



BUILT ENVIRONMENT AND PHYSICAL ACTIVITY IN NEW ZEALAND ADOLESCENTS: A CROSS SECTIONAL STUDY

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3 **BUILT ENVIRONMENT AND PHYSICAL ACTIVITY IN NEW ZEALAND**
4 **ADOLESCENTS: A CROSS SECTIONAL STUDY**
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Abstract

Introduction: Built-environment interventions have the potential to provide population-wide effects and provide the means for a sustained effect on behavior change. Population-wide effects for adult physical activity have been shown with selected built environment attributes; however, the association between the built environment and adolescent health behaviors is less clear.

Aim: This New Zealand study is part of an international project across 10 countries (International Physical Activity and the Environment Network study – Adolescents) that aims to characterize the links between built environment and adolescent health outcomes.

Methods and Analyses: An observational, cross-sectional study of the associations between measures of the built environment with physical activity, sedentary behavior, body size, and social connectedness in 1,600 New Zealand adolescents aged 12-18 years will be conducted. Walkability and neighborhood destination accessibility indices will be objectively measured using Geographic Information Systems (GIS). Physical activity and sedentary behaviors will be objectively measured using accelerometers over seven consecutive days. Body mass index will be calculated as weight divided by squared height. Demographics, socioeconomic status, active commuting behaviors, and perceived neighborhood walkability will be assessed using the Neighborhood Environment Walkability Scale for Youth and psychosocial indicators. A web-based computer-assisted personal interview (CAPI) tool (VERITAS) and Global Positioning System (GPS) receivers will be used in a subsample of 300 participants. A qualitative research component will explore barriers and facilitators for physical activity in adolescents with respect to the built and social environment in a subsample of 80 participants.

Ethics and dissemination: The study received ethical approval from the Auckland University of Technology Ethics Committee (12/161). Data will be entered and stored into a secure (password protected) database. Only the named researchers will have access to the data. Data will be stored for 10 years and permanently destroyed thereafter. The results papers will be submitted for publication in peer-reviewed journals.

Strengths and limitations of this study

- Limited data exists on detailed and multilevel relationships of interaction between the social and physical environments specific to the NZ adolescents.
- The use of GPS/VERITAS will define the adolescents' geographical context and will provide accurate estimates of location in which physical activity takes place.
- The study forms the NZ arm of the international IPEN-Adolescents collaboration, whereby adolescents' physical activity and sedentary behaviour data are collected using a common methodology across multiple countries.
- Parents may self-select neighborhoods, therefore associations between built environment and walkability may in part be a reflection of neighborhood self-selection bias. Parents' neighborhood preference and self-selection will be accounted for in the analysis.
- When conducting spatial analyses on aggregated data, errors affecting the validity of results may be introduced. Geo-coded data and other techniques will assist in gaining a more accurate understanding of neighborhood boundaries for adolescents.

Built environment and physical activity in New Zealand adolescents: A cross sectional study

Introduction

The benefits of physical activity in youth are well documented [1-5]. Regular moderate-to-vigorous physical activity (MVPA) is positively associated with musculoskeletal health, cardiovascular wellbeing (e.g., healthy blood pressure, lipid and lipoprotein levels, cardiovascular autonomic tone), metabolic health, maintenance of a healthy weight, psychological wellbeing (e.g., improved self-concept, reduced anxiety and depression), and reduced risk of type 2 diabetes [6,7]. The accumulation of at least 60 minutes of MVPA per day is recommended for youth; however, accumulating physical activity below this threshold is still beneficial, especially for those whose health is at risk (e.g., overweight or obese youth) [6]. Despite awareness of the well-established benefits of physical activity, rapid changes in technology and the habitual environment over the last 50 years may have caused an increase in sitting, passive travel, and subsequently a reduction in incidental physical activity [8]. Furthermore, over the course of adolescence, physical activity typically decreases by 60-70% [9], while sedentary behaviour remains high at 7-14 hours per day [10-12]. The latter trend is particularly concerning given that emerging evidence suggests that sedentary behaviour has negative effects on health that are independent of the beneficial effects of physical activity [13-15]. Additionally, levels of activity during school age years significantly predict activity levels [16] and health outcomes [17] into adulthood.

