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Does growing up in a physical activity-friendly neighborhood increase the likelihood of remaining active during adolescence and early adulthood?

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Abstract

Background The SOPHYA-cohort-study investigated whether the objectively characterized and perceived residential neighborhood of Swiss youth predict accelerometer-measured physical activity and activity in specific domains (participation in a sports club and cycling) five years later.

Methods At baseline in 2014, 1230 children and adolescents aged 6 to 16 years participated and wore accelerometers for 7 days. Of these children, 447 participated again in the follow-up study in 2019 and provided longitudinal accelerometer measurements. Sociodemographic factors and perceptions of the local neighbourhood were assessed by questionnaire. Specific objective environmental data (e.g. built environment or social environment) was modelled to the children's address at baseline. Multivariate linear and logistic regression models were applied to identify short- and long-term characteristics that are associated with accelerometer-based physical activity, cycling and participation in organised sport.

Results If the neighborhood-score as perceived by the parents in 2014 was in the middle or lowest tertile, children were significantly less active cross-sectionally in 2014 (-41.1 (-78.0;-4.2) and -52.4 (-88.6;-16.2) counts per minute, cpm), and five years later (-52.4 (-88.6;-16.2) and 48.1 (-86.6;-9.7) cpm). In addition, they were also less likely to accumulate active minutes above the median at both measuring points compared to peers of the same age and sex. Using objective environmental data modeled around the children's residential address, similar associations were found: In the tertile with the lowest proportion of green space children achieved less cpm in 2014, while a high main street density and a low socioeconomic environment, respectively, hindered physical activity tracking above the median longitudinally. Also for cycling and participation in a sport club, the associations with the perceived and objective environment were more pronounced in the longitudinal analyses.

Conclusion The results suggest that growing up in a physical activity friendly neighborhood increases the likelihood of remaining active during adolescence and early adulthood. Interventions should be implemented to ensure that children growing up in an unfavorable neighborhood do not fall behind at an early stage.

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Keywords Physical activity, Accelerometer, Tracking, Cycling, Sports club participation, Neighborhood, GIS, Socioeconomic environment, Children, Adolescents

Background

Irrespective of age, physical activity (PA) is associated with broad health benefits [1] and can be promoted or hindered by different factors [2]. As one of them, the built environment was repeatedly shown to be cross-sectionally associated with PA among the young in Switzerland and elsewhere [3–5]. International systematic reviews show a positive cross-sectional association of children's overall physical activity with traffic speed, access to recreation facilities, walkability and land use mix in their residential neighborhood [4]. For children's transportation PA (e.g. cycling), transportation infrastructure in the surroundings was particularly relevant [6]. Whether these associations are lasting and influence the likelihood of maintaining an active lifestyle is less clear.

The nature of PA changes during childhood. Unstructured PA decreases with age, whereas structured PA increases. Outdoor play as a source of PA decreases, while the importance of sports activities and active transport increases [7]. On the one hand, it can be hypothesized that the influence of the neighborhood environment on children's PA is not durable as time spent playing outdoors decreases while growing up. On the other hand, it can be argued that the influence of the residential environment on a child's PA persists as they grow older, due to skills obtained from playing outdoors leading to acquisition of competences (motor skills, social skills) with a positive long-term influence on PA behavior, possibly facilitating access and retention in sports clubs or active transportation.

The residential environment can be assessed in different ways. First, it can be objectively characterized using geographic information data (GIS data) [8]. GIS based data facilitate comparison with other studies and forego the subjectivity of self-assessment [9]. Second, information on the environment can be collected as self-report. Self-reported environmental variables also reflect the perceived quality of environmental aspects [10].

Also PA can be assessed in different ways. To assess PA in youth, device-derived measures (e.g. with accelerometers) are strongly recommended [11]. Commonly, the minutes spent in moderate to vigorous PA (MVPA) are used as endpoints in epidemiological studies [12]. Total PA (TPA) in counts per minute (cpm)—independent of arbitrary cut-points for intensity categories—is another useful endpoint as it can be converted into caloric expenditure and reflects PA at all intensity levels, including sedentary time. PA can also be self-reported. This is of value as PA occurs in different domains: leisure time PA and exercise, active or sedentary transport, occupational (school) PA and home-based PA [13]. It is unlikely that PA in such different domains is equally influenced by the neighborhood typology. Associations with the built environment are more likely for transportation and leisure PA. This needs confirmation with longitudinal studies looking at the relationship between neighborhood environment and growing up while being physically active.

Switzerland is well positioned for investigating correlations between children's PA and the residential environment. The mean time children play outdoors is comparatively high on an international level [14], and contributes substantially to their overall physical activity [15]. The present population-based study aimed to analyze whether the objectively characterized and the perceived neighborhood around Swiss children's residential addresses predict accelerometer measured physical activity and declared activity in specific domains (sports club participation; cycling for transport) 5 years later.

Methods

Study population & setting

Participants of the SOPHYA-cohort-study were recruited based on national inhabitant registry data. All children born between 1998 and 2007 and registered in Switzerland were eligible to be included in the random sample. The baseline assessment was performed in 2014 and was described in detail before [5]. 1217 participants providing valid accelerometer and socio-demographic data at baseline and who agreed to be contacted again were invited for the follow-up study five years later.

In both waves, participants first responded to a computer-aided telephone interview (CATI) about sport behavior. This was conducted by a commercial service provider (LINK Marketing Services, Switzerland). At the end of the interview, participants were asked to wear an accelerometer for one week and to complete a paper-based questionnaire in parallel.

For the current study, analyses were based on data of children providing valid accelerometer, sports club participation and cycling data in both waves in addition to valid baseline information on socio-demographics, the perceived environment, and a residential address for a GIS-based assessment of the environment. A flow-chart of the study design is presented in Fig. 1.

