPS and accelerometry provided a number of methodological challenges, most important of which was the loss of data and participants during the course of the study: analysis of wear time showed that at both follow-up time points children recorded significantly less minutes per day than at baseline. As wear time decreased, the number of valid weekdays per child also decreased compared to baseline. Future studies are encouraged to explore ways to increase participant adherence during the course of the study, for example by using GPS wrist watches instead of wearing the GPS device on the hip.

In order to prevent a further loss of participants, a relatively liberal 6 hours of combined GPS and accelerometer data was chosen as being a valid weekday [39]. To compensate for this, total weekday analyses were adjusted for daily wear time. The focus on weekdays was chosen because infrastructural changes were only made in the direct school environment, so it was expected that changes would be more likely to occur during weekdays instead of weekend days. Other
methodological challenges concerning the use of accelerometers included the fairly arbitrary choice of cut points, and the accelerometer’s reduced ability to detect children’s PA during cycling [39,40].

Finally, as previously mentioned, there was some heterogeneity in the manner the intervention was executed. Ideally, all relevant stakeholders, i.e., the municipality, the school board, children, parents and local residents, should be involved in the design process of the Schoolzone, but the degree to which this happened was different within and between municipalities. Another challenge during this research was the timing of measurements after Schoolzone construction. Although all Schoolzones were scheduled to be constructed in 2014, some were constructed a year later than planned in the summer of 2015 (Hilversum, The Hague). Moreover, a delay in construction of the Schoolzone in Zaanstad meant that this school was eventually included as an extra school in the control condition, as it did not receive any infrastructural changes during the course of the study.

Conclusions

This natural experiment is one of the first studies that used a combination of GPS and accelerometer data to investigate the longitudinal effect of infrastructural changes to increase traffic safety around primary schools (‘Schoolzone’) on children’s daily PA levels. In this study neither a significant effect was found of infrastructural changes to increase traffic safety around primary schools on total day MVPA, nor on MVPA recorded in the school environment. However, this does not mean that urban planners should not consider these type of interventions as they still might have other beneficial effects, e.g., increasing (perceived) traffic safety and accident prevention.
References


[18] TNO. URBIS. Available at: https://www.tno.nl/urbis.


Chapter 7
Implementing infrastructural changes to promote children’s physical activity: a process evaluation of the ‘Schoolzone’ natural experiment

Submitted
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Evert Verhagen
Frank H Pierik
Willem van Mechelen
Luuk Engbers
Abstract

Background
The objectives of this study were: to investigate the barriers and facilitators of the adoption, implementation and continuation of environmental changes in the vicinity of primary schools, intended to increase children’s daily physical activity (PA) levels, and; to provide insight into the degree of successful implementation of the environmental changes made in the ‘Schoolzones’ natural experiment.

Methods
The ‘Schoolzone’ natural experiment employed a pretest-posttest design, in which intervention schools where environmental changes were made, were compared with matching control schools. Barriers and facilitators were evaluated through semi-structured interviews that were held with municipality employees (n=5) and school principals of the intervention schools (n=5). Subsequently, interviews were coded and grouped into similar concepts, and then presented into three categories: (i) innovation characteristics; (ii) school characteristics, and; (iii) organizational and socio-political characteristics. Additionally, to investigate key process outcomes related to successful implementation, parents (n=136) completed a pre- and postintervention questionnaire, measuring level of agreement with statements on reach, perceived effect and satisfaction with the intervention. Differences between pre- and postintervention statements on traffic safety perception were compared with a Wilcoxon Signed Rank test.

Results
Barriers and facilitators were identified for: (i) innovation (e.g. amount of environmental changes, uniformity and recognizability of ‘Schoolzone’ design); (ii) school (e.g. high workload, lack of parental engagement), and; (iii) organization/sociopolitical characteristics (e.g. staff turnover, lack of policy ‘Schoolzone’).
Of all parents, 88% were aware of environmental changes in the school environment. Post-intervention, more parents agreed that it was safe to cycle to school (Z=4.063, p<0.001) and safe to walk to school (Z=2.846, p<0.01), that the speed of traffic around school was reduced (Z=3.115, p<0.01), and that there were possibilities to safely cross the street in the school environment (Z=2.74, p<0.01). Postintervention, a majority of parents (68.9%) were satisfied with the ‘Schoolzone’ that was constructed, but only one third of the parents (33.6%) were satisfied with solutions that attempted to reduce the amount of traffic during school opening and closing hours.

Conclusion
Implementing environmental changes at primary schools should be part of a multi-component strategy for promoting active transportation and children’s physical activity. Effective communication with stakeholders, engaging parents and children, and an educational program focused on improving children’s cycling behavior should be an essential part of such a strategy.
Background

The importance of physical activity (PA) promotion in youth as a public health and disease prevention strategy has been well established [1,2]. Traffic safety problems in the school environment have been linked to lower physical activity levels in school children [3] and studies have found that parental perceptions of traffic safety could be associated with children’s PA level [4]. This phenomenon may be explained because parental concerns about road safety can be associated with the parental decision to allow their children to use active transportation [5-7]. Also, parental concerns regarding road safety are potential barriers for children’s active free play outdoors [8,9], another source of physical activity. In recent years, parents of primary school children in the Netherlands are increasingly concerned about traffic safety and the increasing intensity of car traffic, especially during school opening and closing hours. As a result, Dutch municipalities have started to construct so-called ‘Schoolzones’ around primary schools. The main goal of these ‘Schoolzones’ is to increase traffic safety in the area around the school. In the ‘Schoolzone’, roads are marked with the text ‘SCHOOL’ along with a traffic sign to make car drivers aware that they are approaching a school. Other infrastructural changes that are made as part of a ‘Schoolzone’ are decided by the municipality, usually after consultation with relevant stakeholders. These changes are tailored to the local situation and can include traffic calming measures, improvement to the sidewalk, additional crossings for pedestrians or cyclists, bicycle facilities and traffic signs. They can also include traffic education programs for parents and children attending the school.

The ‘Schoolzone’ study, on which this paper builds, hypothesized that the construction of a ‘Schoolzone’ could be an effective way to increase the PA level of primary school children [10]. The study consisted of a natural experiment that used a pretest-posttest design with two follow-up measurements, at which the PA level of 9 to 11 year old children attending a school where a ‘Schoolzone’ was constructed (i.e. intervention group) was compared to the PA level of equally-aged children at a school where the built environment remained unchanged (i.e. control group). Contrary to the formulated hypothesis, the construction of ‘Schoolzones’ did not lead to increased PA levels of the children attending these schools[10]. As the study was conducted as a natural experiment, in which the intervention was evaluated under ‘real world’ conditions, the degree of implementation of the intervention may have affected study outcome. Conducting a process evaluation is a way to examine the degree of successful implementation of the Schoolzones in the natural experiment. Moreover, it may also help to identify the key factors that determine why a Schoolzone intervention will be effective or ineffective in increasing traffic safety and could thus influence children’s level of PA.

Consequently, the objective of this study was to investigate barriers and facilitators of the implementation of ‘Schoolzones’ at primary schools in the Netherlands. Moreover, this process evaluation aimed at providing insights into the degree of successful implementation of the constructed ‘Schoolzones’. Based on the results, recommendations can be made to improve the chance of successful
implementation of infrastructural changes around the primary school, thereby possibly increasing future effectiveness of such interventions.

Theoretical Framework
This process evaluation is based on an adapted version of the theoretical framework by Fleuren et al. (see Figure 1) [11]. This framework was originally developed to gain insight in determinants that facilitated or impeded the introduction of innovations in health care. Fleuren et al. proposed that such innovations can entail any idea, practice or object that is perceived as new by the future user [11]. Since the introduction of the framework, it has now successfully been transposed to different contexts: e.g. multiple studies have used the framework to investigate the introduction of PA interventions [12-14]. Similar to these studies, this process evaluation will consider the ‘Schoolzone’ intervention as the innovation that has been introduced. For the introduction of such an innovation (i.e. the ‘Schoolzone’) to be successful, it must go through three different stages of the innovation process as defined by Rogers [15], i.e. adoption, implementation and continuation. In this process evaluation, adoption refers to the amount of schools and the speed with which schools within the municipalities have adopted or declined the ‘Schoolzone’ intervention. Implementation entails the quality of the ‘Schoolzone’ that was constructed, i.e. the level of adherence to ‘Schoolzone’ construction guidelines and the extent to which all elements were implemented. Continuation represents the extent to which infrastructural and additional supporting changes (i.e. financial and educational) that were made for the Schoolzone were maintained [16,17]. Furthermore, each time an innovation (I) is introduced, it is delivered to a user (II) by an organization (III) in a specific socio-political context (IV). Therefore, Fleuren et al. [11] categorized the determinants of the innovation process into four main categories that are each related to the transition from one stage to the next stage of the innovation process (i.e. from adoption to implementation to continuation). Thus, for each of the three stages of the innovation process, four categories of barriers and facilitators were formulated. For this process-evaluation these were defined as follows:

(I) Characteristics of the innovation: the complexity, relevance, clarity of guidelines, and perceived benefit of the ‘Schoolzone’ intervention.

(II) Characteristics of the user: characteristics of the school (i.e. the school board and teachers) adopting the ‘Schoolzone’, such as knowledge, skills, and perceived support.

(III) Characteristics of the organization: characteristics of the municipality delivering the ‘Schoolzone’, such as staff turnover, expertise, procedures of the municipality implementing the Schoolzone intervention.

(IV) Characteristics of the socio-political context: the extent to which the innovation fits existing local and national rules, regulations, and legislations.
Thus, this process-evaluation will investigate the barriers and facilitators for each of the three stages of the innovation process using the above mentioned framework by Fleuren et al. [11] Due to the nature of the Schoolzone intervention there is a great deal of overlap between the categories ‘characteristics of the organization’ and ‘socio-political context’. As a consequence these will be presented together in this process evaluation.

