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Title: Quantification of underestimation of physical activity during cycling to school when using accelerometry

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Abstract

Background Cycling to and from school is an important source of physical activity (PA) in youth but it is not captured by the dominant objective method to quantify PA. The aim of this study was to quantify the underestimation of objectively assessed PA caused by cycling when using accelerometry.

Methods Participants were 20 children aged 11-14 years from a randomized controlled trial performed in 2011. Physical activity was assessed by accelerometry with the addition of heart rate monitoring during cycling to school. Global positioning system (GPS) was used to identify periods of cycling to school.

Results Mean (95% CI) minutes of moderate-to-vigorous physical activity (MVPA) during round-trip commutes was 10.8 (7.1 – 16.6). Each kilometre of cycling meant an underestimation of 9314 (95%CI: 7719 – 11238) counts and 2.7 (95%CI: 2.1 – 3.5) minutes of MVPA. Adjusting for cycling to school increased estimates of MVPA/day by 6.0 (95%CI: 3.8 – 9.6) minutes.

Conclusions Cycling to and from school contribute substantially to levels of MVPA and to mean counts/min in children. This was not collected by accelerometers. Using distance to school in conjunction with self-reported cycling to school may be a simple tool to improve the methodology.

Background

A positive association between active transportation to and from school (ATS) and PA levels is well-documented [1]. Recent studies confirm this association and highlight the importance of distance from home to school [2-4]. This is important as youth PA levels are independently associated with cardiovascular risk factors and the metabolic syndrome [5, 6]. Furthermore both PA and cardiovascular risk show a tendency of tracking into adulthood [7, 8] where these are highly associated with type II diabetes and cardiovascular disease [9].

Children cycling to school have been reported as being less physically active (as assessed by accelerometry) than those walking to school [2, 10, 11] but more active than passive commuters [2, 10]. Differences, however, are not significant. This is contra-intuitive as transportation to school by cycling, but not walking, is associated with higher cardiorespiratory fitness [12, 13] and a better cardiovascular risk factor profile [14] in youth. Two factors are likely to be explanatory in this regard. A low number of cyclists in some populations [1] make it difficult to compare PA levels because of a lack of statistical power. Secondly, as accelerometry is the primary method of objective measurement of PA in children [15] and these instruments are known for their inability to measure PA during cycling when positioned at the hip, results could be caused by a systematic bias in PA measurements.

In recent years cycling has received attention as a health enhancing behaviour [16] and the US and the UK have launched initiatives to increase rates of cycling [17, 18]. This increased focus on cycling means that methods to allow for correction of accelerometer assessments of PA levels of cycling children are warranted. Accelerometry currently offers distinct advantages such as feasibility and ability to differentiate between PA intensity domains but attempts to improve the methodology have been made by combining multiple activity sensors using branched equations and by applying artificial neural networks such as the hidden Markov model[15].

Two studies have combined GPS and accelerometry during ATS in walking children [19, 20] allowing precise estimates of PA during ATS but to date no studies have reported directly measured PA during cycling to school. Employing such an approach, with the addition of a supportive measure of intensity during cycling, PA levels during cycling to school can be assessed. Additionally, underestimation during cycling, when using accelerometry, can be quantified and described as the impact on assessments of PA levels is unknown despite the well-known limitation and widespread use of the methodology. As distance is strongly related to the PA performed by active commuters and distance can be easily assessed using geographic information system (GIS) or GPS [21] this may offer a simple way of improving assessments of PA when using accelerometry.

The aims of this paper are to investigate the extent of underestimation of PA when using accelerometry in children cycling to and from school and quantify implications for assessments of PA

Methods

Study presentation

This study uses data from a randomized controlled trial designed to investigate the effect of a change from passive transportation to school (i.e. car, bus or train) to active transportation to school by cycling (ATSC) in 4-6th grade children on cardiorespiratory fitness (CRF) and the metabolic syndrome. The study took place in the municipality of Odense, Denmark, during spring 2011. Only data from the intervention group is used in this article. Criteria for inclusion were owning a bike and not participating in cycling to school for the last three months. The intervention group were asked to begin daily cycling to and from school during the 8 weeks the intervention lasted. The intervention group consisted of 23 participants of which 20 had data available for this study. All testing was performed at the University of Southern Denmark. Written informed consent was obtained from participants' parent or legal guardian. The study was approved by the regional Ethics Committee. For full information on recruitment and procedures see Østergaard et al [22].