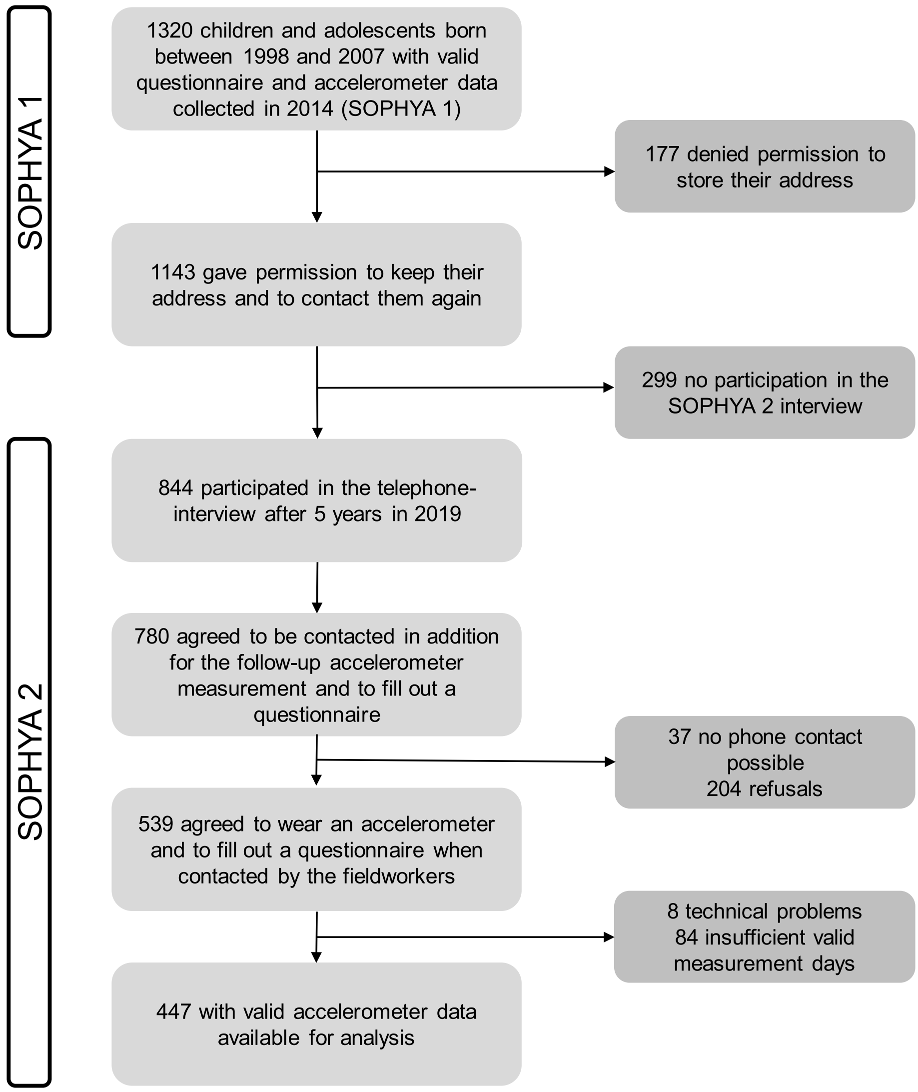

Fig. 1 Flow chart of the study population

Both study-waves were conducted entirely by remote contacts. Instructions on participation in the accelerometry study were first provided over the phone. Accelerometers, questionnaires, and study information as well as informed consent forms were subsequently mailed to the participants. The mailings included a prepaid envelope for returning the accelerometers, filled-in questionnaires and consent forms upon completion of the measurement week.

The study was conducted in accordance with the declaration of Helsinki, and the protocol was approved by the research ethics committee of Nordwest- und Zentralschweiz (EKNZ) (147/13, 2018–01786 and 2018–00549). At baseline, one parent provided written informed consent for their child. Adolescents aged 12 years or older filled in an additional consent form. At follow-up for participants younger than 14 years written informed consent was provided by a parent as a proxy; for participants aged between 14 and 18 years, both parental and an own written informed consent was provided; for youth above 18 years only own written informed consent was given. Throughout the study, we followed the STROBE checklist (Additional file 4).

Study outcomes

Devise-based measurement of physical activity at baseline and follow-up

Physical activity was assessed using accelerometers (GT3x or GT1M, ActiGraph, Pensacola, Florida, USA). For these devices, the vertical axis output is compatible

[16]. Children and adolescents were instructed to wear the accelerometer for seven consecutive days on the right hip, only removing it for water activities and during sleeping hours. For the data download and reduction ActiLife 6.2 (2014) and ActiLife 6.13 (2019) was used (ActiGraph, Pensacola, Florida, USA). Epoch length was set at 15 s and non-wearing time was defined as a period of 60 min of consecutive 0 cpm. For a valid measurement children had to provide at least three weekdays with 10 measuring hours and one weekend day with 8 measuring hours.

First, two endpoints TPA cross-sectionally and longitudinally were formed, reflected by the mean cpm. For both waves mean cpm for the measurement week was calculated multiplying the mean cpm of the weekdays by 5 and the mean cpm of the weekend day by 2 and dividing the sum by 7.

Second, categories reflecting the tracking of MVPA were formed. As age and sex are a strong but not linear correlates of PA, it is difficult to compare PA-development over time across a broad age group. Therefore, a relative measure was derived for the longitudinal course of physical activity compared to peers of the same age and sex to reflect the participants' PA tracking. The concept of "tracking" at the level of individuals refers to the long-term stability of relative ranking within a cohort of behaviors such as PA [17]. The relative measure of tracking was derived according to the following steps. In a first step, cut points for MVPA were defined using the cut points of Freedson [18] with a threshold for moderate activity at 4 METs [19]. In a second step, the median of MVPA for each age (within categories of 1 year) and sex group was calculated for both baseline and follow-up assessments. In a third step, based on the age and sex-specific medians, four categories were defined: a) those who were in the more active half in both assessments, b) those who were in the less active half in 2014 but in the more active half in 2019, c) those who were in the more active half in 2014 but in the less active half in 2019 and d) those who were in the less active half in both assessments.

Self-reported domain-specific physical activity

Physical activity in the domain of cycling was assessed at baseline and at follow-up using the SOPHYA-paper-questionnaire, which supplemented the accelerometer measurements and focused on behavior during the corresponding week. To assess cycling time it was asked how many hours participants rode a bike during the measurement week. Information about sports club participation was collected during the telephone interview in both waves of the SOPHYA-cohort-study asking whether the participant is an active member of a sport club. At baseline, parents filled in the SOPHYA-questionnaires and answered to the telephone interview. At follow-up adolescents and young adults answered the questions themselves.

Socio-demographic information at baseline

Socio-demographic information on age of the child, sex of the child, household income, and nationality were obtained by interviewing one parent as proxy at baseline.

Environmental predictors

Environmental predictors

Perceived residential environment at baseline

Information on the perceived residential neighborhood environment was self-reported at baseline. The SOPHYA-questionnaire was filled in by one parent as a proxy during the week when the child or adolescent was wearing the accelerometer. The questions were based on validated scores of the Australian CLAN study [20]. It assesses the dimensions of road safety (three items), incivilities (four items) and personal safety of the child or adolescent (five items). Each item uses a five-point Likert scale ranging from strong disagreement (-2) to strong agreement ((2). The CLAN study questions were complemented with previously used questions on access to a garden, parks and playgrounds (two items) using the same five-point Likert score [14]. Domain-specific scores were derived from the dimension-specific questions by adding the Likert scale points of the respective questions up and used for classifying children into tertiles for the respective dimensions (highest, medium, lowest tertile of PA friendliness in the respective dimension). An overall total score was derived from the domain-specific tertiles by assigning 1, 2 and 3 points, respectively, to the lowest, medium, and highest PA friendliness tertile and summing the points over the four dimensions. The overall total scores ranged from 4 to 12 and were again grouped into tertiles.