Behavioural modification programmes have only achieved limited and mostly short term physical activity improvements [18-20]. For sustainable changes that optimise positive behaviours, it is important to understand that physical activity and sedentary behaviours occur within a broader ecological framework [21]. It is recognised that in order to be effective, complex integrated interventions are required that include supportive policies and social and physical environments [22,23]. Manipulating social and physical environments to be more health promoting will likely have sustainable and far-reaching impacts on population health behaviours and outcomes. We have previously examined the relationship of objective built environment measures (i.e., destination access, street connectivity, dwelling density, land use mix) with accelerometer-derived and self-reported physical activity in adults [24]. The work was part of a larger international study (IPEN-International Physical activity and Environment Network) with 12 participating countries. The potential of walkable neighborhoods for supporting health-enhancing increases in physical activity, at least for adults, was high [24]. A one standard deviation increase in neighborhood walkability variables yielded a 7-13% increase in physical activity. This effect is likely to be much higher than effects achieved through behavioural intervention alone [25,26].

While the evidence base for associations between the built environment and physical activity in adults has been steadily accumulating [24,27,28], our understanding of this relationship in adolescents is at its infancy [29-38], and at times non-intuitive [33,39]. Adolescents were consistently identified in our adult focus groups in our previous study as a sub-group whose changing needs for independent mobility and age- and culturally-appropriate forms of physical activity are less likely to be met, particularly in more suburban built environment forms [40]. In a recent review, land-use mix and residential density were the most highly correlated built environment variables with overall physical activity in youth [41]. However,

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3 the review did not find any environmental variables that consistently correlated with physical
4 activity in adolescents. Nonetheless, latest research indicates that adolescents' physically
5 activity tends to occur close to their homes [42,43], and that strong associations exist between
6 inactivity with lower neighborhood walkability, amount of public open space, and
7 neighborhood safety [44], as well as higher densities of cul-de-sac networks [36]. MVPA is
8 significantly lower for rural adolescents compared to those living in urban environments,
9 however these differences between neighborhood type are not seen for BMI [45]. Geospatial
10 data indicate that adolescent girls engage in higher intensity physical activity in places with
11 parks, schools, and higher population density, and accumulate lower levels of physical
12 activity in places with more roads and food outlets [32]. Low-income adolescents were
13 physically active at fields/courts, indoor recreation facilities, small and large parks, and
14 swimming pools [43] but reduced accessibility of physical activity facilities and food outlets
15 was associated with being overweight [34].
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18 In the Built Environment and Adolescent New Zealanders (BEANZ) study, we seek to
19 understand the relationship of physical activity, sedentary behaviour, and body size with
20 neighborhood-level built environment features in New Zealand (NZ) adolescents. We
21 hypothesise that neighborhood walkability and neighborhood destination accessibility indices
22 will be positively associated with minutes of MVPA, and inversely associated with minutes
23 of sedentary time and body mass index (BMI). We will also investigate associations between
24 the built environment and social connectedness to the community [46], the moderating effects
25 of ethnicity and mediating effects of active commuting, neighborhood mobility, and
26 perceived neighborhood walkability. A novel aspect of this study is the use of portable
27 global positioning system (GPS) receivers together with web-based interactive mapping and
28 geocoding software to examine adolescents' mobility and access to regular destinations.
29 These ancillary data will enable the shape and scale of environmental exposure to be defined
30 in considerable detail.
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32

33 Our study forms part of the IPEN-Adolescent collaboration, using comparable data
34 collection, management, and protocol sharing across 10 countries. By comparing diverse
35 countries, built environmental heterogeneity can be captured (and therefore generate robust
36 estimates of the real effects) while facilitating intra- and inter-country comparisons. The goal
37 is to generate credible evidence to guide long-term town planning, policy change, and
38 redesign of existing urban environments to maximise physical activity and community
39 connectedness and minimise sedentary behaviour and body size, all key determinants of
40 human health.
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44 **Method and analysis**

45
46 The standardized checklist for the Strengthening the Reporting of Observational Studies in
47 Epidemiology (STROBE) recommendations was used to ensure that all elements
48 recommended were address within this section [47].
49