Subsequently, this process-evaluation also aims to investigate the degree of successful implementation of Schoolzones at the schools that participated in the natural experiment [10]. This was done through an evaluation of key process outcomes that are known to be related to successful implementation [12,16,17]: i.e. reach, dose delivered, perceived effect, and satisfaction. This part of the process evaluation focused on parental perception of the changes made in the school environment, as parents are thought to play a pivotal role in children’s active transportation behavior [18]. Therefore the outcomes were defined as follows:

- **Reach** was defined as the extent to which the parents were aware of the intervention.
- **Dose delivered** referred to the amount or proportion of the Schoolzone intervention that was delivered.
- **Perceived effect** referred to the extent to which the Schoolzone intervention was perceived to increase the traffic safety around school.
- **Satisfaction** entails to which degree parents were content with the different components of the Schoolzone intervention.
Methods

Participants and recruitment
Municipality employees in suburban municipalities (i.e., Zaanstad, Haarlemmermeer, Edam-Volendam, Hilversum and The Hague) located in the Randstad, an urban agglomeration in the western part of the Netherlands, were recruited to participate in the study. Municipality employees were then asked to select schools that were to receive a Schoolzone during the Spring or Summer of 2014. School principals of these schools were contacted by e-mail and telephone, and invited for a face-to-face explanatory meeting. When school principals agreed to take part in the study, parents of children (8-11 years old) who had participated in the ‘Schoolzone’ study [10] were asked to participate in this process evaluation and were informed about the study through letters and pamphlets that were handed out by the teachers.

Measurement barriers and facilitators
Semi-structured interviews were used to evaluate barriers and facilitators of the innovation process of Schoolzones at the participating municipalities. Interviews were held with the municipality employees (n=5) responsible for the construction of the Schoolzone and with the school principal of each participating school (n=5). Interviews were all held and recorded digitally by the first author (DD) and took place after the ‘Schoolzone’ construction had been completed (in the period between April 2015 and June 2016). Examples of questions used are: “What was the procedure that was used for the construction of ‘Schoolzone’?”, “Are you satisfied with the construction of the ‘Schoolzone’?”, “How did you experience the co-operation with other stakeholders during ‘Schoolzone’ construction?”, and “What would you recommend other municipalities or schools that want to start ‘Schoolzone’ construction?”. All recorded interviews (n=10) were transcribed verbatim. Subsequently, interviews were coded and grouped into similar concepts, after which a meeting was held with a second researcher (LE) to discuss codes, concepts and interpretation of the data. Facilitators and barriers were then ordered and presented according to the framework of Fleuren et al. [11]

Measurement of process outcomes
To determine the process outcomes reach, perceived effect and satisfaction, parents of the school children who had participated in the ‘Schoolzone’ study [10] were asked to complete a questionnaire before ‘Schoolzone’ construction (pre-intervention) and within 6 months after ‘Schoolzone’ completion (post-intervention). Dose delivered was determined based on information provided by the municipality employees after the interviews. Questions in the questionnaires were answered on a 5-point Likert-scale with answers ranging from 1 (“Totally agree”) to 5 (“Totally Disagree”). Statements in the post-intervention parental questionnaire regarding reach, perceived effect and satisfaction were summarized to provide the percentage of respondents that agreed to the respective statements by answering ‘Agree’ or ‘Totally Agree’, the percentage of neutral responses, and the percentage of respondents that disagreed to the statements by answering ‘Disagree’ or ‘Totally Disagree’ on the 5 point Likert-scale. In addition, pretest
and posttest response to the questions regarding perceived traffic safety were compared using a Wilcoxon Signed Rank test and were visualized using the Likert package [19] in R version 3.3.3.

Results

A full overview of barriers and facilitators that were mentioned in the semi-structured interviews with municipality employees and school principals is presented in Table 1. Highlights of the outcomes are detailed below per each category.

(I) Characteristics of the innovation: the ‘Schoolzone’
Having a plan of action with clearly defined guidelines before the start of the ‘Schoolzone’ construction was mentioned as being beneficial for successful adoption and implementation of ‘Schoolzones’. Beneficial factors for successful implementation were the inclusion of an educational program and the number of infrastructural changes made in the school environment. In addition, municipality employees stressed the importance of using a uniform approach at all schools throughout the area to ensure that ‘Schoolzones’ are easily recognized by traffic users. Although the use of (primary) colors in the ‘Schoolzone’ design increases its visibility and recognizability for car drivers, excessive use of colors in the ‘Schoolzone’ design led to complaints of residents living in the ‘Schoolzone’ area and had a negative impact on adoption.

Hampering factors for successful implementation were the lack of a legal status of the ‘Schoolzone’ and the absence of traffic laws associated with the ‘Schoolzone’. For instance, there are no national laws for speed limits in the ‘Schoolzone’ area. Also, the so-called Kiss&Ride areas that were sometimes used in the ‘Schoolzone’ have no official status, which makes it difficult for police or other law enforcement officers to enforce the correct use of these areas and to prevent that cars are being parked in the ‘Schoolzone’ for a longer duration. A barrier to the successful implementation and continuation of the ‘Schoolzone’ was the limited visibility of the effectiveness of the ‘Schoolzone’, as most municipalities did not include a structured evaluation program after the ‘Schoolzone’ was constructed.

(II) Characteristics of the user: School
Highly motivated parents and teachers and a strong commitment of parents and teachers to educational programs were viewed as being beneficial factors for ‘Schoolzone’ adoption, by both municipality employees as well as school principals. Encouraging parents to use active transportation was viewed as an effective way to decrease traffic intensity in the school environment, e.g., by involving children to motivate parents to use active transportation. On the other hand, municipality employees reported that they had noticed that some schools were hesitant to start the process of ‘Schoolzone’ construction, because of the already high workloads at school. This is reflected in the lack of perceived time for schools to be involved in the design process, as reported by school principals.
Furthermore, creating high expectations of the infrastructural changes at the start of the project was conceived of as a barrier for successful implementation, as it had a high chance of leaving parents and teachers disappointed and thus demotivated to actively contribute to a safe school environment.

(III & IV) Characteristics of the organization and socio-political context: Municipality
During all three stages of the innovation process, effective communication within and between municipality departments involved in the development of the ‘Schoolzone’ was perceived as being a facilitating factor for successful implementation. Also, broad political and organizational support, e.g. in the form of sufficient financial resources was an important beneficial contributor to successful ‘Schoolzone’ implementation. Moreover, all municipality employees emphasized the importance of incorporating feedback of local residents into the ‘Schoolzone’ design in order to gain the support of residents living in the ‘Schoolzone’ area and to prevent complaint procedures afterwards. Another strategy used by municipality employees was to address complex traffic situations in the school area in separate projects, to prevent unnecessary delays of the ‘Schoolzone’ construction project. Limited law enforcement availability and staff turnover at the municipality were also seen of as a barrier for successful implementation.
Table 1. Barriers and facilitators of the ‘Schoolzone’ innovation process, as identified from semi-structured interviews with municipality employees and school principals.

<table>
<thead>
<tr>
<th>Schoolzone characteristics</th>
<th>Facilitators</th>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adoption</strong></td>
<td>Formulating clear defined guidelines before the start of Schoolzone construction</td>
<td>Lack of national guidelines for Schoolzone construction</td>
</tr>
<tr>
<td></td>
<td>Creating Schoolzones that are fitting with history and aesthetics of the city (e.g. no excessive use of colors)</td>
<td>No standards in the use of traffic signs within a school zone</td>
</tr>
<tr>
<td></td>
<td>Infrastructural changes that require a traffic decree can delay or prevent schoolzone construction</td>
<td></td>
</tr>
<tr>
<td><strong>Implementation</strong></td>
<td>Uniformity and recognizability of Schoolzones within the same municipality</td>
<td>Lack of official legal status and/or traffic laws in the Schoolzone area</td>
</tr>
<tr>
<td></td>
<td>Implementing an educational program in addition to infrastructural changes</td>
<td>Focus of Schoolzones on infrastructural changes in school environment; not looking at school routes outside school environment</td>
</tr>
<tr>
<td></td>
<td>Amount of infrastructural changes (e.g. safe crossings, speed bumps, speed limits)</td>
<td>Emergency services may need main roads near school, limiting infrastructural changes on these school routes</td>
</tr>
<tr>
<td><strong>Continuation</strong></td>
<td>Limited visibility of Schoolzone effects because of lack in evaluation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>School characteristics</th>
<th>Facilitators</th>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adoption</strong></td>
<td>Presence of highly motivated school principle and/or parents</td>
<td>Residents complaining about car parking problems in the school area</td>
</tr>
<tr>
<td></td>
<td>High workloads at school; causing a lack in perceived time for schools to complete tasks asked in Schoolzone preparation</td>
<td>High workloads at school; causing a lack in perceived time for schools to complete tasks asked in Schoolzone preparation</td>
</tr>
<tr>
<td><strong>Implementation</strong></td>
<td>High commitment of teachers and parents to educational programs</td>
<td>Lack of available parental volunteers (e.g. as crossing guard)</td>
</tr>
<tr>
<td></td>
<td>Involvement of children to motivate parents to use active transportation</td>
<td>Creating high expectations causes disappointed and/or demotivated parents and schools</td>
</tr>
<tr>
<td></td>
<td>Presence of active neighborhood councils that formulate needs of local residents</td>
<td></td>
</tr>
<tr>
<td><strong>Continuation</strong></td>
<td>Involvement of parents and teachers to promote safe school environment</td>
<td>Changes in school staff and/or school principal leaving during the project</td>
</tr>
<tr>
<td></td>
<td>Active parents leaving school after school year has finished</td>
<td></td>
</tr>
</tbody>
</table>
Process outcomes