Anthropometry

Prior to initiation of the intervention anthropometric measurements were taken after a small breakfast on site. Height was measured by a stadiometer (SECA, Hamburg, Germany), participants wearing socks or bare feet. Weight was assessed by a 0.1 kg precision scale (Soehnle Professional, Murrhardt, Germany) wearing only shorts and t-shirts.

$\dot{V}O_2$-HR relationship

CRF ($\dot{V}O_2$peak) was assessed using an incremental step test on an electronically braked cycle ergometer (Monark 839 Ergomedic, Varberg, Sweden). Resistance was increased by 40 watts every 2 minutes after a 5 min. warm-up period at 40 watts. The test was terminated at volitional fatigue despite verbal encouragement. Cadence was self determined but recommended between 60-80 rpm. Pulmonary gas exchange was measured with a metabolic cart (Amis2001, Innovision, Odense, Denmark) with epoch set at 15 seconds. The equipment was calibrated between each test and was validated against the Douglas bag method before both measurement periods. The test was deemed maximal if participants fulfilled one of the following criteria in addition to being exhausted as judged subjectively by the test leader: heart rate (HR) ≥185 beats/min or respiratory exchange ratio≥ 0.99 [23]. $\dot{V}O_2$peak was determined as the mean $\dot{V}O_2$ (ml $O_2 \cdot kg^{-1} \cdot min^{-1}$) of the highest measurements during 30 seconds. HR was measured with a heart rate monitor (Polar RS800CX, Kempele, Finland) with epoch set to 1 sec. Maximal HR (HRmax) was defined as the highest value observed. The incremental test was additionally used to create individual $\dot{V}O_2$-HR relationships. Individual equations were generated by linear regression of synchronized $\dot{V}O_2$ and HR data points representing means of 15 seconds. An in-depth description of the establishing of these relationships is included [see additional file 1].

Assessment of physical activity

Participants were instructed to report daily mode of school transportation in a custom made transportation diary, which served as registration of compliance. PA levels beyond cycling were assessed using accelerometry (Actigraph GT3X, Fort Walton Beach, FL, USA) during one week of the intervention (week 5 of the intervention). These assessments are presented as PA levels (counts/min) and as minutes of MVPA/day. Participants were instructed to wear the device at the right hip for 7 consecutive days and received both verbal and written instructions on how to wear the device. Epoch was set to 2 seconds but data was extracted in 1 min epochs. A minimum of three days with minimum 10 hours of recording were required in order to be included in the analysis. Periods lasting longer than 30 minutes of continuous measurements of 0 counts were discarded as non-wear. Data was extracted using customized software (Propero, Odense, Denmark). Only data from the vertical axis was included.

Intensity cut-points for MVPA were based on the age-specific Freedson/Trost equations [24] which uses 4 metabolic equivalents (METs) as the threshold for MVPA.

During accelerometer assessments of PA participants received a GPS logger (Qstarz BT-Q1300S, Qstarz International Inc., Taiwan) and a heart rate monitor (PolarTeam^2, Polar, Kempele, Finland). Participants were instructed to wear the devices during journeys to and from school on one school day. Both devices were set at 5 sec epoch. A letter thoroughly explained each step in setting up and how to wear the instruments. All GPS data were transferred to commercial software (Travel recorder v. 5.0) and corrected for drift using manufacturer software. The GPS was the reference for all data from heart rate monitors. Mean HR of school transportation, if verified by the transportation-diary, was calculated as the mean of the measurements from the first data point when the participants exceeded a speed of 5 km/h when leaving home, to the last data point above 5 km/h when arriving at school. This period was defined as the journey and was the basis of distance and journey minutes.