50 **Design**

51
52 BEANZ will be based on an observational, cross-sectional design that examines the
53 associations of objective and subjective measures of the built environment with physical
54 activity, sedentary behaviour, body size, and social connectedness in 1,600 NZ adolescents
55 aged 12-18 years from eight secondary schools (approximately 200 participants per school).
56 Demographics, socioeconomic status, active commuting, psychosocial indicators, and
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3 perceptions of the built environment will be measured in the full sample. A GPS and
4 interactive mapping sub-study of approximately 300 participants will assess neighborhood
5 mobility by geolocating participants' destinations, modes of travel, activity locations,
6 walking/cycling area, and perceived neighborhood boundaries. Focus groups will explore
7 barriers and facilitators for physical activity with respect to neighborhood built and social
8 environment in a subsample of approximately 80 participants. Data will be collected from
9 two major cities in New Zealand: Auckland and Wellington. Auckland is the largest city in
10 New Zealand with a population of approximately 1.4 million residents (one third of the
11 country's population) [48], with a population density comparable to Los Angeles and
12 Helsinki [49]. Wellington, the capital city of New Zealand, is located on the southern part of
13 the North Island and has a population density comparable to Vancouver and Honolulu [49].
14 Ethical approval was received by the Institution's Ethics Committee (AUTEC, 12/161).
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17 Neighborhood, school and participant selection

18
19 Associations between exposure and outcome variables are estimated based on data collected
20 using a multistage sampling strategy. This strategy maximises heterogeneity in the exposure
21 variables (built environment) while allowing comparisons to be made between those of low
22 and high socioeconomic status (SES). In the first instance, GIS will be used to calculate three
23 built environment measures – street connectivity, residential density, and land use mix –for
24 each meshblock (smallest census tract units available in New Zealand) [40]. The raw scores
25 for these built environment measures will be normalised and summed to create a basic
26 walkability index. Next the basic walkability index and and pre-existing deprivation data (NZ
27 Dep 2006) will be used to classify all Auckland and Wellington urban meshblocks) into one
28 of four strata: (1) higher walkable, higher SES; (2) higher walkable, lower SES; (3) lower
29 walkable, higher SES; and (4) lower walkable, lower SES. Meshblocks with the top four
30 walkability/SES deciles are classified as higher walkable/SES, and meshblocks with the
31 bottom four walkability/SES deciles are classified as lower walkable/SES. Meshblocks with
32 walkability or SES in deciles 5 and 6 are excluded.
33
34

35 School selection will be based on convenience and close proximity to large numbers of
36 meshblocks in each of the four strata. Within each school, all potential participants will be
37 sampled, regardless of the quadrant they reside, and for each participant walkability will be
38 calculated: all students will be assigned to the strata of the meshblock they primarily reside
39 in. This procedure will take place prior to the consent process. Adolescents living in one of
40 the four meshblock strata will be invited to participate in the study. Participation in the study
41 will require written, informed consent from a parent or caregiver and written assent from the
42 adolescent. Subsequent schools will be selected on the basis of the quadrants that need to be
43 balanced. In addition to this approach, care will be taken to balance student numbers across
44 the four strata both within and across schools. A similar sampling strategy was used in our
45 previous study of the environmental correlates of physical activity in adults; the heterogeneity
46 generated by this technique permitted several meaningful associations to be detected [40]. A
47 sub-sample of approximately 40 participants will be randomly selected from each school for
48 the GPS and interactive mapping measurements.
49
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51 Sample size

52
53 In adjusted multilevel models, it has been estimated that a sample of 1,600 adolescents
54 recruited from two schools within each stratum (eight in total) would allow the detection of a
55 small effect size (i.e., 1.4% of explained outcome variance found in similar studies conducted
56 elsewhere [50]) with 80% power. The calculated sample size assumes a two-tailed probability
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level of 5%, a conservative clustering effect equivalent to an intra-class correlation coefficient of 0.10, and a regression model with 25 background covariates explaining 25% of the outcome variance (comparable to what might be expected from the selected variables). With an anticipated sample size of 320 Māori adolescents (our smallest sub-group comparison), the corresponding detectable effect size will be 7% of explained outcome variance (medium effect size).

Exposure, outcomes and covariates

Exposures

GIS data provide multiple spatially-referenced layers that can be used to create meaningful and objective exposure measures of the built environment. They are used to objectively characterise the built environment surrounding the primary home address of each participant and can be applied across a range of road network buffers (e.g., 500 m, 800 m, 1000 m, and 1600 m) in order to evaluate differences between various limits of exposure. Road network buffers can be created to define areas that can be reached on the street network system, but exclude areas that are not accessible due to major barriers (motorway, river, lake). Two main indices, each a composite function of 2-8 other variables, are used to assess physical environmental features: walkability index [51] and neighborhood destination accessibility index [52]. These are described in more detail below. All exposure measures (Table 1) follow the common protocols established for the international IPEN-Adolescents collaboration.