Objectively measured residential environment at baseline

The physical environment at the participant's residential baseline address was characterized with the help of GIS-derived information using ArcMap 10.2 (Esri, Teadlands, CA USA). As a measure of road safety, the main street density within a 200 m circular buffer (m/200 m radius) was calculated. The classification of main street was based on Swiss Topo Vector 25 [21]. For the attribute greenness, the satellite-derived Normalized Difference Vegetation Index (NDVI) in 2014 [22] was used. The continuous data on both, main street density and greenness was grouped into tertiles to parallel the tertile approach for the perceived environment (see above).

The classification into rural, peri-urban and urban area referred to the definition of the Federal Office of Statistics [23].

The Swiss neighborhood index of socioeconomic position (SEP) [24] was used as an objective measure of the socioeconomic environment. It is a validated score from 1 (lowest tenth) to 10 (highest tenth). It is a composite score derived from information on income, education, occupation, and housing conditions at the level of households. Each residential address is assigned the mean score of the 50 nearest households. Consistent to previous studies scores of 5 and less were classified as low SEP and scores above 5 as high SEP area [5].

Statistical analyses

All analyses were conducted with STATA 16.1.

For the assessment of attrition bias socio-demographic characteristics at baseline were compared between SOPHYA1 accelerometry participants included versus not included in this longitudinal analysis (Supplementary Table 1).

All associations of objectively assessed and self-reported environmental neighborhood predictors at baseline with TPA (measured as cpm) and with cycling and sports club participation during the measurement week, respectively, were tested a) cross-sectionally (association with TPA/cycling/sports club activity at baseline) and b) predictively (association with TPA/cycling/sports club activity at follow-up). The associations with MVPA tracking categories were a priori only testable predictively.

For both, device-based PA and self-reported domain-specific PA the following stepwise approach to statistical analysis was followed.

First, the age- and sex-adjusted associations of baseline socio-demographic characteristics (age,(adjusted for sex), sex (adjusted for age), household income, nationality) with PA indicators were assessed. The cross-sectional and predictive associations with TPA (cpm) were tested by linear regression models. Regression coefficient estimates for cpm were determined using a bootstrap with 1000 replications in order to account for a skewed distribution of the residuals. Equivalently the cross-sectional and predictiveassociations with cycling and sports club participation were tested using a logistic regression. The predictive association of baseline socio-demographic characteristics (household income, nationality) with the age- and sex-specific tracking categories was tested by chi2-test.

Second, the cross-sectional and predictive association of each perceived and objectively measured neighborhood attribute at baseline with PA outcomes was assessed in separate multivariate models adjusting for the baseline socio-demographic characteristics included in the above models (age, sex, family income, nationality; each of this variables were associated with at least one PA endpoint in the above models) and additionally for the season of measurement. The associations with TPA (cpm) at baseline and follow-up, respectively, were tested by multivariate linear regression models with cpm as the dependent variable. Models were adjusted for age, sex, family income, nationality, and the season of measurement. Because of the skewed distribution of the residuals for all models, a bootstrap with 1000 replications was used. The predictive associations with each of the four tracking categories were tested by logistic regression models. Interactions between total perceived environment and SEP were tested in models containing total perceived environment and SEP as main effects as well as interaction terms. The cross-sectional and predictive associations with cycling (yes/no) and sports club participation (yes/no) as dependent variables were tested by separate logistic regression models. Interactions of cycling and sports club participation with SEP were also tested.

Third, the same models as described in step two above (separate models for each perceived and objective environmental attribute) were rerun, including both, the total perceived environment score and the objectively measured environmental attributes in the same single models to assess the independent associations of the perceived and the objective environment with PA.

For all analyses the baseline perspective of the environmental variables was taken, however, an additional sensitivity analysis was carried out in which the 20 children who changed address between the baseline and the follow-up assessment were excluded.

Results

Characteristics of the study population and attrition

The SOPHYA-cohort-study included 447 participants with longitudinal accelerometer data (Fig. 1). The average time interval between baseline and follow-up examination was 4.96 years (range 3.8 to 6.4 years).

Their mean age of the participants was 10.0 years at baseline (range 6 to 16 years old) and 14.8 at follow-up (range 11 to 21 years). 215 (48%) of them were boys. Younger children and those from households with a higher income were more likely to participate at follow-up, but no statistically significant difference was seen for accelerometer-based TPA between the two groups (Supplementary Table 1). Mean MVPA decreased from 85.0 min per day in 2014 to 47.7 min per day in 2019. The sample size for cycling and sports club participation was slightly lower. For cycling 411 out of 447 participants provided information for both measurement periods and for sports club attendance 445 out of 447.

Socio-economic characteristics and accelerometer-measured physical activity tracking

The distribution of socio-demographic characteristics at baseline and their cross-sectional and longitudinal associations with device-based PA characteristics are described in Table 1. In 2014 as well as in 2019, cpm decreased with age and boys were more active than girls. No difference in TPA or the tracking of PA by household income or nationality was present.

Residential environment and accelerometer-measured physical activity

The cross-sectional and longitudinal associations of perceived and objective neighborhood scores with device-based PA are presented in Table 2.

First, regarding the perceived environment, if the neighborhood scores as perceived in 2014 by the parents were in the middle or lowest tertile, children achieved lower cpm-values on average. This difference was statistically significant cross-sectionally in 2014 for road safety, aesthetics and incivilities, personal safety and the total score, and remained statistically significant longitudinally with cpm five years later except for aesthetics and incivilities. This predictive association with TPA measured as cpm is in line with the finding that children from the lowest perceived road safety tertile, the lowest perceived access to gardens or green spaces and the lowest perceived total neighborhood environment scores were more likely to persistently exhibit MVPA below the age- and sex-specific median over the follow-up period. The association of perceived poor access to gardens and green spaces with unfavorable MVPA tracking was particularly pronounced among children living in a low SEP area. They were statistically significantly less likely to reach MVPA minutes above the median at both measuring points ($OR_{\text{median vs. highest tertile of perceived access}}$ and 95% CI: 0.7 (0.3; 1.6) and and $OR_{\text{lowest vs. highest tertile of perceived access}}$ 0.3 (0.1; 0.9). In contrast, among children living in a high SEP area, the perceived access to gardens and greenspaces was not associated with the likelihood of reaching MVPA minutes above the median in both measuring points ($OR_{\text{median vs. highest tertile of perceived access}}$ and 95% CI: 1.1 (0.6; 2.0) and $OR_{\text{lowest vs. highest tertile of perceived access}}$ 1.2 (0.6; 2.6).