Propero was used to time-match accelerometer data with the GPS and HR data in one minute epochs. This was done in order to compare mean intensity (represented by counts/min) and minutes of MVPA collected by accelerometers during ATSC with that measured by HR during the same period and thus quantifying the extent of underestimation by accelerometers. Accelerometer results during ATSC are presented as counts/min (ACCcount) and minutes of MVPA (ACCMVPA). The mean HR during ATSC was converted to counts/min (HRcount) using the Freedson/Trost equations [24] and the $\dot{V}O_2$-HR relationships. METs were calculated from mean HR during each minute of ATSC using the individual $\dot{V}O_2$-HR relationships. Thus minutes of MVPA measured by HR (HRMVPA) was determined as each minute of ATSC with a mean HR exceeding 4 METs. METs where found by dividing the $\dot{V}O_2$ of an activity with the resting oxygen uptake (RMR) calculated using the age-specific Schofield equations including height and weight [25]. These equations have been validated against indirect calorimetry and used similarly elsewhere [26]. HRMVPA was the reference for minutes of MVPA during ATSC.

The underestimation of accelerometer assessed PA during per cycled kilometre to school was found by dividing the total underestimation of counts and minutes of MVPA during journeys by the total distance. Where underestimation was available at only one journey (n=11) this value was doubled. In case of GPS data available for only one journey (n=2) time and distance at the other journey were assumed to be identical to the journey with data. Accelerometer assessments of PA are presented in two ways: 1) as conventional estimates (i.e. not adjusted for ATSC) and 2) as accelerometry + underestimated minutes of MVPA and counts/min during ATSC (adjusted MVPA/day and adjusted PA levels). The adjusted values were calculated by multiplying the underestimated minutes of MVPA and counts with the proportion of days the participant cycled to school during assessments of PA (using the transportation diary as reference) and adding this value to the conventional estimate.

Statistics

Assumptions of normality were checked by examining residuals within a qq-plot and by using Shapiro Wilk´s test. Most data from accelerometers were positively skewed and were transformed using the natural logarithm. All skewed data justified assumptions of normality after transformation. Parametric tests were used on transformed data and then presented as exponentiated geometric means with 95% CI (95% CI ratios to the geometrics means). The logarithmic transformations makes data more robust to outliers (i.e. means and confidence intervals) by using the same data, but at a different scale (as is done with standard deviations). The transformed values are however, not as easily interpreted. Therefore, one can present exponentiated (antilogged) values, which are then reported in the original scale. This antilogged value is a geometric mean. Results are shown as mean and standard deviations (SD) and geometric mean with 95% confidence intervals (95% CI) if assumptions of normality where justified in untransformed or log-transformed data, respectively. Observations presented as geometric means are forced from zero to 1 to retain information [27]. If assumptions were justified paired t-test was performed in order to examine whether differences differed significantly from zero. If assumptions were not justified the non-parametric Wilcoxon signed-rank test was used. Associations were investigated using Spearman's rho with confidence intervals (95%) derived after Fischer´s transformation. Effect sizes were calculated using mean difference with the unadjusted SD as shared variance as suggested by Dunlop et al. [28] when dealing with paired designs to avoid overestimating the effect size due to reduced variance in "treatment" groups. We calculated effect sizes on log transformed data. A two-tailed P-value of 0.05 or less was considered statistically significant. Propero results were exported from Excel to STATA IC V.11.0 (STATA Corp, College Station, Texas, USA) where analyses were performed.

Results

Of the 23 participants in the intervention group 3 were excluded. Reasons for excluding were not completing the CRF test (n=1), invalid GPS measurements (n=1) and did not attend school during the intervention (n=1). One participant did not achieve 3 days of valid PA measurements and was not included in analysis of assessments of PA. This report thus includes 20 participants. Baseline characteristics for these participants are shown in table 1. Accelerometers were worn for a mean (SD) of 6.2 (1.3) days. Mean (SD) wear time was 13.5 (0.8) hours.