Table 1. Summary of study exposure, outcomes, and covariate

Exposure	Covariates
Detailed walkability index	Demographics
- Net residential density	- Age
- Land use mix	- Sex
- Retail density	- Ethnicity
- Street connectivity	- School
- Street discontinuity	Socioeconomic status
Neighborhood destination accessibility index	- Parent education
- Education destinations	- Parent occupation
- Transport destinations	- Family car ownership
- Recreation destinations	- Household crowding
- Social and cultural destinations	Active commuting
- Food retail destinations	- Frequency of active commuting
- Financial destinations	- Duration of active commuting
- Health destinations	Neighborhood mobility
- Other retail	- Frequency and location of regular destinations
	- Frequency and location of activity
	- Total walking area
	- Total cycling area
	- Perceived neighborhood boundary
	Perceived neighborhood walkability
	- Perceived residential density
	- Perceived land use mix
	- Perceived traffic/crime safety
Outcomes	
Physical activity behaviour	
- Minutes of MVPA	
- Minutes of light activity	
Sedentary behaviour	
- Minutes of overall sedentary activity	
- Minutes of television watching	
Body size	

- Body mass index	- Perceived aesthetics
- Waist circumference	Psychosocial indicators
	- Self-efficacy
	- Cons/barriers
	- Family support
	- Peer support
	Weather
	- Total rainfall
	- Mean temperature
	- Hours of daylight

Detailed walkability

The detailed walkability index is a summary score of five distinct variables calculated within GIS: net residential density, land use mix, retail density, street connectivity, and street discontinuity. This protocol was created for the US-based Neighborhood Quality of Life Study project, [51] and has been subsequently implemented in the US-based TEAN study [53], the Australian PLACE study, [54] and all IPEN Adult country study sites [55].

Neighborhood Destination Accessibility

Pedestrian access to destinations will be calculated using the Neighborhood Destination Accessibility Index (NDAI) [52]. The NDAI is an objective measure of pedestrian access to neighborhood destinations; it characterises the distribution of urban infrastructure within an 800m street network distance from residence. The NDAI has an advantage over most previous area-level measures of the urban environment in that it captures the range and intensity of everyday destinations such as schools, supermarkets and cafes, which may encourage active travel and enhance recreational physical activity at the population level. As well, the NDAI has been specifically designed for the New Zealand environment. The eight domains captured in the NDAI are education, transport, recreation and play, social and cultural, food retail, financial, health, and other retail.

Outcomes

Physical Activity

Minutes of MVPA will be objectively measured using hip-mounted triaxial accelerometers (Actigraph GT3X+) over seven consecutive days. The GT3X+ is a small, durable, and water resistant device worn on an elastic belt that records the frequency, duration, and intensity of physical activity with a high level of accuracy and precision [56]. Participants are asked to wear the Actigraph during all waking hours (except when bathing or swimming) for seven days; however, at least five complete days (including at least one weekend day) will be required for analysis to ensure reliable estimates of MVPA [57]. Consistent with previous research, a valid day will be defined as at least 10 hours of data for weekdays and 8 hours for weekend days; non-wear time will be defined as 60 minutes of consecutive zero counts [58,59]. In addition, each participant will be given a seven-day compliance log to complete daily, which assists with identifying non-wear periods. Upon collection of the accelerometer, data are downloaded and screened for completeness and possible malfunction using the Meterplus software (www.meterplussoftware.com). Accelerometer count data will be classified into minutes of light, moderate, and vigorous activity using thresholds developed

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3 by Evenson and colleagues [60]; these have performed well in a recent comparison of
4 accelerometer count thresholds for youth [61].

5 6 *Sedentary Behaviour*

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8 Minutes of sedentary activity will be objectively assessed using the GT3X+ accelerometer
9 over the seven-day measurement period. The aforementioned cut-points established by
10 Evenson and colleagues [60] will be used to define sedentary time (< 100 counts per minute).

11 12 *Body Size*

13
14 Height, weight, and waist circumference of each participant will be measured by trained field
15 researchers using a stadiometer, calibrated scales, and a tape measure. These procedures
16 occur immediately before the researchers distribute the accelerometers; participants wear
17 light clothing and shoes are removed. BMI will be calculated as weight divided by squared
18 height. Participants are classified into weight status categories using age- and sex-specific
19 BMI thresholds [62].