Table 1 Association of socio-demographic factors with accelerometer-based CPM (2014 and 2019) and tracking of physical activity

			Total physical activity (TPA)[a]		Tracking of physical activity (MVPA)				
		n (%)	**CPM 2014 Mean (SD)**	**CPM 2019 Mean (SD)**	**Active below median[b], in both time points (*n* = 120)**	**Became less active[a] (*n* = 97)**	**Became more active[a] (*n* = 96)**	**Active above median[a], in both time points (*n* = 134)**	**p_{X2} for difference between tracking groups**
Age	Younger (6 to 10 at baseline)(ref.)	314 (70.3)	618 (169)	470 (163)	-	-	-	-	
	Older 11 to 16 at baseline	133 (29.8)	**476 (171)*** **	**413 (171)** **	-	-	-	-	
Sex	Boys (ref)	215 (48.1)	635 (192)	487 (152)	-	-	-	-	
	Girls	232 (51.9)	**521 (151)*** **	**422 (176)*** **	-	-	-	-	
Household income	Low (ref)	81 (19.3)	570 (227)	460 (193)	29.6%	21.0%	27.2%	22.2%	
	Medium	138 (32.7)	573 (183)	435 (144)	29.7%	20.3%	17.4%	32.6%	
	High	186 (41.6)	581 (161)	467 (176)	23.7%	22.0%	22.0%	32.3%	
	No indication	42 (9.4)	573 (165)	438 (150)	26.2%	23.8%	23.8%	26.2%	0.8
Nationality	Swiss(ref)	312 (69.8)	578 (184)	457 (167)	26.0%	21.4%	20.5%	32.1%	
	Non-Swiss	42 (9.4)	574 (172)	492 (213)	31.0%	14.2%	28.6%	26.2%	
	Dual Citizen	93 (20.8)	569 (177)	425 (145)	28.0%	28.0%	19.3%	24.7%	0.4

[a] The analyses with total physical activity as outcome were adjusted for age and sex; the age and sex associations with total physical activity were only adjusted for sex and age, respectively)

[b] Compared to peers of the same sex and the same age

* *p*-value ≤ 0.05

** *p*-value ≤ 0.01

*** *p*-value ≤ 0.001

Table 2 Cross-sectional and predictive associations of perceived and objectively assessed neighborhood environmental attributes with physical activity ($n = 447$ children)

		Total physical activity (TPA)[a,b]		**Tracking of physical activity (MVPA) [a,b]**			
		CPM 2014 Coeff. (95% CI)	**CPM 2019 Coeff. (95% CI)**	**Active below median, in both time points ($n = 120$) OR (95% CI)**	**Became less active ($n = 97$) OR (95% CI)**	**Became more active ($n = 96$) OR (95% CI)**	**Active above median, in both time points ($n = 134$) OR (95% CI)**
Perceived environmental factors	**Tertiles of PA friendliness**						
Road safety score	Highest tertile (ref.)	1	1	1	1	1	1
	Medium tertile	-16.5 (-51.8; 18.8)	-24.4 (-58.6; 9.8)	1.2 (0.7;2.1)	1.2 (0.7;2.1)	0.7 (0.4;1.2)	0.9 (0.6;1.5)
	Lowest tertile	**-33.9 (-68.2; 0.0)***	**-33.4 (-66.8; 0.0)***	**1.7 (1.0;2.9)***	1.0 (0.6;1.9)	0.8 (0.4;1.3)	0.7 (0.4;1.2)
Aesthetics and incivilities score	Highest tertile (ref.)	1	1	1	1	1	1
	Medium tertile	-31.6 (-65.6; 2.5)	-27.5 (-61.8;6.9)	1.3 (0.7;2.1)	1.1 (0.6;1.9)	1.1 (0.6;1.9)	0.7 (0.4;1.2)
	Lowest tertile	**-31.9 (-63.0;-0.8)***	-15.2(-48.2; 17.8)	1.2 (0.7;1.9)	1.2 (0.7;2.0)	1.2 (0.7;2.1)	0.7 (0.4;1.1)
Personal safety score	Highest tertile (ref.)	1	1	1	1	1	1
	Medium tertile	-14.6 (-50.5;18.2)	**-49.1 (-85,7;-12.6)****	1.2 (0.1;2.2)	1.2 (0.7;2.2)	0.7 (0.4;1.3)	0.9 (0.6;1.6)
	Lowest tertile	**-45.0 (-77.0;-13.0)****	**-37.4 (-69.6;-5.1)***	**1.5 (0.9;2.5)**[(*)]	1.2 (0.7;2.1)	0.7 (0.4;1.2)	0.7 (0.4;1.2)
Access to garden, parks and playground	Highest tertile (ref.)	1	1	1	1	1	1
	Medium tertile	-11.2 (-43.3; 20.9)	-18.3 (-51.1;-14.5)	1.0 (0.6;1.7)	1.4 (0.8;2.3)	0.9 (0.5;1.5)	0.8 (0.5;1.3)
	Lowest tertile	-21.4 (-60.5;17.7)	-20.0 (-55.9; 15.9)	**1.8 (1.1;3.1)***	1.4 (0.8;2.5)	**0.5 (0.3;1.0)***	0.7 (0.4;1.2)
Total Score of perceived environmental tertiles[c]	Highest tertile (ref.)	**1**	**1**	1	1	1	1
	Medium tertile	**-41.1 (-78.0;-4.2)***	**-49.6 (-91.0;-8.3)***	**1.8 (1.0;3.2)***	1.0 (0.6;2.0)	0.8 (0.4;1.4)	0.7 (0.4;1.2)
	Lowest tertile	**-52.4 (-88.6;-16.2)****	**-48.1 (-86.6;-9.7)***	1.6 (0.9;2.9)	1.4 (0.7;2.5)	0.8 (0.5;1.6)	**0.6 (0.3;1.0)***
GIS Data							
Mainstreet density	Lowest tertile (ref.)	1	1	1	1	1	1
	Medium tertile	-0.9 (-34.1; 32.3)	**-39.7 (-75.5;-3.9)***	1.5 (0.9;2.6)	0.8 (0.4;1.2)	0.8 (0.5;1.4)	1.0 (0.6;1.6)
	Highest tertile	-0.9 (-36.1; 34.4)	**-38.2 (-76.0; -0.3)***	**2.0 (1.2;3.4)****	0.7 (0.4;1.2)	0.9 (0.5;1.6)	0.7 (0.4;1.3)
Green spaces	Highest tertile (ref.)	1	1	1	1	1	1
	Medium tertile	10.3 (-21.6; 41.9)	1.9 (-38.5; 42.2)	0.8 (0.5;1.4)	0.9 (0.5;1.5)	0.9 (0.5:1.6)	1.4 (0.9;2.4)
	Lowest tertile	**-34.2 (-68.0;-0.4)***	-21.1 (-60.7; 18.6)	1.3 (0.8;2.2)	0.7 (0.4;1.3)	1.1 (0.7;2.0)	0.9 (0.5;1.6)
Urbanicity	Urban (ref.)	1	1	1	1	1	1
	Peri-urban	0.8 (-33.5; 35.1)	**37.5 (0.4; 74.7)***	1.1 (0.6; 2.0)	0.7 (0.4; 1.2)	0.9 (0.5; 1.7)	1.4 (0.8; 2.5)
	Rural	-2.1 (-37.7; 33.6)	5.4 (-32.1; 43.0)	**1.9 (1.0; 3.5)***	0.7 (0.3; 1.3)	0.7 (0.4; 1.5)	1.0 (0.5; 1.9)
Socioeconomic environment	High (ref.)	1	1	1	1	1	1
	Low	-14.8 (-41.4;11.8)	**-28.3 (-56.5;-0.1)***	**1.8 (1,2;2,8)***	0.8 (0.5;1.3)	0.9 (0.5;1.4)	0.8 (0.5;1.2)