Reach, Dose Delivered, Perceived Effect and Satisfaction

Out of the 208 parents who were approached on the intervention schools, 65.4% (n=136) returned the post-intervention questionnaire. Results are presented in Table 2, which shows that most of the parents were aware of the new ‘Schoolzone’ that was constructed at the school of their child (88.1%). A small majority of the parents that had completed the questionnaire (58.2%) reported that they believed that the ‘Schoolzone’ was effective in increasing traffic safety in the area around the school and most parents were satisfied with the ‘Schoolzone’ that had been constructed (68.9%). After ‘Schoolzone’ completion, 73% of the parents believed that it was safe to walk to school for their child, while 56% believed it was also safe to cycle to school (See Figure 2). The Wilcoxon Signed-ranks test indicated that compared to pre-intervention, post-intervention parents were more in agreement with the statements that it was safe to cycle to school (Z=4.063, p<0.001), safe to walk to school (Z=2.846, p<0.01), speed of traffic around school was slow (Z=3.115, p<0.01), and that there were possibilities to safely cross the street in the school environment (Z=2.74, p<0.01). No significant differences were found for amount of traffic (Z=1.189, p=0.23) and drivers exceeding the speed limit (Z=−0.578, p=0.56) in the school environment. Figure 1 shows a visualization of the Likert scale responses on the questions regarding perceived traffic safety, comparing the pre-intervention responses with post-intervention responses. Finally, Table 3 shows the different elements that were included in the ‘Schoolzone’ designs at the five participating schools in the current study i.e., the dose delivered.
### Table 2. Process outcomes based on parent questionnaire after Schoolzone construction

<table>
<thead>
<tr>
<th>Reach</th>
<th>Total (n)</th>
<th>N parents disagree (%)</th>
<th>N parents neutral (%)</th>
<th>N parents agree (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you agree with the following statements…</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am aware that a Schoolzone was constructed around the school of my child</td>
<td>135</td>
<td>4 (2.9%)</td>
<td>12 (8.9%)</td>
<td>119 (88.1%)</td>
</tr>
<tr>
<td>I have seen the measures that are taken around the school of my child</td>
<td>134</td>
<td>5 (3.7%)</td>
<td>22 (16.4%)</td>
<td>107 (79.9%)</td>
</tr>
<tr>
<td>The Schoolzone is recognizable to all traffic users</td>
<td>135</td>
<td>16 (11.8%)</td>
<td>31 (22.9%)</td>
<td>88 (65.2%)</td>
</tr>
<tr>
<td>Perceived effect on traffic safety around school</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic safety around school has improved because of the Schoolzone</td>
<td>134</td>
<td>15 (11.2%)</td>
<td>41 (30.5%)</td>
<td>78 (58.2%)</td>
</tr>
<tr>
<td>Schoolzone satisfaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are you satisfied with..</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Schoolzone that was constructed</td>
<td>135</td>
<td>11 (8.1%)</td>
<td>31 (22.9%)</td>
<td>93 (68.9%)</td>
</tr>
<tr>
<td>Measures to limit traffic speed in the Schoolzone</td>
<td>134</td>
<td>19 (14.2%)</td>
<td>37 (27.6%)</td>
<td>78 (58.2%)</td>
</tr>
<tr>
<td>Possibilities to safely cross the street in the Schoolzone</td>
<td>133</td>
<td>20 (15.0%)</td>
<td>36 (27.1%)</td>
<td>77 (57.9%)</td>
</tr>
<tr>
<td>Possibilities to park your car in the Schoolzone</td>
<td>134</td>
<td>37 (27.6%)</td>
<td>41 (30.6%)</td>
<td>56 (41.8%)</td>
</tr>
<tr>
<td>Solutions for amount of traffic during school opening and closing hours</td>
<td>134</td>
<td>36 (26.9%)</td>
<td>53 (39.6%)</td>
<td>45 (33.6%)</td>
</tr>
<tr>
<td>Do you agree with the following statements…</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would have liked to be more involved in the construction of the Schoolzone</td>
<td>136</td>
<td>49 (36.0%)</td>
<td>63 (46.3%)</td>
<td>24 (17.6%)</td>
</tr>
<tr>
<td>My child should have been more involved in the construction of the Schoolzone</td>
<td>134</td>
<td>42 (31.3%)</td>
<td>63 (47.0%)</td>
<td>29 (21.6%)</td>
</tr>
</tbody>
</table>

### Table 3. Dose delivered, elements of Schoolzone design at the participating schools

<table>
<thead>
<tr>
<th></th>
<th>Zaanstad</th>
<th>Haarlemmermeer</th>
<th>Edam-Volendam</th>
<th>The Hague</th>
<th>Hilversum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry roads marked with the text ‘SCHOOL’</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Traffic speed calming infrastructure (e.g. speed humps, road narrowing)</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Sidewalk improvements</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycling path</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facilities for crossing busy road (e.g. zebra-striped crossing, traffic light)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Educational program at school</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Kiss&amp;Ride zone</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playground markings on sidewalks</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Comparison of pre-intervention vs. post-intervention parental response to statements regarding traffic safety in the school environment.

**Wilcoxon Signed-ranks test indicated a significant difference (p<0.05) in level of agreement with the statement, pre-intervention compared to post-intervention.**
Discussion

The main objective of the current study was to gain insight into facilitators and barriers of the adoption, implementation and continuation of ‘Schoolzones’ at primary schools in the Netherlands. Moreover, the process outcomes of reach, dose delivered, perceived effect and satisfaction related to the constructed ‘Schoolzones’ were presented to evaluate whether the ‘Schoolzones’ in the study [10] were successfully implemented.

Facilitators and barriers

One of the key facilitators for successful implementation mentioned was the uniform design and recognizability of the ‘Schoolzone’ area for traffic users. In the current study 65% of parents thought that the ‘Schoolzone’ was recognizable to all traffic users. To improve this perceived recognizability, it is important that municipalities formulate a plan of action with clearly defined guidelines describing what the ‘Schoolzone’ will look like, before the adoption process starts. Currently there are no national guidelines or laws that state how the ‘Schoolzone’ needs to be designed, which means that there is a large variation in ‘Schoolzone’ design between and within municipalities.

National guidelines and an official legal status of the ‘Schoolzone’ may also be necessary to improve homogeneity of ‘Schoolzones’ throughout all municipalities in the Netherlands. A recent US study illustrated that such state laws, which were designed to increase traffic safety in the school environment, may be able to reduce barriers for active transportation to school [20]. For example, requirements for speed zones in the school area were found to be associated with a higher chance of children using active transportation to school [20]. Furthermore, they found that when state laws required crossing guards near a school, they were especially effective in reducing barriers for active transportation.

An important barrier for successful implementation was the high workload at the schools, which is consistent with literature in which competing responsibilities have been reported as one of the strongest barriers of program implementation at schools [22].

Lack in parental engagement is also frequently reported as a barrier for school-based interventions [21]. Schools in the current study also reported that they struggled with engaging parents, for example, to volunteer as a crossing guard. Motivating parents and teachers was one of the most important challenges for successful ‘Schoolzone’ implementation.

Moreover, a lack of community involvement has been identified as an important barrier for environmental- or policy-related changes. A similar study in Texas, USA, which also investigated the implementation of a ‘safe route to school’ program, concluded that the biggest challenges for completing such projects lies in efficient communication and navigating approval processes and policies at the local and/or state level [23]. Municipalities are thus strongly advised to employ effective communication strategies with local residents and schools before starting to
implement environmental changes, e.g., by organizing community meetings to ask feedback from all of the stakeholders that are involved and to provide schools with adequate information materials regarding possible (infrastructural and educational) changes in the school environment.

**Process outcomes in the ‘Schoolzone’ natural experiment**

Effective interventions aim to reach as many participants as possible [16]. Thus, for the ‘Schoolzone’ to be effective, it was crucial that parents knew about the environmental changes that were made around the school building. This seems to be the case, as around 88% of parents answered that they were aware of the environmental alterations in the school area, whereas 80% of the parents also indicated that they had seen the changes themselves.

Around 60% of parents thought the ‘Schoolzone’ succeeded in increasing traffic safety around the school building. Compared to the start of the study, parents were significantly more in agreement with statements that it was safe to cycle to school, safe to walk to school, speed of traffic around school was slow, and that there were possibilities to safely cross the street in the school environment. After the intervention, 73% parents thought it was safe to walk to school for their child, whereas before the intervention this was 64%. That a majority of parents already thought it was safe to walk may also be explained by the high quality of the pedestrian infrastructure in the Netherlands [24]. Presence and quality of sidewalks are significant predictors of neighborhood walkability [25]. Surprisingly, despite a significant increase after ‘Schoolzone’ construction, only around half of the parents in this study reported that it was safe for their child to cycle to school. Although it might be tempting to think that the use of protective gear, such as safety helmets, could decrease such safety concerns by parents, cycling experts and planners from the Netherlands suggest that this is a counter-productive measure. Safety helmets can give cyclists a false sense of security, thereby encouraging them and other traffic users to engage in riskier behavior [26]. Moreover, they believe that part the success of cycling in the countries such as Denmark, Germany and the Netherlands is that cycling is made as convenient and attractive as possible. Still, the low percentage of parents that thought that it was safe for their child to cycle to school is worrying, as most of the children in the study were in their final year of primary school and would soon attend high school. High schools in the Netherlands are typically located further away from home, requiring more of the children to cycle to school. The transition from primary to high school is thus a crucial phase, in which children need to be encouraged to use active transportation. Many primary schools in the Netherlands now do include a cycling exam at the end of the curriculum to ensure children know how to cycle to their new school.