20 21 *Covariates*

22 23 *Demographics and socioeconomic status*

24
25 Age, sex, ethnicity, and SES will be collected from the participants. Consistent with the
26 IPEN-adolescents protocol, household income will be the preferred SES indicator, but
27 highest level of parental education will be used when income is unavailable.

28 29 *Active commuting*

30
31 The frequency, distance, duration, and mode of all active commuting trips to or from the
32 home address in the previous six months will be assessed with the CAPI. The recall of each
33 trip will be aided by a basic travel log (time, location, and mode of transport only) to be
34 completed nightly with the accelerometer compliance log. Participants will be asked to bring
35 this information with them to the subsequent CAPI.

36 37 *Neighborhood Mobility*

38
39 The majority of studies investigating the built environment and health have focused
40 exclusively on residential neighborhoods as a predictor of exposure [63,64], and overlooked
41 the prospect that a large proportion of activity choices may be influenced by additional
42 environments that are experienced during daily routines. This may reduce the accuracy of
43 environmental exposure assessment [65] and introduce errors that may confound research
44 results. It has been suggested that investigating aspects of daily mobility (regular destinations
45 and the movement between them) will be important to enhance the assessment of exposure
46 [66] and resolve the Uncertain Geographic Context Problem [67]. Using GPS and interactive
47 activity destination questionnaires, we aim to accurately capture the full extent of daily
48 mobility, and its mediating built environment effect on health.

49
50 The Visualization and Evaluation of Route Itineraries, Travel Destinations, and Activity
51 Spaces (VERITAS) is a web-based CAPI tool integrating interactive mapping capacities
52 (based on Google Maps) and has the potential to explore destinations both inside and outside
53 the residential neighborhood. VERITAS was initially developed and tested for the RECORD
54 Cohort Study, a major longitudinal study of over 7,200 French adults [68-71]. While we will
55 be using GIS to provide an objective assessment of the surrounding environment (i.e.,
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3 exposure measures), VERITAS will allow the research team to search and geolocate
4 participants' regular destinations (visited within the previous 6 months), activity locations,
5 walking/cycling area, routes and modes of travel between locations, travel companions, and
6 perceived or experienced neighborhood boundaries (i.e., neighborhood mobility). The
7 VERITAS programme will run through an internet browser on a laptop computer, and will be
8 designed to automatically upload all participant responses to our secure database when
9 connected to a wireless network. Spatio-temporal data will be collected using the Qstarz BT-
10 Q1000XT GPS receiver (Qstarz International, Taipei, Taiwan) which has been deemed one of
11 the more accurate portable GPS receivers on the market [72]. The GPS will be worn in a
12 pouch alongside the accelerometer. GPS data will be cleaned, filtered and merged with
13 accelerometer data using the Personal Activity Location Measurement System (PALMS,
14 refer to: <https://ucsd-palms-project.wikispaces.com>) [73]. The merged data streams retrieved
15 from PALMS will be disaggregated into discrete trips and imported into ArcGIS for further
16 analysis. Data obtained from GPS and VERITAS differ both temporally (previous 1 week
17 and 6 months, respectively) and spatially (a continuous sequential polyline compared with
18 point data). Although VERITAS will be able to obtain data for extended periods, it lacks the
19 temporal sequence of events available from GPS tracking. However, as short periods of GPS
20 monitoring may not truly represent destinations visited over extended periods, the
21 combination of both has been recommended to create complementary and more robust
22 measures of environmental exposure [70].
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26 The neighborhood mobility data will allow the demarcation of the territorial range by active
27 travel modes. A spatial 'polygon' will be created consisting of a multisided geometric shape
28 surrounding the home address that connects the various locations to which participants claim
29 to have walked or cycled. The area (m²) within these polygons will be calculated and used to
30 define separate shapes based on the travel modes. In situations where participants walk or
31 cycle to only one location (e.g., school) the polygon area will be the distance between the
32 location and home addresses multiplied by 1 m. As with the active commuting assessment,
33 the recall of visited locations and trips will be aided by the travel log that will be completed
34 daily. Finally, using VERITAS, each participant will be able to map their perceived
35 neighborhood boundary, allowing us to isolate the effects of their self-defined neighborhood
36 environment on the outcome measures.
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39 *Perceived Neighborhood Walkability*