[a] The association of each environmental predictor with PA indicators was assessed in a separate model

[b] All analyses are adjusted for age, sex, season of measurement, household income and nationality

[c] The total score of the perceived environment was based on the sum of the four dimension (1 for the lowest tertile and 3 for the highest tertile) resulting in a scrore from 4 to 12

[*] p-value ≤ 0.05

[**] p-value ≤ 0.01

[***] p-value ≤ 0.001

Second, regarding GIS-based environmental data, children living in a residential environment in the lowest tertile of green space achieved less cpm in 2014, but the predictive association was no longer statistically significant. In contrast, for main street density and low SEP neighborhood no cross-sectional, but a predictive association with low TPA and unfavorable MVPA tracking was observed. For urbanicity the most favorable longitudinal PA development was seen among those growing up in a peri-urban area. The associations between objectively measured environmental data and PA outcomes were not modified by SEP.

Third, with regard to the independent association of total perceived and the objectively measured environment, results from the mutually adjusted models confirmed the single models with the perceived environmental score showing the strongest association to TPA in the cross-sectional and in the longitudinal analysis (Supplementary Table 2). Some of the objectively assessed environmental variables became only borderline significant, because of larger confidence intervals caused by the larger number of categories.

Finally, a sensitivity analysis excluding 20 children who changed address between the baseline assessment and follow-up showed no material difference to the results in the full sample (data not shown).

Socio-demographic characteristics and domain-specific physical activity

The distribution of socio-demographic characteristics and their association with domain-specific PA (cycling as an indicator of active transport; sports club attendance as an indicator of leisure time activity) is described in Table 3. Cycling was less common in dual citizens in the cross-sectional analysis and in girls and children from families with a low household income in the longitudinal analysis. Sports club attendance was less common in non-Swiss children in the cross-sectional analysis. There was a strong positive association between household income and sports club participation predictively.

Residential environment and domain-specific physical activity

The cross-sectional and longitudinal associations of perceived and objective neighborhood scores with domain-specific PA are presented in Table 4.

First, regarding cycling, the lowest perceived road safety as well as a high objectively measured main street density were associated with less engagement in cycling in the cross-sectional analyses. These associations became weaker in the predictive analyses and remained only borderline statistically significant. In contrast, the association of cycling with personal safety, access to parks and the total score of the perceived neighborhood environment became only statistically significant in the longitudinal analyses when participants had become adolescents or young adults. The adverse associations of high main street density with cycling was more prominent in low SEP areas (in low SEP area: cross-sectional association with cycling: $OR_{\text{medium tertile vs. lowest tertile main street density}}$ 0.6 (0.3; 1.1); $OR_{\text{highest vs. lowest tertile main street density}}$ 0.9 (0.5;

Table 3 Association of socio-demographic factors with cycling and sports club participation at baseline and at follow-up

		Cycling (*n* = 411)[a]		**Sport club participation (*n* = 445)[a]**	
		Cross-sectional (2014) (53.5% = yes) OR (95% CI)	**Longitudinal (2019) (56.7% = yes) OR (95% CI)**	**Cross-sectional (2014) (68.9% = yes) OR (95% CI)**	**Longitudinal (2019) (69.0% = yes) OR (95% CI)**
Age	Younger (6 to 10 at baseline) (ref.)	1	1	1	1
	Older 11 to 16 at baseline	2.0 (0.9; 4.4)	1.5 (0.7; 3.4)	**0.4 (0.2; 1.0)***	1.5 (0.7; 3.4)
Sex	Boys (ref)	1	1	1	1
	Girls	1.0 (0.7; 1.5)	**0.6 (0.4;0.9)****	0.8 (0.5; 1.2)	1.2 (0.8; 1.8)
Household income	Low (ref)	1	1	1	1
	Medium	0.9 (0.5; 1.6)	**2.2 (1.2; 4.0)***	1.3 (0.7; 2.3)	1.7 (0.9: 3.1)
	High	0.7 (0.4; 1.3)	**1.8 (1.0; 3.2)***	1.2 (0.7; 2.2)	**2.6 (1.5; 4.7)*****
	No indication	0.7 (0.3; 1.4)	2.0 (0.9; 4.6)	0.7 (0.3; 1.5)	**2.7 (1.1; 6.4)***
Nationality	Swiss(ref)	1	1	1	1
	Non-Swiss	1.0 (0.5; 2.0)	0.8 (0.4; 1.7)	**0.4 (0.2; 0.8)****	1.4 (0.6: 3.0)
	Dual Citizen	**0.6 (0.4; 1.0)***	0.7 (0.4: 1.2)	1.5 (0.9; 2.6)	1.2 (0.7; 2.0)

[a] The analyses cycling and sport club attendance, respectively, as outcome were adjusted for age and sex; the age and sex associations with total physical activity were only adjusted sex and age, respectively)

* *p*-value ≤ 0.05

** *p*-value ≤ 0.01

*** *p*-value ≤ 0.001

Table 4 Cross-sectional and predictive associations of perceived and objectively assessed neighborhood attributes with domains of PA