Table 1 is to be inserted here

.*Active transportation to and from school*

Table 2 shows descriptive results obtained during ATSC. Eighteen participants had GPS data at both journeys. One participant had GPS data to school and one had from school only. Nine participants had HR data at both journeys. Nine participants had HR data to school and 2 had HR data from school only.

Table 2 is to be inserted here

The geometric mean duration of journeys were 7.2 and 8.0 minutes while the geometric mean HRMVPA during these were 5.7 and 5.9 minutes, to and from school respectively. The mean (95% CI) proportion of MVPA during journeys was 76% (64-87%). Significant differences in HRcount and METs were found between journeys ($p<0.01$ and<0.01, respectively) among the 9 participants with GPS and HR at both journeys. No significant differences between journeys were found for journey duration ($p=0.19$) or HRMVPA ($p=0.54$) but journeys from school took almost a minute longer.

There were no differences in ACCcounts between journeys to and from school (p=0.55), but at both journeys ACCcounts were significantly lower than HRcounts with a mean (95% CI) difference of 2239 (1886 – 2592) p<0.01) counts/min at journeys to school and 1915 (1396 – 2434) p<0.01) counts/min at journeys from school. Each kilometre of cycling meant that accelerometers underestimated PA levels by a geometric mean (95% CI) of 9314 (7719 – 11238) counts. Only 3.3% and 2.5% (both geometric mean) of HRMVPA were collected by accelerometers at journeys to and from school, respectively. Eleven participants did not achieve any minutes of MVPA during cycling according to accelerometers. Each kilometre of cycling meant that accelerometers underestimated a geometric mean (95% CI) of 2.7 (2.1 – 3.5) minutes of MVPA.

Among those with GPS data at both journeys (n=18) a strong association between journey minutes to and from school was found (Spearman’s rho=0.87 (95% CI: 0.67 – 0.95), p<0.01) with a similar association between HRMVPA (n=9) to and from school (Spearman’s rho=0.88 (95% CI: 0.52 – 0.97), p<0.01). The association between HRMVPA during journeys to school and distance to school was significant (Spearman’s rho: 0.90 (95% CI: 0.75 – 0.96), p<0.01). ACCMVPA was not related to distance to school (Spearman’s rho: 0.07 (95% CI: 0.00 – 0.52), p=0.79)

Physical activity assessments

Table 3 is to be inserted here

Table 3 presents PA levels and minutes of MVPA/day for the 19 participants with valid assessments of PA and at least one journey where underestimation could be quantified. These participants completed 91% of possible journeys to and from school during the intervention assessments of PA. Mean compliance during the entire intervention was 88%. A mean of 4.2 days with ATSC were included in 4.6 weekdays of accelerometer data. The geometric mean (95% CI) HRMVPA during ATSC for these participants was 10.8 (7.1 – 16.6) which was achieved during a geometric mean (95% CI) of 14.9 (11.1 – 20.1) journey minutes. This is translated into a geometric mean (95% CI) of 15.6% (8.9% – 27.5%) of the estimate of adjusted minutes of MVPA/day. The association between the contribution of HRMVPA to adjusted MVPA/day and round trip distance is shown in figure 1. The association was significant (Spearman’s rho: 0.76 (95% CI: 0.46 – 0.90), p<0.01). Assessment of PA in cyclists using accelerometry resulted in a significant underestimation of minutes of MVPA/day (p<0.01) and mean counts/min (p=0.01). The difference between conventially assessed minutes of MVPA/day and adjusted minutes of MVPA/day was a geometric mean (95% CI) of 6.0 (3.8 – 9.6) while mean counts/min differed by a geometric mean (95%CI) of 24 (16 – 38). These differences amounted to an effect-size of 0.32 (95% CI: -0.33 - 0.95) and 0.18 (95% CI: -0.45 - 0.82) for MVPA/day and mean counts/min, respectively.