Furthermore, one of the main reasons that ‘Schoolzones’ are being constructed is parental concern about traffic intensity during school opening and closing hours. Unfortunately, the construction of the Schoolzone did not have a significant effect on how parents viewed traffic congestion in the school environment (see also Figure 1). Also questions regarding parental satisfaction showed that there is room
for improvement in this regard, as only 33.6% of parents was satisfied about this aspect of the new school environment.

Finally, although traffic safety in the school environment may be associated with a higher percentage of active transportation to school [5-7], other factors also play a role in this regard. For instance, McDonald [27] showed that 75% of parents driving their children less than 2 miles to school said they did this for convenience and to save time. This needs to be addressed in order for parents to change their transport behavior. Thus, promotion of physical activity and active transportation to school almost always requires a multi-component strategy [4,28]. When implementing environmental changes to the school environment, it is crucial to combine this with an educational program aimed at changing parental behavior.

**Strengths and limitations**
Interventions need to consider the context in which they are executed, i.e., the larger physical, social and political environment in which they take place [16]. Process evaluations are a way to take this context into account. A major strength of this study is that it conducted a process evaluation with the use of the theoretical framework of Fleuren et al. [11], which has previously been used in other process evaluations in the school context, making results comparable to these and future studies [12-14]. However, a limitation is that the current study interviews were held with school principals only at schools that had participated in the Schoolzone project. This small sample of schools (n=5) participating in the study means that results may not be representative for other countries, but most of the findings will certainly be applicable to other municipalities in the Netherlands. Also, there was a large degree of variation in the way that municipalities made alterations to school environments, partly because there currently are no national guidelines or regulations regarding ‘Schoolzone’ design.

**Conclusions**
Uniform design and therefore the recognizability of the school area for traffic users were perceived to be especially important for successful ‘Schoolzone’ implementation. National guidelines may further contribute to increased homogeneity of ‘Schoolzone’ design throughout the Netherlands. Moreover, although the environmental changes in the ‘Schoolzone’ study did succeed in improving parental perception of traffic safety in the school environment, they did not have a significant effect on traffic congestion in the school environment. Implementing such environmental changes should be part of a multi-component strategy for promoting active transportation. Effective communication with stakeholders, engaging parents and children, and an education program focused on improving children’s cycling behavior should be an essential part of this strategy.
Chapter 7

References


Chapter 8

General Discussion

Given the small number of children that currently adhere to the physical activity (PA) guidelines [1-3], it is important to develop effective interventions that promote children’s PA. To achieve this, there is a need to examine how, when and where children accumulate time as moderate-to-vigorous physical activity (MVPA) to meet the recommended daily levels of PA. With the emergence of novel methods of PA assessment, i.e., combining GPS and accelerometer data, it is now possible to examine the intensity and location of PA with much greater precision. Out of the important physical environment settings in which children are expected to accumulate minutes of MVPA, i.e. public roads, streets, the school environment, and children’s home environment [4], the school environment is an especially interesting setting for interventions. It provides the opportunity to reach a high proportion of children with diverse sociodemographic backgrounds, as most children spend a substantial proportion of their time in and around the school [5]. Thus, the aim of this thesis was to use GPS and accelerometer data: (1) to gain a better understanding of children’s PA in and around the school environment; (2) to investigate children’s active transportation on the journey between home and school, and; (3) to evaluate the effect of infrastructural traffic safety changes in the school environment on children’s PA levels.

Main findings

Children’s PA in and around the school environment
Chapter 2 described how long and at what intensity children are physically active on the schoolyard during different time segments of the day. The contribution of schoolyard physical activity towards achieving the recommended guideline for daily PA was also described in this chapter. On average, children spent around 40 minutes per day on the schoolyard. The highest intensities of PA on the schoolyard were recorded during school recess periods, in which boys recorded 39.4% of their total time on the schoolyard as MVPA. Girls were significantly less physically active during this segment of the day, 23.4% of their time on the schoolyard was defined as MVPA during recess. Although children were present only on the schoolyard for 6.1% of the total recorded time, this time contributed towards 17.5% and 16.8% of boys' and girls' minutes of MVPA. In contrast, children were practically physically inactive when they were inside the school building; only 2-3% of their time inside school was spent as MVPA. These results suggest that the schoolyard, especially during school recess, should be regarded as an important setting for accruing minutes of MVPA.

Children’s active transportation between home and school
With regard to the second aim of this thesis, chapters 3, 4 and 5 investigated children’s active transportation on the journey to school. This was done by analyzing the trips from home to school that were extracted from the GPS data. A majority, i.e. around 80%, of the home-school trips that were recorded in the studies, was classified as ‘active transportation’. Chapter 3 and 4 showed that larger amounts of motorized transport were observed, with increasing distance
of the journey between home and school. Almost all GPS tracks less than 400 meters were defined as active transportation. On the other hand, out of the tracks above 900 meters more than half was commuted passively. Moreover, parental perception of slow traffic speed in the school environment was shown to be positively associated with walking between home and school. Also, children were less likely to cycle on the school journey with higher amounts of car parking facilities in the school environment. Chapter 5 focused on children's route choice to determine environmental characteristics of active transportation routes. This was done by comparing actual walking and cycling routes with the GIS-determined shortest route to school. On average, actual walking routes were 5.6 % longer, and actual cycling routes were 10.9 % longer than the corresponding GIS-determined shortest route. During their actual cycling routes, children encountered significantly more traffic lights and these routes contained more junctions with other streets than the shortest route. Furthermore, children who cycled to school avoided streets with a high incidence of accidents. Both on their walking and cycling routes, children preferred residential streets over other type of streets. Most of the findings could be explained by the preference of children (and their parents) to avoid walking or cycling along busy roads on their way to school.

Creating infrastructural changes in the school environment
Chapter 6 presented the results of a natural experiment in which the longitudinal effect was evaluated of infrastructural changes around primary schools ('Schoolzone') on children's daily PA levels. Unfortunately, the infrastructural changes, designed to increase traffic safety in the direct vicinity of the primary school building did neither show a significant effect on children's total accumulated minutes of MVPA per day, nor on the minutes of MVPA per day recorded in the school environment. A possible explanation for the apparent lack of effects is that the percentage of active transportation from and to school in the study population was already high at baseline, more than 80% of trips were classified as active transportation. Finally, chapter 7 investigated barriers and facilitators for creating such infrastructural changes, and showed that a clear plan of action, homogeneous design, recognizability of the school area for traffic users, community involvement and parental engagement were important for successful 'Schoolzone' implementation. Moreover, although the 'Schoolzone' did succeed in improving parental perception of traffic safety in the school environment, the infrastructural changes did not have a significant effect on traffic congestion in the school environment. Based on our results it is fair to state that if environmental changes are implemented with the aim of promoting active transportation, the changes should be part of a multi-component strategy. Effective communication with stakeholders, engaging parents and children, and an education program focused on improving children’s cycling behavior should also be an essential part of such a strategy.
Methodological considerations

This thesis comprised of four cross-sectional studies, a natural experiment and a process evaluation. These studies were based on data collected within two different study samples. Chapters in the thesis are ordered chronologically, the second and third chapter discuss data collected during measurements in 2008 in the Spatial Planning and Children’s Exercise (SPACE) study. The next four chapters discuss data collected from 2014-2016 in the ‘Schoolzone’ study. Methodological considerations regarding study design, generalizability of the findings and measurement methods are discussed below.

Participants and study design
The SPACE study examined the relationship between the built environment and physical activity among school-aged children, using 7-day physical activity diaries. The study was set in five neighborhoods that were due to be (partially) restructured between 2004 and 2008. These neighborhoods were located in five different municipalities with >70,000 residents in the Netherlands, i.e. in Amersfoort, Haarlem, Hengelo, Rotterdam and Vlaardingen. In 2008, from the total of twenty schools involved in the SPACE study, a convenience sample of six primary schools agreed to participate in the studies presented in the current thesis. This resulted in a group of 93 children, 6-11 years old, that was asked to wear GPS and accelerometers in addition to filling in a physical activity diary. As a convenience sample of schools was used to examine this novel method of PA monitoring, this group of participants may have been susceptible to selection bias. Selection bias can occur when participants are selected non-randomly, which may result in a biased study sample that is not representative of the population that is studied. However, outcomes presented in these first two chapters were comparable to the outcomes found in the studies of the second study sample described in the other chapters, e.g., the amount of wear time, the percentage of active transportation on the journey to school, and the amount of MVPA accumulated during the day. This suggests that both study samples were indeed representative for this age group and selection bias has been limited.

The ‘Schoolzone’ study consisted of a natural experiment using a pretest-posttest design with two follow-up measurements. The aim of the study was to investigate the effect of infrastructural changes to increase traffic safety around primary schools. Recruitment of primary schools in the Schoolzone project was done in 5 different suburban municipalities, i.e. in Zaanstad, Haarlemmermeer, Edam-Volendam, Hilversum and The Hague. These cities were all located in the Randstad, an urban agglomeration in the western part of the Netherlands. Schools that were selected by the municipalities to construct a ‘Schoolzone’, and that were designated to receive this intervention during the Spring or Summer of 2014, were invited to participate in the study. This resulted in a group of 463 children, 8-11 years old, out of which 299 children (64.6%) had received consent of their parents to participate in the study. This was one of the first longitudinal experiments investigating the effect of environmental changes on children’s PA with objective methods, i.e. with a combination of accelerometry and GPS. However, most
studies presented in the thesis were based on cross-sectional data, for example using the baseline measurements of the ‘Schoolzone’ study. Such a cross-sectional study design makes it impossible to demonstrate causal relationships [6]. Moreover, organizing a randomized controlled trial (RCT) is often considered to be the gold standard to reduce bias in effect studies [7]. Unfortunately, such a design can sometimes be difficult to implement in the Public Health setting, and alternative designs are warranted [8]. In the current study, given the nature of the intervention, randomization was not possible. As exposure to the event, or intervention of interest, was not manipulated by the researchers, the design is then considered to be a natural experiment [9]. Assignment of schools to either the intervention or control condition is non-random in such a design, and thus more susceptible to bias. One way to deal with this is to find matching unexposed clusters of individuals which are similar to those receiving the intervention, and compare outcomes in the two groups [9]. In the ‘Schoolzone’ study this was achieved by matching intervention schools with control schools based on geographical location, degree of urbanization, child demographics, and neighborhood characteristics.