		Cycling ($n=411$)[a,b]		Sport club attendance ($n=445$)[a,b]	
		Cross-sectional (2014) (53.5% = yes) OR (95% CI)	**Longitudinal (2019) (56.7% = yes) OR (95% CI)**	**Cross-sectional (2014) 68.9% = yes) OR (95% CI)**	**Longitudinal (2019) (69.0% = yes) OR (95% CI)**
Perceived environmental factors	**Tertiles of PA friendliness**				
Road safety score	Highest tertile (ref.)	1	1	1	1
	Medium tertile	0.9 (0.5;1.3)	1.0 (0.6;1.7)	1.2 (0.7;1.8)	0.8 (0.5;1.4)
	Lowest tertile	**0.6 (0.4;0.9)***	**0.6 (0.4;1.0)[(*)]**	1.3 (0.7;2.1)	0.9 (0.5;1.6)
Aesthetics and incivilities score	Highest tertile (ref.)	1	1	1	1
	Medium tertile	0.7 (0.4;1.2)	0.9 (0.5;1.5)	1.1 (0.6;1.8)	1.0 (0.6;1.8)
	Lowest tertile	1.0 (0.6;1.7)	0.8 (0.5;1.3)	0.9 (0.6;1.5)	**0.6 (0.4;1.0)[(*)]**
Personal safety score	Highest tertile (ref.)	1	1	1	1
	Medium tertile	1.5 (0.9;2.6)	1.4 (0.8;2.4)	1.2 (0.7;2.2)	0.6 (0.4;1.1)
	Lowest tertile	0.9 (0.5;1.4)	**0.6 (0.4;0.9)***	1.0 (0.6;1.6)	0.7 (0.4;1.2)
Access to parks and playground	Highest tertile (ref.)	1	1	1	1
	Medium tertile	0.9 (0.6;1.5)	**0.5 (0.3;0.9)****	0.9 (0.5;1.4)	0.7 (0.4;1.1)
	Lowest tertile	0.8 (0.5;1.4)	0.6 (0.4;1.1)	1.2 (0.7;2.1)	0.6 (0.4;1.2)
Total score of perceived environment-tertiles[c]	Highest tertile (ref.)	1	1	1	1
	Medium tertile	1.1 (0.6;1.9)	0.8 (0.5;1.4)	0.8 (0.5;1.4)	0.8 (0.5;1.5)
	Lowest tertile	0.9 (0.5;1.5)	**0.5 (0.3;0.8)****	1.0 (0.6;1.7)	**0.6 (0.3;1.0)***
GIS Data					
Mainstreet density	Lowest tertile (ref.)	1	1	1	1
	Medium tertile	0.7 (0.4;1.1)	1.4 (0.8; 2.3)	1.3 (0.8;2.1)	1.1 (0.6;1.8)
	Highest tertile	**0.6 (0.4;1.0)[(*)]**	1.0 (0.6; 1.7)	1.0 (0.6;1.7)	1.0 (0.6;1.8)
Green spaces	Highest tertile (ref.)	1	1	1	1
	Medium tertile	1.0 (0.6;1.7)	**1.6 (1.0; 2.7)[(*)]**	1.2 (0.7;2.0)	1.5 (0.9;2.6)
	Lowest tertile	1.0 (0.6;1.6)	1.0 (0.6; 1.7)	1.4 (0.8;2.3)	1.1 (0.7;1.9)
Urbanicity	Urban (ref.)	1	1	1	1
	Periurban area	0.8 (0.5; 1.4)	0.8 (0.5; 1.3)	1.3 (0.7; 2.3)	1.1 (0.6; 2.0)
	Rural	1.3 (0.7; 2.2)	1.2 (0.7; 2.2)	1.3 (0.7; 2.4)	0.9 (0.5; 1.6)
Socioeconomic environment	High (ref.)	1	1	1	1
	Low	0.9 (0.6; 1.4)	**0.6 (0.4; 1.0)***	1.1 (0.7; 1.7)	0.8 (0.5; 1.3)

[a] The association of each environmental predictor with PA domains was assessed in a separate model

[b] All analyses are adjusted for age, sex, season of measurement, household income and nationality

[c] The total score of the perceived environment is based on the tertiles of each dimension (1 for the lowest tertile and 3 for the highest tertile)

(*) p-value ≤ 0.1

* p-value ≤ 0.05

** p-value ≤ 0.01

*** p-value ≤ 0.001

1.7); predictive association with cycling $OR_{\text{medium tertile vs. lowest tertile main street density}}$ and $OR_{\text{highest tertile vs. lowest tertile main street density}}$ 0.7 (0.3; 1.5); and 0.4 (0.2; 0.9), whereas no considerable differences in cycling were observed neither cross-sectionally nor predictively between tertiles of main street density in high SEP areas. In addition, in low SEP-areas cycling was more common in peri-urban (OR and 95% CI: 1.4 (0.7; 2.6) and rural areas 2.4 (1.0; 5.6)*), whereas it was the opposite for high SEP areas (OR and 95% CI: 0.3 (0.1; 0.8) for peri-urban and 0.7 (0.3; 1.8) for rural areas).

Second, with regard to sports club participation the built environment seemed to be of less importance. No cross-sectional associations with either perceived or objectively measured environmental attributes were found. However, sports club participation was lower in

2019 if children grew up in the least PA friendly environment as perceived by the parents. The associations between environmental attributes and sports club attendance did not depend on neighborhood SEP.

Third, with regard to the independent association of total perceived and the objectively measured environment with domain-specific PA, the mutually adjusted model did not change the association between personal and environmental factors with cycling and sports club participation substantially. However, power was again low because of the greater number of categories, resulting in large confidence intervals and thus in more associations, which were not statistically significant (Supplementary Table 3).

Again, the sensitivity analysis excluding the 20 children who changed the address between the baseline assessment and follow up did not reveal any substantial difference to the results in the full sample (data not shown).

Discussion

Using longitudinal SOPHYA study data, we analyzed whether the objectively characterized and the perceived neighborhood around Swiss children's residential addresses predicted accelerometer measured PA and declared activity in specific domains (sports club participation; cycling for transport) 5 years later. The neighborhood environment was broadly associated cross-sectionally with PA in children, but it also exhibited long-term associations with PA five years later in adolescence and early adulthood. For some neighborhood factors, the association became stronger in the predictive analyses. Some suggestive pathways could be identified (e.g. impact of environment on acquiring cycling as a habit). Additionally, general motor skills gained when playing outside could be important mediators between neighborhood environment and PA development over time. To grow up in a less PA friendly neighborhood environment showed even a stronger negative association with longitudinal PA than the individual low socioeconomic or migration background. Neither household income nor nationality were associated with a participant's device-based PA measurements and MVPA tracking.