Figure 1 is to be inserted here

Discussion

This study demonstrates that accelerometer assessed PA among children who cycle to school is significantly underestimated. This was not surprising as this limitation of the methodology is well-recognized [15] and substantial inaccuracy has been found in controlled settings [29]. This is the first attempt to take ATSC into account by combined GPS and HR thus enabling quantification of the underestimation. This study is also novel in its ability to demonstrate the magnitude of the bias introduced when comparing accelerometer mean counts/min and minutes of MVPA/day between children using ATSC and those using other modes of transportation to school if ATSC is not addressed specifically. The importance of ATSC was recently highlighted in the European Youth Heart Study (EYHS) where cycling to school explained the same amount of variation in CRF as accelerometer assessed PA [30]. This study allows for the correction of cycling in future studies using accelerometry thus serving as an improvement to the methodology.

The intensity during cycling was underestimated by 2239 and 1915 counts/min (to and from school, respectively). Minutes of MVPA measured by accelerometers during ATSC represented 3.3% and 2.5% of MVPA measured by HR thus demonstrating that some minutes of MVPA are in fact captured by accelerometers although amounts are negligible. The size of the bias introduced by accelerometers when children are cycling, which so far has been completely neglected, is put into perspective with the findings of a recent meta-analysis demonstrating that interventions to increase PA in children raised levels equivalently to 4 minutes of MVPA/day [31] whereas 6 minutes were not collected by accelerometers during cycling to school in the present study. Effect sizes of 0.32 for MVPA/day and 0.18 for mean counts/min are, by Cohen’s definitions, characterized as medium and small, respectively. However, it is always important to consider context and as the corresponding (standardized) effect sizes reported in the meta-analysis were 0.16 and 0.12 the effect of underestimation of PA during cycling may thus be larger than what we can currently achieve when performing comprehensive interventions in children. As can be observed from the wide confidence intervals the estimate is however calculated with uncertainty.

This study confirms the strong relationship between minutes of MVPA during journeys and distance travelled [2, 3, 19]. It extends knowledge from earlier studies by clearly showing the effect in cyclists and using a precise identification of journeys instead of previously used hour-by-hour estimates [2, 3]. ATS is the main, but not the only, contributor to minutes of MVPA during mornings [19, 20], which could be a cause of imprecision and possibly a systematic bias when comparing hour-by-hour estimates [2-4]. Distance to school can be assessed by GIS, GPS [32] or by having children mark their usual route to school in a web-based system [22]. Because minutes of MVPA during cycling was so strongly related to distance, and accelerometer assessed minutes of MVPA was not, distance could thus be an easy method to correct assessments of PA for unmeasured cycling. Additionally, the estimate of underestimation of counts/km can be used to adjust assessments of PA levels. As ATSC contributed to 15.6% of minutes of MVPA/day adjusting accelerometer assessments for cycling is a needed improvement to the methodology. Previous efforts to amend this limitation have focused on combining field-based methods such as heart rate monitors and temperature sensors with accelerometry [15]. These methods have great potential but are still unfeasible in large epidemiological studies and require the use of branched equations or artificial neural networks which increases complexity. The use of a simpler measure such as distance could be incorporated into large studies by using questionnaires to asses, which children are cycling, and how many times per week. This would not increase participant burden substantially as most studies would already be using questionnaires to assess demographic variables. Currently cycling is rare in most westernized countries and the impact on overall PA levels, and therefore the implication of results presented in this manuscript, is limited in these populations if the study is primarily descriptive. But as the validity of measurements are vital for establishing true relationships with complex phenomena such as youth health were causality to hard-endpoints (i.e. cardiovascular disease, mortality) is near impossible to establish and inference has to be drawn from associations from epidemiological studies, a known bias must be corrected. This is particularly important as this bias is not unrelated to PA. So whether or not the extra effort of quantifying school-cycling to correct assessments of PA is feasible may thus somewhat dependent on the sample levels of cycling and the research objective in question. But in recent years it has become public policy to increase levels of cycling which, if successful, would increase implications for population level PA. However as the relationship between PA and distance may differ in different age groups large studies in other populations would need to use subsamples to generate similar estimates specific to the whole sample. Until more sophisticated methods are available distance to school could be the best way of improving assessment of PA when using accelerometry.