**Generalizability of the findings**

Generalizability of the findings refers to the extent to which results can be generalized to other people, contexts or situations [10]. The studies presented in this thesis took place in suburban municipalities in the Netherlands. The Netherlands has a unique cycling culture [11]: in the past decades the Netherlands has invested in policies and infrastructure to make bicycling a safe, convenient and practical way to navigate its cities [12]. The Netherlands also is a densely populated country. Most of the participating children lived relatively close to school, i.e. within a straight-line distance of 1 kilometer. Short distance between home and school has consistently been shown to be correlated with active transport behavior [13-15]. Thus, given the unique Dutch cycling culture, the high quality of the traffic infrastructure, and the relative small distances between home and school, it is likely that the effect of infrastructural changes to increase the traffic safety in the school environment may have had limited added effect. Safe-route-to-school-interventions may be more effective in stimulating active transportation and children’s PA in countries where the percentage of active transportation is much lower (such as the U.S., Great Britain, Australia [16-18]). In addition, this thesis focused on children in the later stage of primary school, aged 8-12 years old. As children age, both their independency and cycling skills improve, making it more likely that they will use active transportation on their journey to school. Moreover, other studies have already shown that there is strong seasonal variation in children’s PA levels and active transportation behavior [19,20]. Although some of the measurements were done in the Winter, most of the measurements took place in the Spring. These phenomena were reflected in the percentage of active transportation trips that was detected in both study populations (see also chapter 3 & chapter 4). Percentages of active transportation and children’s PA levels may be different for children in younger age groups or in other seasons.
Moreover, the use of GPS influenced the type of consent procedure that was needed for the ‘Schoolzone’ study. Participation rates have been shown to drop considerably when parents need to actively approve participation by giving active consent, and this in turn may hamper validity and generalizability of the research results in question [21]. Consequently, similar studies investigating children’s physical activity with accelerometers and GPS have also used passive consent procedures to recruit participants [5,22]. Passive consent can be considered as a viable option when studying children in this age category, i.e. 8-12 years old, but only in case of minimal risk for participants, back-up procedures to reach parents, and appropriate privacy safeguard measures [21]. However, with the use of GPS it is always possible to identify the location of residence of the participants. Thus, anonymity of participants cannot be guaranteed: researchers will always be able to derive the participant’s identity with the location of residence. As a consequence, careful reconsideration of the ‘Schoolzone’ research protocol ultimately resulted in a replacement of the passive informed consent procedure with an active informed consent procedure, leading to a participation rate of 64.6%. Although such a participation rate may hamper generalizability of the results, it is very similar to other studies using a comparable active consent procedure. For example, the Dutch ‘Active Living’ study also used active consent to carry out accelerometer recordings and reported a participation rate of 58.9% [23]. The SPEEDY study, that measured physical activity changes among 10-year-old British children over 12 months, reported a response rate of 57% [24].

**GPS & accelerometry measurements**

Besides influencing consent procedures, using GPS and accelerometer devices also had some other practical implications, most important of which were the loss of data and its effect on adherence of participants during the course of the study. An analysis of wear time in the ‘Schoolzone’ study showed that at both follow-up time points children recorded significantly less minutes per day compared to baseline, resulting in less valid weekdays that could be used in the analysis. When using combined GPS and accelerometry, there currently are no standards for the minimum amount of minutes per day and the minimum amount of days to be recorded to acquire sufficient data that can be considered to be representative of an participant’s actual week. In the ‘Schoolzone’ study, children had to record at least 1 weekday with ≥360 minutes of combined GPS and accelerometer data to be included in the study. To correct for this relatively liberal criterion [25], the recorded number of minutes of MVPA per day were adjusted for total wear time. Still, future studies that intend to use accelerometer and GPS technology are encouraged to explore other methods to increase participant adherence. The use of wrist watches or smartphone technology may prove to be a big step forward in this regard.

**Global Positioning Systems**

Enriching accelerometer data with location data is a relatively new and innovative method to assess children’s daily free-living PA. Other technologies include wearable cameras and Radio Frequency Identification, but GPS currently is the most commonly used technology to assess the location of PA [26]. Since its first
introduction in 1997, the number of publications on the use of GPS to derive locations of PA has exponentially grown [26]. The use of smartphone technology has a lot of potential for future research [27], but out of the current GPS devices available, the GPS receiver used in studies in this thesis (i.e. Travel recorder X, BT-Q1000X, QStarz International Co) was the most popular for monitoring daily PA. Still, there are several methodological challenges and limitations associated with the use of GPS that need to be addressed.

One of the challenges in the current study was that memory and battery life of the GPS receivers were limited. Parents had to be asked to recharge the GPS receivers during the evening, when the children were asleep. To limit data loss, parents were handed a manual along with the receiver in which they could read back instructions. Despite these measures, the majority of the children still did not record GPS data for the full week that they were carrying the devices. Moreover, given the memory storage capacity of the GPS receiver, the geographical location could only be logged every 5 seconds, unlike the accelerometer which recorded PA with a frequency of 30 Hz. It is inevitable that technological improvements in both battery life as well as memory storage capacity will reduce future data loss caused by these phenomena. However, this might also present some new challenges, such as the larger size and amount of data files.

Furthermore, the receiver was able to record the geographical location with a positional accuracy of <3 m Circular Error Probability CEP (50%). But, as is the case with most GPS devices, its performance suffered in situations where satellite view was obstructed, e.g., in case of urban canyoning or being indoors. When the new European satellite system (GALILEO) will become publicly available, future studies might be able to increase the accuracy of location positioning with >15% in the case of urban canyoning or recording at locations indoors [28]. One of the major challenges was dealing with such missing, erroneous and/or inaccurate positional data. Depending on the research question, there are many ways to deal with such issues. Some studies simply remove outlier data by using certain cut-off points for recorded speed and/or height, e.g., removing all GPS points with a speed above 105 km/h [4]. Other studies use a circular buffer around common indoor locations to exclude data from the analysis [4], e.g., GPS data points falling within 60 meters of the home location [29], or to classify such data as being indoors [30]. In the papers presented in the current thesis, a cluster detection method was used to define the home and school location, an automated trip detection method was used to detect children’s trips between these locations, and mode of transportation of these trips was defined based on recorded speed and maximum speed recorded [31]. Also, in one of the papers, school class times were manually derived from the GPS data to increase the accuracy when distinguishing between indoor and outdoor PA. This method proved to be very laborious, which is why in the longitudinal effect paper (chapter 6), a buffer size of 100 meter was used to map all PA in the school environment.
Another challenge was in choosing the right buffer size to match the recorded location with environmental characteristics. Buffer sizes potentially influence the result of a geospatial analysis, because aggregated environmental characteristics may be different dependent on the boundaries that are drawn[32]. Besides buffer sizes, there also was a large heterogeneity in methods available to calculate environmental characteristics. There already are multiple ways to represent the amount of green within a certain buffer, for instance with a greenness index, the percentage of green along the route, or distinguishing between types of green [4]. Such ambiguities in GPS data handling make it difficult to compare results between studies. Unfortunately, as the field of GPS monitoring in PA research is in its relative infancy, there are currently no standard methods available for processing GPS data in children’s PA research [4,33]. Such standards need to be developed for definitions of environmental characteristics, but also for the minimum amount of minutes per day and the minimum amount of days to be recorded to acquire sufficient data representative of a participant’s actual PA.

**Accelerometry**

Accelerometers are a way to provide a valid, practical and objective way to assess children’s daily free-living PA [34]. Rapid technological advancements have ensured that devices are now small enough to be relatively easy to wear, without interfering too much with activities during daily life [35]. Moreover, both battery life and memory storage capacities of the devices have greatly improved during the past decades [36]. The studies presented in this thesis, in which PA was assessed with accelerometers (Chapter 2 and Chapter 7), both used the Actigraph GT3X device (ActiGraph LLC, Pensacola, Florida). This device presently is the most commonly used device in scientific research to assess children’s free-living PA [37]. Although accelerometers are considered the current best method to capture children’s free-living PA, the use of these devices also involves some methodological choices and challenges.

A limitation of the way the Actigraph device was used in the current studies, i.e. being worn on the hip, is that upper body activities were not taken into account when estimating energy expenditure. Also, as cycling does not involve any vertical displacement of bodyweight, this activity was very difficult to quantify in terms of MVPA using only accelerometer data. Moreover, vertical accelerations are typically represented in accelerometer output as ‘counts’ with a minute-by-minute time resolution. Children’s PA often encompasses short bursts of spontaneous play, and therefore shows a more intermittent pattern of activity. It is thought that longer epoch lengths of 1-minute, which is commonly used in adults, may mask a proportion of children’s PA and would underestimate their time spent at higher intensities (e.g. time spent as MVPA) [38]. As data needed to be matched with GPS epochs, it was decided that each 5-seconds epoch was considered to contribute to reaching their daily PA requirement.

Furthermore, there are multiple cut-off points available for school-aged children. All of these are obtained from separate calibration studies that each estimate children’s energy expenditure based on their own linear regression model. This
model is then used to define cut-points that convert counts into time recorded as sedentary, light, moderate or vigorous PA. The choice for a certain set of cut points potentially influences the outcome of studies, while the variation in available cut points also complicates comparisons between studies. Based on the review by Trost et al. [34], studies in this thesis used the Evenson cut-off point of >574 counts per 15 second epoch to determine the minutes of MVPA [39]. It should also be noted that these cut points are only referencing to counts from the vertical axis. Children’s PA patterns involve movements in three different planes and are thus thought to be captured by the recordings of all three axes. Unfortunately, for this specific age group (i.e. children between 8-12 years old) calibration studies that used all three different axes were not available.