Our findings are in line with a previous longitudinal Norwegian study that found an unfavorable built environment to hinder children to develop adequate motor skills, express enjoyment and positive experiences of PA, resulting in low active behavior over time [25]. This is of health relevance for the children concerned because a systematic review reported low activity trajectories to be less modifiable over time than more active trajectories [26]. In this study we found the strongest adverse associations of PA with environmental factors in the inactive tracking group.

The positive associations with PA of having access to green spaces [9] and of traffic safety [4] and the importance of outdoor PA have been highlighted in systematic reviews [27]. However, other neighborhood aspects, such as perceived personal safety were identified as poorly investigated [9]. Our data show that perceived personal safety was not only associated with TPA in the short-term but even more so longitudinally. Furthermore, parental safety-concerns were more common in children who were persistently active below the median over the five years of follow-up. Our results thus contribute to decreasing the knowledge gap on the relevance of safe neighborhoods. It remains to be explored whether neighborhood safety itself hinders children to be active or whether the persistently low activity results from of parental restrictions that hinder children's motor experiences. Parental concern does not seem to fully explain the observed associations, given that for road safety and green spaces also objective environmental data were available and associated with PA tracking to a similar degree as perceived environment. In addition, the multivariate model including both, the total environmental score based on parental perceptions as well as objectively assessed environmental data did not change the result. However, interventions to improve PA friendly neighborhood should be complemented with efforts to increase parental sense of security [5].

An important aspect of the associations between the environment and PA is that several studies found a moderation effect by the socioeconomic environment [28]. In previous studies, there were different patterns across geographical regions indicating that in contrast to the US, in Europe, having a walkable neighborhood was more important for low socioeconomic positioned youth [29]. Our data confirm the stronger association between the neighborhood environment and PA in low SEP areas for some aspects, but for others, the association was there for both groups.

In order to plan interventions and to understand pathways by which the residential environment influences PA in the long term, domain-specific effects have to be analyzed. The most prominent association with neighborhood characteristics was observed for cycling. Insufficient road safety was associated with less cycling in children – at an age when they usually acquire the necessary motor skills to learn cycling – and it tended to remain disadvantageous five years later. The association of cycling with the environment changed with age: Perceived safety indicators and the overall safety score were more strongly associated with cycling in the long term. This change in associations over time and with aging possibly reflects that cycling in adolescents and adults is used for commuting, whereas children more often cycle without having a destination in mind [30]. This might also be the reason for the u-shaped association of cycling with green spaces, meaning that bike paths should not only be safe, but also lead to a destination, which is more likely to be the case in urban than in rural areas [31]. The long-term impact of the neighborhood on cycling was also observed in a Finnish study that concluded that active transport during adolescence predicted PA in later life [32].

For sports club participation, we argue that children may profit from the motor competency achieved through active outdoor play. We found that children with the lowest environmental scores were less likely to be members of a sports club at follow-up. This may be one of the pathways underlying the observed long-term effect of the neighborhood on accelerometer-based PA. The association is in line with a previous study showing that team sports or individual sports during adolescence were related to the activity level in adulthood [25] and that inactivity maintainers turned out to be the ones participating less in sports club or active commuting during youth [25].

The strengths of our study are the population-based sampling, the longitudinal design and the acccelerometer-based measurement of PA. A strength is also the additional collection of information on domain-specific PA in a prospective study, as this allows exploring mediating pathways towards evidence-based interventions to promote PA. Finally, obtaining information on both, objective and perceived neighborhood factors, allowed to interrogate their relative importance for PA behavior.

Our results must be interpreted taking into account several limitations. First, as in any longitudinal study there was a loss to follow-up with an overrepresentation of socioeconomically advantaged children at follow-up. As the PA behavior of children participating in follow-up did not materially differ from those not participating at follow-up the likelihood of differential bias is minimal. Second, cycling and sports club participation was only assessed for the measurement weeks/in the short period before at in the telephone interview and may not adequately reflect longer-term behavior. Third, although longitudinal data were used, residential self-selection bias cannot be excluded. It could be that physically active parents chose to live in more PA friendly neighborhoods and have an impact on children's behavior through role-modeling or PA support. Finally, the power at follow-up was low for large mutually adjusted models. In particular, the high correlation between individual perceived environmental attributes did not allow for assessing their independent associations with device-based and domain-specific PA.

Conclusion

A PA-friendly built environment may not only have a positive effect on PA in the short-term but may also positively influence an active lifestyle later in adolescence and early adulthood. Children growing up in an activity-friendly neighborhood, therefore are more likely to become more active adolescents and young adults. Interventions should be implemented to ensure that children growing up in an unfavorable neighborhood do not fall behind at an early stage. Unfavorable neighborhoods, particularly areas with heavy road traffic, with low personal security for children and low access to playgrounds should be made activity-friendly and the specific needs of children and adolescents in that respect should be considered.

Abbreviations

CATI	Computer-aided telephone interview
CLAN-Study	Children Living in Active Neighborhoods-Study
CI	Confidence interval
CPM	Counts per minute
GIS	Geographic information system
MVPA	Moderate to vigorous physical acticity
NDVI	Normalized Difference Vegetation Index
OR	Odds ratio
PA	Physical activity
SEP	Swiss neighborhood index of socioeconomic position
SOPHYA	Swiss children's Objectively measured PHYsical activity
TPA	Total physical activity

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-20373-4.

Additional file 1: Supplementary Table 1. Comparison of study characteristics at baseline (2014) between children participating and those not participating at the follow-up (2019).

Additional file 2: Supplementary Table 2. Mutually adjusted cross-sectional and predictive association of total perceived and objectively assessed neighborhood environmental attributes at baseline with accerelrometer based physical activity.

Additional file 3: Supplementary Table 3. Cross-sectional and predictive association of domains of physical activity with objectively and perceived assessed neighborhood environmental attributes at baseline: mutually adjusted model.

Additional file 4. Strobe Checklist.

Additional file 5.

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Authors' contributions

Conceptualization and study-design, BBI, JH, BK, LSS, AD, and NPH; Data collection BBI, JH, BK, LSS and NPH; Data curation BBI, JH and NPH; KdH contributed the GIS data. Investigation, formal analysis, writing original draft and editing BBI and NPH. All authors have read and agreed to the published version of the manuscript.