Journeys to and from school took 7.2 and 8.0 minutes, respectively. This is similar to results obtained using self-report [33] To our knowledge no other studies have reported objectively measured journey times in cycling children. No significant difference in minutes of MVPA was found between journeys to or from school in this study which is similar to walking children [19]. This was despite the fact that intensity was lower at journeys from school, but METs were still above the MVPA threshold. The proportion of journey time as MVPA during walking to school has previously been reported to range from 30% - 60% [19, 20, 34] which is less than the proportion found in the cycling children observed in this study. It is noteworthy that although the proportion of time as MVPA may be smaller when walking the absolute amounts of MVPA minutes might be larger because of the differences in speed. Distances to school reported by Southward et al were almost identical to this study (1.4 vs. 1.6 km), but minutes of MVPA achieved was almost two times higher [19]. This might favour walking, but higher intensity during cycling means that in addition to being a source of MVPA, CRF may be affected by cycling [12, 13]. CRF is related to youth health irrespective of PA levels [5, 6]. This is important as PA and CRF may benefit health through different pathways [6] and ATSC could thus be a feasible and effective method of primary prevention [14, 22].

The results from this study are limited by several weaknesses. 1) The main mode of transportation to school in Denmark is cycling [35] and as participants were recruited based on not cycling despite living relatively close to school, these children may differ from the general population in other aspects. CRF and PA levels were, however, similar to those measured in other Nordic studies [11, 36], and all children were accustomed to cycling, just not as transportation to school. Therefore the underestimation of activity during cycling is not specific to irregular cyclists. 2) Four METs were found to be on average 47% of $\dot{V}O_2$max (data not shown), which is defined as moderate intensity activity, but as the cut point it may be high [29]. This suggests underestimation of MET values whereby particularly calculated counts/min (HRcounts) and underestimated counts/km would be affected. 3) The estimate of adjusted minutes of MVPA/day was based on one day of measurements only. Reactivity may be high which could cause higher intensity during ATSC as is found in adults [37]. Intensity is also found to be lower at journeys from school in this study. The intensity was, however, still well above the MVPA cut-point. 4) No data on PA during cycling not related to school journeys were collected. It is therefore unknown whether the underestimation presented can be applied to cycling for other reasons than transportation to school.

GPS monitors were highly reliable in this study. The GPS devices used had a quick satellite signal capability (cold start: 36 seconds (manufacturer average)) but participants were instructed to turn devices on 10 minutes before leaving home. This may be important to prevent loss of data due to missing satellite connections. The Actigraph GT3X was used in this study, but underestimation of activity during cycling is not limited to certain manufacturers, and the significant underestimation of PA is thus expected to apply for all types of accelerometers.

Conclusions

PA during ATSC was found to be highly underestimated when using accelerometry and the estimates of PA levels were biased when not taking ATSC into account. This may be a source of considerable error in populations where cycling is common. Increasing the proportion of children and adolescent who walk or cycle to and from school is considered an important factor for increasing population levels of PA, irrespective of previous PA level. These data suggest that such strategies need to take ATSC specifically into account if trends are to be evaluated properly and a simple tool to do so is suggested. In line with previous results distance was found to be determining of the amount of MVPA achieved during journeys. The use of combined HR, GPS and accelerometry was feasible in this relatively small sample with HR data at the journey home being the main source of missing data. Distance as a predictive measure of physical activity during ATSC should be further investigated in larger samples.

Authors contributions

JT drafted the manuscript, collected, analysed and interpreted the data and is the guarantor. LBA designed the study, interpreted results and revised the manuscript. LØ designed the study, performed the randomization, analysed, interpreted the data and revised the manuscript. All authors read and approved the final manuscript.