Today’s possibilities to capture and store larger volumes of raw acceleration data allow further advancements in the analysis methods of accelerometer data. These lie in the use of the information derived from all three axis, but also in the use of other features extracted from the raw accelerometer data. Machine learning approaches, such as neural networks, are already being deployed to develop algorithms that classify the type of activity that is being performed [40]. The shift from a count-based approach that uses regression estimation of energy expenditure to an approach based on activity identification may be a necessary change in order to measure free-living PA more accurately in the future [36]. The combination of accelerometry data with time specific data from other devices, such as GPS or heart rate monitoring[41], may further improve the accuracy when classifying daily activities and estimating energy expenditure. In this regard, the use of smartphone technology and wrist-based wearables, which could potentially integrate all of these data, has a lot of potential to accurately measure and promote PA [42].

Implications for practice

In order to bridge the existing gap between research and practice, it is important to translate research findings into practical implications and develop evidence-based and efficacious interventions [43]. Practical implications of the findings in the different chapters are discussed below.

This thesis confirmed that the school environment is an important setting in which children accumulate at least one third of their total minutes of MVPA per day. Unfortunately, most of the time that children spent inside the school building was sedentary (2-3% of time in MVPA). Besides stressing the importance of PA promotion outside class hours (e.g. by stimulating walking and cycling to school during school recess [44]), these low PA levels inside the school should inspire researchers to come up with innovative ideas to interrupt physical inactivity during class hours (e.g. by in-class physical activity breaks, environmental cues and equipment, such as standing easels [45]). On the schoolyard, school recess was the period during which children spent a relative high percentage of time as MVPA. Interventions on the schoolyard during recess have already been shown
to be a promising method for PA promotion (e.g. [46-48]). The ‘Schoolzone’ study also showed that increased traffic safety did not influence children’s PA levels in the school environment outside school hours. Thus, improving accessibility of the schoolyard outside school hours might not be enough: although all schoolyards in the study were accessible outside school hours, children scarcely used them during these periods. Also, although providing access to a supportive physical environment may be one of the requirements for PA promotion, complementary strategies are necessary to influence individual and social environmental factors [49]. Organizing extracurricular activities, providing schoolyard supervision, and making the schoolyard available for childcare after school hours are examples of such strategies.

In the studies presented in this thesis, walking and cycling to school were the most important modes of transportation on the journey to school. On those walking and cycling routes to school, children seemed to avoid busy roads. Furthermore, children in the study all lived relatively close to the school, but even within this group of children, shorter distances were associated with increased amounts of active transportation. This proportion of active trips as a function of the distance is relevant for urban planning. Based on the findings presented in this thesis, primary schools should be preferably be located within 400 meter from the children’s residence. Parents should thus be encouraged to select a school within close distance of their house, but this could also be achieved with policy changes that encourage children to attend schools in their own neighborhood, for example by assigning children to schools based on their postal code.

This thesis also showed that parental perceptions of low traffic speeds in the school environment were associated with higher odds of walking to school. The ‘Schoolzone’ study confirmed that creating infrastructural changes in the school environment (e.g. zebra crossings, pedestrian signals, traffic calming measures) could successfully alleviate these negative parental perceptions on traffic safety in the school environment. However, parents also drive their children to school for convenience, to save time (e.g. on their way to work), and out of habit [50]. Such factors are not always addressed when municipalities construct ‘Schoolzones’. Based on the study findings, a roadmap was developed for municipalities to aid the implementation of such multi-component strategies [51]. Schools that plan to construct a ‘Schoolzone’ in the near future, and schools that already have constructed a ‘Schoolzone’, could both benefit from this roadmap. Creating and maintaining a safe school environment is an ongoing cyclical process in which active transportation behavior and traffic safety problems in the school environment should evaluated each year.
Directions for future research

At the moment it is difficult to compare studies that have used GPS and/or accelerometer data to map children’s PA. In literature there is a lot of variation in the type of processing methods and data analysis (e.g. type of GIS-variables, amount of minutes to be recorded for a valid day, definition of transportation mode). Although this may also be dependent on the research question that is being investigated, future research is warranted to develop standardized methods for the processing and analysis of combined GPS and accelerometer data. On the other hand, while standardizing methods of data processing is crucial, continuing the development of innovative data processing and measurement methods could also contribute to an increased understanding of children’s PA patterns. For example, visualizing children’s PA patterns through the development of heat maps could reveal important locations of children’s PA. Figure 1 shows
an example of such a heat map. To create this heat map, which was based on baseline measurements in the “Schoolzone” study, all GPS locations of MVPA recordings of children attending the school were grouped together. Subsequently, these were converted to a density plot to highlight the areas where many children recorded time in MVPA. A similar approach could also be applied to different areas (e.g. schoolyard, neighborhood, city or country) or to different groups (e.g. comparing children by age, gender, school class). Alternatively, such heat maps could also be created while using other measuring methods. For example, TNO has developed an algorithm to convert camera images into heat maps to display locations and intensity of children’s PA on the schoolyard [52]. Other devices for ambulatory assessment of PA, such as mobile phone apps, may also be suitable to map the social context of the school environment.

Combining infrastructural changes with other interventions in a more multi-disciplinary approach might be another promising way to promote children’s PA levels. The effects of such an approach are expected to be larger at schools where active transportation rates are low. Moreover, such initiatives should find ways to increase parental engagement, implement educational programs focused on improving children’s cycling abilities, but may also include other environmental changes such as schoolyard renovations. For example, a recent Dutch study showed that elements of social and physical schoolyard design (e.g. type of equipment, teacher supervision, school policy) were associated with increased PA and decreased sedentary behavior [53].

Future research could also focus on other age groups. Studies that were presented in this thesis focused on children in the higher grades of primary school (6-11 years old). Younger children in the earlier stages of primary school are expected to be less independent [54], while older children need to make the transition to high school [55]. The amount of PA accumulated in the school environment, percentage of active transport, and the effect of environmental changes can be expected to be different for these other age groups.
Conclusions

The aim of this thesis was to assess children’s PA levels in the school environment, to investigate children’s active transport behavior, and to examine the effect of infrastructural traffic safety changes in the school environment on children’s PA levels. Although most children participating in the studies used active transportation on their way to school, a majority of the children still did not meet the PA guidelines. Moreover, although the ‘Schoolzones’ succeeded in improving parental perception of traffic safety in the school environment, the infrastructural changes did not have a significant effect on children’s PA levels. To instigate changes in children’s PA behavior, it is essential that environmental changes are part of a multi-component strategy [56]. National and local policy decisions, effective communication with stakeholders, engaging parents and children, and an educational program improving children’s cycling skills should be an essential part of such a strategy. However, given the already high percentage of children that use active transportation on the journey to school, environmental changes in the school environment aimed directly at increasing outdoor free play (such as schoolyard renovations, playground markings, play equipment, playground supervision) may prove to be a more effective method for promoting children’s PA levels in the Netherlands.
Summary

Physically activity is associated with a large number of health benefits, also for school-aged children. Therefore, the World Health Organization (WHO) recommends that children should participate in at least 60 minutes of moderate-to-vigorous physical activity (MVPA) every day. Ideally, this should be combined with strength exercises three times a week. Unfortunately, it seems that only a small proportion of children worldwide meets these recommended levels of physical activity (PA). Thus, insight in children’s PA patterns is warranted in order to develop effective interventions to promote children’s PA. This thesis focused on examining the PA levels of children aged 8-12 years old in the primary school setting. With a novel method, i.e. the combination of GPS and accelerometry the following was investigated: (1) children’s PA on the schoolyard; (2) children’s active transportation on the journey between home and school, and; (3) the effect of infrastructural traffic safety changes in the school environment on children’s PA levels.

Data was collected within two different study samples. The first sample was measured as part of the Spatial Planning and Children’s Exercise (SPACE) study. For this study, children (n=97) were recruited at 6 schools that were located in 5 cities in the Netherlands (>70,000 residents). All children were asked to wear for one week a GPS receiver and an accelerometer. Measurements were conducted between December 2008 and April 2009. The second sample was measured as part of the ‘Schoolzone’ study. This was a natural experiment with a pretest-posttest design and two follow-up measurements. Baseline measurements started in April-June 2014. Follow-up measurements were conducted 6 months and exactly 1 year after baseline. Recruitment of the 11 primary schools in the ‘Schoolzone’ study was done in 5 suburban municipalities located in the Randstad; i.e. an urban agglomeration in the Western part of the Netherlands. This procedure resulted in a group of 463 children, 8-11 years old, out of which 299 children (64.6%) received parental consent to participate in the study. Children in the study were asked to wear a GPS receiver and an accelerometer during all 3 measurement weeks. Parents of the children filled in a questionnaire regarding questions about their neighborhood and changes in the school environment. In addition, semi-structured interviews were held with the school board and municipality employees.

Schoolyard physical activity
Based on GPS and accelerometer recordings in the SPACE study, insight was established in children’s amount of MVPA on the schoolyard and inside the school building. Time on the schoolyard was broken down into different segments of the school day: pre-school, school recess, lunch break and post-school. During an average school day, children recorded 40.1 minutes on the schoolyard. PA levels on the schoolyard were significantly higher than their daily average PA level. Although children were only present on the schoolyard for 6.1% of the total recorded time, this time contributed towards 17.5% and 16.8% of boys’ and girls’ minutes of MVPA. The children were most active on the schoolyard during school
recess, during which boys recorded 39.5% and girls recorded 23.4% of the time as MVPA. Boys were more active on the schoolyard than girls, with 27.3% of their time spent as MVPA compared to 16.7% for girls. Also remarkable are the low numbers of MVPA that were accumulated when children were inside the school. For boys, only 2.1% of time that was recorded inside the school building was spent as MVPA, girls recorded 2.8% of their time inside school as MVPA. Thus, interventions are needed to interrupt this physical inactivity during class hours (e.g. by in-class physical activity breaks, environmental cues and equipment, such as standing easels).