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Data availability
The datasets generated and/or analysed during the current study are not publicly available due but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study protocol was approved by the research ethics committee of Nordwest- und Zentralschweiz (EKNZ) (147/13, 2018–01786 and 2018–00549). At baseline, one parent provided written informed consent for their children. Adolescents aged 12 years or older filled in an additional consent form. At follow-up for participants younger than 14 years written informed consent was provided by a parent as a proxy; for participants aged between 14 and 18 years, both parental and an own written informed consent was provided; for youth above 18 years only own written informed consent was given.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. WHO. Global recommendations on physical activity for health. Geneva: World Health Organisation; 2010. p. 58.
2. Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. Annu Rev Public Health. 2006;27:297–322.
3. D'Haese S, Cardon G, Deforche B. The environment and physical activity. 2015.
4. Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth a review. Am J Prev Med. 2011;41(4):442–55.
5. Bringolf-Isler B, Schindler C, de Hoogh K, Kayser B, Suggs LS, Dossegger A, Probst-Hensch N, Group SS. Association of objectively measured and perceived environment with accelerometer-based physical activity and cycling: a Swiss population-based cross-sectional study of children. Int J Public Health. 2019;64(4):499–510.
6. Prince SA, Lancione S, Lang JJ, Amankwah N, de Groh M, Jaramillo Garcia A, Merucci K, Geneau R. Examining the state, quality and strength of the evidence in the research on built environments and physical activity among children and youth: an overview of reviews from high income countries. Health Place. 2022;76:102828.
7. Fletcher AC, Nickerson P, Wright KL. Structure leisure activities in middle childhood: Links to wellbeing. J Community Psychol. 2003;31:641–59.
8. ESRI: ArcGIS Desktop. Release 10. Redlands: Environmental Systems Research Institute; 2011.
9. Pontin FL, Jenneson VL, Morris MA, Clarke GP, Lomax NM. Objectively measuring the association between the built environment and physical activity: a systematic review and reporting framework. Int J Behav Nutr Phys Act. 2022;19(1):119.
10. Kremers SP, de Bruijn GJ, Visscher TL, van Mechelen W, de Vries NK, Brug J. Environmental influences on energy balance-related behaviors: a dual-process view. Int J Behav Nutr Phys Act. 2006;3:9.
11. Rowlands AV, Eston RG. The measurement and interpretation of children's physical activity. J Sports Sci Med. 2007;6:270–6.
12. Migueles JH, Aadland E, Andersen LB, Brond JC, Chastin SF, Hansen BH, Konstabel K, Kvalheim OM, McGregor DE, Rowlands AV, et al. GRANADA consensus on analytical approaches to assess associations with accelerometer-determined physical behaviours (physical activity, sedentary behaviour and sleep) in epidemiological studies. Br J Sports Med. 2022;56(7):376–84.
13. Kelly P, Fitzsimons C, Baker G. Should we reframe how we think about physical activity and sedentary behaviour measurement? Validity and reliability reconsidered. Int J Behav Nutr Phys Act. 2016;13:32.
14. Bringolf-Isler B, Grize L, Mader U, Ruch N, Sennhauser FH, Braun-Fahrlander C. Built environment, parents' perception, and children's vigorous outdoor play. Prev Med. 2010;50(5–6):251–6.
15. Bringolf-Isler B, Grize L, Mader U, Ruch N, Sennhauser FH, Braun-Fahrlander C. Assessment of intensity, prevalence and duration of everyday activities in Swiss school children: a cross-sectional analysis of accelerometer and diary data. Int J Behav Nutr Phys Act. 2009;6:50.
16. Robusto KM, Trost SG. Comparison of three generations of ActiGraph activity monitors in children and adolescents. J Sports Sci. 2012;30(13):1429–35.
17. Jones RA, Hinkley T, Okely AD, Salmon J. Tracking physical activity and sedentary behavior in childhood: a systematic review. Am J Prev Med. 2013;44(6):651–8.
18. Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. Med Sci Sports Exerc. 2005;37(11 Suppl):S523-530.
19. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc. 2008;40(1):181–8.
20. Carver A, Timperio A, Crawford D. Perceptions of neighborhood safety and physical activity among youth: the CLAN study. J Phys Act Health. 2008;5(3):430–44.
21. Bundesamt für Landestopographie der Schweiz: Landestopographie Bf. VECTOR25–Das digitale Landschaftsmodell der Schweiz. Wabern; 2000.
22. Measuring Vegetation (NDVI & EVI) http://earthobservatory.nasa.gov/Features/MeasuringVegetation/.
23. Räumliche Gliederung. https://www.bfs.admin.ch/bfs/de/home/grundlagen/raumgliederungen.html.
24. Panczak R, Galobardes B, Voorpostel M, Spoerri A, Zwahlen M, Egger M. A Swiss neighbourhood index of socioeconomic position: development and association with mortality. J Epidemiol Community Health. 2012;66:1129–36.
25. Mathisen FKS, Torsheim T, Falco C, Wold B. Leisure-time physical activity trajectories from adolescence to adulthood in relation to several activity domains: a 27-year longitudinal study. Int J Behav Nutr Phys Act. 2023;20(1):27.
26. Lounassalo I, Salin K, Kankaanpaa A, Hirvensalo M, Palomaki S, Tolvanen A, Yang X, Tammelin TH. Distinct trajectories of physical activity and related factors during the life course in the general population: a systematic review. BMC Public Health. 2019;19(1):271.
27. Eigenschenk B, Thomann A, McClure M, Davies L, Gregory M, Dettweiler U, Ingles E. Benefits of outdoor sports for society. A systematic literature review and reflections on evidence. Int J Environ Res Public Health. 2019;16(6):937.
28. Van Dyck D, Cerin E, Cardon G, Deforche B, Sallis JF, Owen N, de Bourdeaudhuij I. Physical activity as a mediator of the associations between neighborhood walkability and adiposity in Belgian adults. Health Place. 2010;16(5):952–60.
29. Andersen OK, Gebremariam MK, Kolle E, Tarp J. Socioeconomic position, built environment and physical activity among children and adolescents: a systematic review of mediating and moderating effects. Int J Behav Nutr Phys Act. 2022;19(1):149.

30. Agran PF, Winn DG. The bicycle: a developmental toy versus a vehicle. Pediatrics. 1993;91(4):752–5.
31. Bringolf-Isler B, Kriemler S, Mader U, Dossegger A, Hofmann H, Puder JJ, Braun-Fahrlander C. Relationship between the objectively-assessed neighborhood area and activity behavior in Swiss youth. Prev Med Rep. 2014;1:14–20.
32. Yang X, Telama R, Hirvensalo M, Tammelin T, Viikari JS, Raitakari OT. Active commuting from youth to adulthood and as a predictor of physical activity in early midlife: the young Finns study. Prev Med. 2014;59:5–11.