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Table 1 – Baseline characteristics

Cycling Group	**Boys (n=13)**	**Girls (n=7)**	**Total (n=20)**
Age (years)	12.2 (0.9)	11.8 (0.5)	12.0 (0.8)
Height (cm)	152.9 (8.5)	152.3 (5.3)	152.7 (7.4)
Weight (kg)	44.5 (8.5)	41.9 (6.8)	43.6 (7.8)
CRF (ml $O_2 \cdot kg^{-1} \cdot min^{-1}$)	43.9 (7.1)	36.7 (2.5)	41.4 (6.8)
HRmax (bpm)	192.8 (6.9)	195.1 (8.3)	193.6 (7.3)
RMR (ml $O_2 \cdot kg^{-1} \cdot min^{-1}$)	4.76 (0.42)	4.37 (0.43)	4.62 (0.46)

Baseline characteristics for the 20 participants with available results for this study. Results are shown by gender and total as mean (SD).

Table 2 - Descriptive results during active transportation to and from school by cycling

	To school	From school	Mean difference between journeys (95% CI)	P value for difference between journeys
Intensity (% of HRmax)	72.3 7.6 N=18	68.5 7.2 N=11	5.0 (1.9 – 8.1) N=9	**<0.01**
METs	5.0 0.6 N=18	4.7 0.7 N=11	0.6 (0.3 – 0.9) N=9	**<0.01**
HRcount (counts/min)	3249 701 N=18	2903 659 N=11	600 (238 - 962) N=9	**<0.01**
ACCcount (counts/min)	966 577 N=19	1088 640 N=19	- 90 (-406 - 225) N=18	0.55
HRMVPA (min)	5.7 3.9 – 8.2 N=18	5.9 3.3 – 10.8 N=11	-0.67 (-3.04 - 1.70) N=9	0.54
ACCMVPA (min)	1.2 0.9 – 1.4 N=18	1.2 0.9 – 1.6 N=11	N=9	0.16
Journey minutes (min)	7.2 5.4 – 9.6 N=19	8.0 6.0 – 10.7 N=19	-0.8 (-1.9 - 0.4) N=18	0.19
Distance (km)	1.63 1.17 – 2.28 N=19	1.78 1.32 – 2.39 N=19	N=18	**0.05**

Results from measurements of HR, GPS and accelerometry during ATSC presented by journeys. Comparisons between journeys are performed for participants with data at both time points only. Counts/min measured by accelerometers (ACCcount), intensity, METs and counts/min calculated from HR (HRcount) are presented as mean (SD). Journey minutes, minutes of MVPA measured by HR (HRMVPA), minutes of MVPA measured by accelerometers (ACCMVPA) and distance are presented as geometric means with 95% CI. Comparisons of journeys to and from school are presented as mean with 95% CI except for distance and ACCMVPA where only a p-value is presented as differences did not achieve normality. Significant p-values are bold. Positive differences indicate numerically higher estimate at journeys to school.

Table 3 - Physical activity levels and minutes of MVPA/day

n=19	Conventional	Adjusted	Conventional-Adjusted
PA level (counts/min)	564 (469 - 678)	608 (518 - 713)	24 (16 – 38) **p=0.01**
MVPA/day (min)	54.5 (40.4 – 73.5)	66.4 (52.6 – 83.5)	6.0 (3.8 – 9.6) **p<0.01**

Physical activity assessments for participants with at least one journey where underestimated activity during cycling could be calculated and who had 3 days of valid accelerometry (n=19). Values are presented as geometric mean with a 95% CI**.** Paired t-tests were performed. Significant p-values are bold.

Figure 1 - Association between the proportions of total minutes of MVPA/day achieved during ATSC and round-trip distance

Legend figure 1

Association between the contribution (%) of HRMVPA to adjusted minutes of MVPA/day and round-trip distance. The solid line represents the best fit. Spearman's rho: 0.7556, p<0.001 (n=19).

Additional file 1

Additionalfile1.pdf contains a detailed description of the establishing of the $\dot{V}O_2$-HR relationships.