*Children’s active transportation between home and school*

Children’s active transportation on the school journey was examined based on GPS data collected in both the SPACE study and the Schoolzone study. An automated procedure was used to extract GPS trips between home and school. The mode of transport of these trips (i.e., walking, cycling, motorized transport) was then determined using the average and maximum speed of the GPS tracks. First, the SPACE study data was used to explore active transport to school in relation to the distance between home and school. Then, baseline measurements of the Schoolzone study were used to examine the relationship between parental perceptions of the neighborhood and active transport to school. These baseline measurements were also used to investigate route characteristics of children’s active transportation routes.

Out of all school trips that were recorded in the SPACE study (n=812), 79.2% were classified as active transportation. Similar numbers were observed in the baseline measurements of the ‘Schoolzone’, where out of a total of 1,297 school trips 83.0% was classified as active transportation. In both studies, the proportion of walking trips declined significantly with increased school trip distance, whereas the proportion of cycling trips and motorized transport increased. In practice, this proportion of active trips as a function of the distance could be relevant for urban planners involved in decisions where to site schools and residences. Primary schools should preferably be located within 400 meters from the children’s home, since almost no motorized transport was recorded on trip lengths below this distance. Moreover, other environmental characteristics should also be considered. For example, primary schools should not be located near main roads. When parents perceived traffic speed in the school environment to be low, this was associated with higher odds of walking on the school trips. Also, perceptions of car parking availability in the school environment was correlated with fewer cycling trips between home and school.

Route characteristics of children’s active transportation routes were investigated by comparing characteristics of actual walking and cycling school trips with the GIS-derived shortest possible route to school. GPS recorded actual routes were on average 5.6% longer than the shortest routes, but this difference was not significant (p=0.38). Although length of the actual route was comparable to the shortest route, children did not follow the exact same route as the shortest GIS-route. Route characteristics were compared by creating a 25 meter buffer of the
routes. Median overlap between the two buffered routes was 69.3% (interquartile range: 48.8%-86.2%) for cycling routes, and 64% (interquartile range: 33.4%-81.7%) for walking routes. Children mainly traveled through residential areas on their way to school (>80% of the route). Compared to the shortest routes, traffic lights were more often present along the actual routes. Also, percentage of visible surface water along the actual route was higher compared to the shortest routes, and streets with a high occurrence of accidents were less often used during cycling to school. Most of the results of the study seem to suggest that children avoid to walk or cycle along busy roads on their way to school.

**Infrastructural changes in the school environment**

The ‘Schoolzone’ study was one of the first longitudinal experiments to investigate the effect of environmental changes on children’s PA with objective methods, i.e. a combination of accelerometry and GPS. At baseline, children recorded 50.3 (±19.5) minutes of MVPA per school day on average. Out of these minutes, 17.9 (±10.6) minutes were recorded in the school environment (<100 meter from the school building). Overall, both at the control and at the intervention schools, children recorded less minutes of MVPA during follow-up measurements. When corrected for wear time, the difference with baseline measurements was around 7 minutes. Similar declines in PA have been shown in other longitudinal studies; children generally become less physically active when they age. Unfortunately, no significant effects between intervention and control group were found for ‘Schoolzone’ construction on MVPA recorded during the total day, nor on MVPA recorded in the school environment. This apparent lack of effects may be explained partially because of the high percentage of active transportation when the study started. During baseline measurements, more than 80% of school trips was classified as active transportation. Also, the change from a passive to an active consent procedure resulted in a lower participation rate (64.6%) than anticipated at the start of the study. Such a participation rate hampered the power and generalizability of the results, but was comparable to other studies using such an active consent procedure.

Barriers and facilitators of ‘Schoolzone’ implementation were identified for (i) innovation characteristics (e.g. the amount of environmental changes, uniformity and recognizability), (ii) school characteristics (e.g. high workload, lack of parental engagement), and (iii) municipality characteristics (e.g. staff turnover, lack of policy). Moreover, key process outcomes of implementation (reach, perceived effect and satisfaction) were measured using parental questionnaires. A majority of parents (88%) was aware of the environmental changes in the school environment. After the ‘Schoolzone’ was constructed, significantly more parents agreed that it was safe to cycle to school, safe to walk to school, that the speed of traffic around school was reduced, and that there were possibilities to cross the street safely in the school environment. A majority of parents (68.9%) was satisfied with the ‘Schoolzone’ that was constructed, but only one third of the parents (33.6%) was satisfied with solutions that attempted to reduce the amount of traffic during school opening and closing hours.
**Conclusions**

Although most children participating in the studies used active transportation on their way to school, most of the children did not meet the MVPA recommendations by the WHO. On the schoolyard, children’s PA levels were higher than on average over the whole day. PA levels were particularly high during school recess. Furthermore, ‘Schoolzones’ succeeded in improving parental perception of traffic safety in the school environment, but the environmental changes did not result in a higher amount of MVPA recorded by the children. To promote children’s PA, it is crucial that environmental changes are part of a multi-component strategy that includes policy decisions, communication with all stakeholders, strategies to increase parental engagement and a traffic education program focused on children’s cycling skills. However, considering the high percentage of children in the Netherlands that already use active transportation on the journey to school, environmental changes aimed directly at increasing outdoor play (such as schoolyard renovations, playground markings, play equipment, teacher supervision) may be a more effective method for promoting children’s PA in the school environment. Moreover, future research is warranted to develop standardized methods for the processing and analysis of combined GPS and accelerometer data, while continuing the development of innovative data processing and measurement methods to explore children’s PA patterns.
Samenvatting
Samenvatting

Lichamelijk actief zijn heeft een groot aantal gezondheidsvoordelen, ook voor schoolgaande kinderen. De Wereldgezondheidsorganisatie (WHO) beveelt daarom aan dat kinderen elke dag minstens 60 minuten matig-tot-intensief actief zouden moeten bewegen. Ideaal gezien zou dit driemaal per week moeten worden gecombineerd met krachttoefeningen. Helaas lijkt het erop dat slechts een klein deel van de kinderen wereldwijd aan deze aanbevolen richtlijnen voor lichamelijke activiteit voldoet. Juist omdat kinderen veel tijd doorbrengen op en nabij schoolpleinen, kan het veilig inrichten van schoolpleinen en de route daarnaartoe mogelijk bijdragen aan het actief sport- en beweeggedrag van de jeugd. Inzicht in de lichamelijke activiteit van schoolgaande kinderen is dan ook noodzakelijk, zodat effectieve interventies kunnen worden ontwikkeld. Voor dit proefschrift werd daarom als doel gesteld de lichamelijke activiteit van schoolgaande kinderen tussen de 8 en 12 jaar in kaart te brengen. Met nieuwe methodes, dat wil zeggen de combinatie van GPS en versnellingsmeters, werd bij schoolgaande kinderen het volgende onderzocht: (1) de lichamelijke activiteit op het schoolplein (2) het actief vervoer tussen huis en school, en (3) het effect van infrastructurele aanpassingen in de schoolomgeving op lichamelijke activiteit.

Samenvatting

Lichamelijke activiteit op het schoolplein
Allereerst werd op basis van GPS- en versnellingsmeterdata in de SPACE-studie de lichamelijke activiteit van kinderen in de schoolomgeving in kaart gebracht. Daarbij werd onderscheid gemaakt tussen lichamelijke activiteit op het schoolplein en lichamelijke activiteit binnenin het schoolgebouw. Deze tijd op het schoolplein werd daarnaast opgedeeld in verschillende periodes van de schooldag (voor schooltijd, schoolpauze, lunchpauze en na schooltijd). In dit onderzoek waren kinderen gemiddeld 40,1 minuten per dag op het schoolplein aanwezig. Per dag waren kinderen gemiddeld 6,1% van de totale dag aanwezig op het schoolplein, maar deze tijd op het schoolplein droeg bij aan 17,5% en 16,8% van de dagelijkse lichaamsbeweging. Verder waren kinderen op het schoolplein vooral actief tijdens de schoolpauze: jongens bewogen 39,5% van de schoolpauze matig-tot-intensief actief; voor meisjes was dit 23,4% van de tijd. Jongens bewogen dus significant meer op het schoolplein dan meisjes. Dat gold zowel voor de schoolpauze als voor de rest van de dag. Ook opvallend was dat kinderen erg inactief waren wanneer ze zich in het schoolgebouw bevonden. Jongens waren slechts 2,1% van hun tijd in het schoolgebouw lichamelijk actief. Voor meisjes gold dat ze slechts 2,8% van hun tijd in het schoolgebouw matig-tot-intensief actief bewogen. Dit zou aanleiding moeten zijn voor interventies die inactiviteit in de school beperken, bijvoorbeeld door de introductie van beweegpauzes en statafels in de klas.

Actief op weg naar school
Het reisgedrag van kinderen op de route tussen huis en school is onderzocht met behulp van GPS-gegevens die werden verzameld in zowel de SPACE-studie, als in de ‘Schoolzone’ studie. Daarbij werd een geautomatiseerde procedure gebruikt om de GPS-tracks tussen huis en het schoolgebouw te kunnen vaststellen. De wijze van vervoer tijdens deze tracks (dat wil zeggen wandelen, fietsen, gemotoriseerd vervoer) is vervolgens bepaald met behulp van de gemiddelde en maximale snelheden van de GPS-tracks. Allereerst werd data van de SPACE studie gebruikt om de relatie te onderzoeken tussen de afstand-van-huis-naar-school en actief transport. Daarna werden de eerste metingen van de ‘Schoolzone’ studie gebruikt om de relatie te onderzoeken tussen ouderlijke percepties van de buurt en actief vervoer naar school. Data van deze metingen werd ook gebruikt om de routekenmerken te onderzoeken van de actieve transportroutes van kinderen.

Van alle GPS-tracks tussen huis en school in de SPACE studie (n = 812) werd 79,2% geclassificeerd als actief transport. Soortgelijke verhoudingen werden gevonden in de ‘Schoolzone’ data. Daarin werd, van de in totaal 1297 trips tussen huis en school, 83,0% geclassificeerd als actief. In beide studies was het percentage wandeltrips significant lager bij grotere afstanden tussen huis en school; met toenemende afstand steeg ook het aantal fietsroutes en de hoeveelheid gemotoriseerd vervoer. Aangezien bij afstanden onder de 400 meter vrijwel geen gemotoriseerd vervoer werd waargenomen zouden basisscholen bij voorkeur maximaal 400 meter van het ouderlijk huis moeten liggen. Bij zulke beleidsbeslissingen kunnen ook andere omgevingskenmerken worden overwogen. Zo was er een significant verband waarneembaar tussen de snelheid van het
verkeer in de directe schoolomgeving en het aantal kinderen dat lopend naar school komt. Nieuwe basisscholen kunnen dus beter niet in de buurt van de grotere wegen worden gevestigd. Ook was de perceptie van de beschikbaarheid van parkeerplaatsen in de schoolomgeving gecorreleerd met minder fietsgebruik.

Routekenmerken van de actief gebruikte routes van kinderen zijn vervolgens onderzocht door de kenmerken van deze daadwerkelijke wandel- en fietsroutes met de GIS-afgeleide kortst mogelijke route te vergelijken. Werkelijke actief transportroutes waren gemiddeld 5,6% langer dan de kortste routes, maar dit verschil was niet significant (p = 0,38). Routekenmerken konden worden bepaald met behulp van een 25 meter buffer rondom beide routes. De overlap tussen de twee gebufferde routes was 69,3% (interkwartielafstand: 48,8%-86,2%) voor de fietsroutes en 64% (interkwartielafstand: 33,4%-81,7%) voor de wandelroutes. Hoewel de afstand van de werkelijke route vergelijkbaar was met de kortste route, legden kinderen dus niet geheel dezelfde route af als de kortst mogelijke route. Kinderen reisden voornamelijk door woonwijken op weg naar school (> 80% van de route). Daarbij werd gekozen voor routes waar significant meer verkeerslichten aanwezig waren dan op de kortst mogelijke route. Ook het percentage van zichtbaar oppervlaktewater langs de werkelijke route was hoger vergeleken met de kortste routes. Verder werden straten waar veel ongevallen plaatsvonden significant minder vaak gebruikt op fietsroutes. De resultaten van deze studie lijken erop te wijzen dat kinderen drukke wegen vermijden wanneer ze naar school lopen of fietsen.

**Infrastructurele veranderingen in de schoolomgeving**

De ‘Schoolzone’ studie was een van de eerste longitudinale studies die met behulp van de combinatie van accelerometrie en GPS de effecten van omgevingsveranderingen op de lichamelijke activiteit van kinderen PA onderzocht. Bij aanvang van de Schoolzone-studie bewogen deelnemende kinderen gemiddeld 50,3 (±19,5) minuten matig-tot-intensief per dag. Van deze tijd werd 17,9 (±10,6) minuten geregistreerd in de schoolomgeving (<100 meter van het schoolgebouw). Zowel bij de controlescholen als bij de interventiescholen bewogen kinderen minder tijdens de vervolgmetingen. Na corrigeren voor draagtijd was het verschil met de eerste metingen ongeveer 7 minuten. Soortgelijke dalingen in hoeveelheid lichaamsbeweging zijn eerder ook gemeten in andere longitudinale studies, kinderen worden doorgaans minder lichamelijk actief als ze ouder worden. Helaas werden tussen de interventie- en controlegroep geen significante verschillen gevonden in hoeveelheid lichaamsbeweging na het aanleggen van de Schoolzone. Ook werden er geen verschillen gevonden in de hoeveelheid lichaamsbeweging die in de schoolomgeving (<100 meter) werd geregistreerd. Het gebrek aan effect van de interventie op lichaamsbeweging kan gedeeltelijk worden verklaard door het hoge percentage actief transport bij aanvang van de studie. Tijdens de baselinemetingen werden meer dan 80% van de schooltrips al geclassificeerd als actief (wandelen of fietsen). Ook leidde de wijziging van een passieve naar een actieve toestemmingsprocedure tot een lagere deelnamegraad (64,6%) dan verwacht aan het begin van de studie. Deze relatief lage deelnamegraad had een negatief effect op de power.
van de studie en op generaliseerbaarheid van de studiebevindingen, maar is tegelijkertijd zeer vergelijkbaar met andere studies die ook een dergelijke actieve toestemmingsprocedure toepasten.

Belemmerende en bevorderende factoren voor ‘Schoolzone’-implementatie werden geïdentificeerd voor: (i) kenmerken van de innovatie (bijv. de hoeveelheid veranderingen in de omgeving, uniformiteit en herkenbaarheid); (ii) schoolkenmerken (bijv. hoge werkdruk, gebrek aan ouderlijke betrokkenheid) en; (iii) sociaalpolitieke kenmerken (bijv. personeelsveranderingen bij de gemeente, gebrek aan officieel beleid). Belangrijke procesmaten voor implementatie van de interventie (bereik, het waargenomen effect en de tevredenheid) werden gemeten met behulp van de vragenlijsten voor de ouders. De meeste ouders (88%) waren zich bewust van de omgevingsveranderingen die in de schoolomgeving hadden plaatsgevonden. In vergelijking met de vragenlijst ingevuld voor de aanleg, waren ouders na de totstandkoming van de Schoolzone het significant meer eens met de stellingen dat: ‘het veilig was om naar school te lopen’, ‘het veilig was om naar school te fietsen’, ‘de snelheid van het verkeer rond school laag was’, en ‘dat er mogelijkheden waren om de straat veilig over te steken rondom school’. Een meerderheid van de ouders (68.9%) was uiteindelijk tevreden met de aangelegde Schoolzone. Opvallend genoeg was maar één derde van de ouders (33.6%) tevreden met oplossingen om de hoeveelheid verkeer in de schoolomgeving te beperken.

Conclusie
Alhoewel de deelnemende kinderen in het onderzoek vooral actief naar school reisden, voldeed de meerderheid van de kinderen niet aan de beweegrichtlijnen van de WHO. Op het schoolplein waren de kinderen gemiddeld wel actiever dan gedurende de rest van de dag. Vooral tijdens de schoolpauze bewogen kinderen veel op het schoolplein, en dan met name de jongens. Ook werd in het onderzoek gedemonstreerd dat met de aanleg van Schoolzones de ouderlijke perceptie van verkeersveiligheid in de schoolomgeving werd verbeterd. Helaas kon de interventie niet bewerkstelligen dat kinderen daarna significant meer bewogen. Om lichaamsbeweging van kinderen te bevorderen dienen dergelijke omgevingsaanpassingen dan ook onderdeel uit te maken van een meer multifactoriële strategie waarin o.a. beleidsaanpassingen, communicatie met alle belanghebbenden, ouderlijke betrokkenheid en verkeerseducatie gericht op het verbeteren van de fietsvaardigheid allemaal een rol krijgen. Echter, gezien het hoge percentage kinderen in Nederland dat al wandelt of fietst naar school, zijn omgevingsaanpassingen rechtstreeks gericht op het verbeteren van lichamelijke activiteit in de schoolomgeving (zoals renovatie van schoolpleinen, speeltoestellen, markeringen op het schoolplein, toezicht) mogelijk effectievere methodes dan omgevingsaanpassingen gericht op het vergroten van verkeersveiligheid. Toekomstig onderzoek doet er daarnaast goed aan om meer gestandaardiseerde methoden te ontwikkelen voor de verwerking en analyse van gecombineerde GPS- en versnellingsmeterdata. Tegelijkertijd blijft ook de ontwikkeling van nieuwe innovatieve methoden voor de verwerking van deze data noodzakelijk.
About the author
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Dirk Dessing was born on May 30, 1983 in Naarden, the Netherlands. In 2001 he graduated from high school at OSG de Meergronden in Almere, the Netherlands. Afterwards, he became a student at the VU university in Amsterdam, where he completed his bachelor in Human Movement Sciences in 2007.

After a short side-step into the field of Physiotherapy, he chose to extend his academic career at the VU. In 2011 he earned his Master’s degree in Health Sciences in the field of ‘Prevention and Public Health’ (Cum Laude). During the internship at TNO that was part of this study, he became interested in mapping physical activity through the use of GPS and accelerometers.

The research presented in this thesis was part of his doctoral research at the VU and TNO. From 2013 to 2017, he was employed as a PhD candidate at the department of Public & Occupational Health and the Amsterdam Public Health research institute of the VU University Medical Center. During this period he also worked as guest researcher at the department of Child Health at TNO in Leiden, the Netherlands. As a PhD candidate he was under supervision of prof.dr. Willem van Mechelen, prof.dr. Evert Verhagen and dr. Frank Pierik.

Currently, Dirk is pursuing a career as a data scientist. He works at Médecins Sans Frontières (MSF) where he supports the missions in the field by giving insight in data that was collected and maintained at the Amsterdam headquarters.

Besides being a researcher and scientist, he is an avid sports, film and music enthusiast.
Publication list


Submitted:


Dankwoord
Dankwoord

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Lieve Şirvan, seni seviyorum.
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