40
41 In order to understand the mediating effect of individual perceptions of the neighborhood on
42 the relationship between the objectively-measured built environment and physical activity
43 behaviour, the Neighborhood Environment Walkability Scale for Youth (NEWS-Y) [81] will
44 be administered as a self-completion hard copy survey. NEWS-Y is based on the NEWS,
45 which has demonstrated good reliability and validity [74-78]. In addition to the GIS-based
46 walkability index variables (residential density, land use mix, street connectivity), NEWS-Y
47 assesses pedestrian/cycle facilities, aesthetics, traffic safety, and crime safety. The ten
48 NEWS-Y subscales have acceptable test-retest reliability (ICC: 0.56-0.87) and specific
49 subscales were correlated significantly with physical activity for adolescents [79].
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52 *Psychosocial Indicators*

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54 A small number of psychosocial variables associated with adolescent physical activity will be
55 measured in the study. These include: self-efficacy; perceived barriers to being physically
56 activity; family support; and peer support [79]. These variables have shown the most
57 consistent psychosocial correlations with adolescent physical activity in the literature [80].
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3 Further, by including such items we are able to examine our findings within a multilevel
4 framework thereby accounting for and separating the various layers of influence (i.e.,
5 individual, social, and physical environments) [81].
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7 Weather

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9 We have previously demonstrated the significant impact of inclement weather conditions on
10 physical activity in New Zealand children [82]. To monitor these potential confounding
11 effects we will obtain hourly rainfall, mean temperature, and hours of daylight statistics from
12 the New Zealand Met Service for each data collection day and use these as covariates in the
13 models.
14

15 Procedures

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17 Data will be collected from participants within the school setting in school hours. During the
18 measurement session, the NEWS-Y [79] questionnaire will be administered, anthropometric
19 measures will be taken and accelerometers and compliance logs will be distributed. Text
20 messages will be sent to adolescents/parents before data collection session as a reminder to
21 attend. A random sub-sample of 40 adolescents per school will be allocated a GPS receiver to
22 wear in conjunction with the accelerometer, and will complete the VERITAS interview. All
23 participants will be instructed on the correct use, wear-time, and care of the equipment.
24 Participants will be issued with a \$20 shopping voucher upon completion of data collection
25 and return of the monitors and compliance logs.
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28 Quantitative Analyses

29
30 The proposed dataset will have a hierarchical independent variable structure which consists
31 of person-level observations nested within neighborhoods and schools. The main aim of the
32 study is to examine confounder-adjusted associations of environmental variables with
33 physical activity and body size outcomes. For this purpose, cross-classified (by
34 neighborhoods and schools) generalized linear mixed models (MGLM) with random
35 intercepts will be used. These can account for multiple sources of dependency (schools and
36 neighborhoods) and different types of data (e.g., continuous or binary) following a Normal or
37 other types of distributions (e.g., negative binomial, Poisson) [83]. MGLMs perform well
38 when the number of observations across areas is highly unbalanced, [84] which will be
39 relevant to this project as the number of participants may vary substantially across schools
40 and neighborhoods. Given the relatively small number of strata included in the study,
41 MGLMs will be estimated using Restricted Maximum Likelihood (REML) or Bayesian
42 Markov chain Monte Carlo (MCMC) methods with non-informative priors, [85] the latter
43 appropriate for binary (e.g., overweight/obese vs. normal weight) [85,86] or non-normally
44 distributed outcomes [83]. Non-linear relationship will be examined using restricted cubic
45 splines [87]. A probability level of 0.05 will be adopted.
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50 Qualitative Methodology

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52 A total of 16 focus groups, with approximately 5-8 participants, will be conducted at eight
53 participating schools. Variability in walkability will be sought by recruiting two schools in
54 Auckland (representing relatively low walkability) and Wellington (relatively high
55 walkability). However students within focus groups will be selected to represent a range of
56 neighborhood settings to facilitate discussion on differing experiences of the built
57 environment. Participants will also take part in the quantitative component and completed all
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3 data collection. To aid open discussion and allow meaningful comparisons separate focus
4 groups will be conducted by age, with younger students (approximately 12-14 years) further
5 stratified by sex, and older students (approximately 15-18 years) in mixed sex groups [43].
6 Focus groups will be conducted using 40 min school periods to accommodate school
7 timetables semi-structured interview. The focus groups are designed to examine the enablers
8 and barriers to being physically active, particularly with regard to active transport,
9 engagement in formal and informal physical activity, safety, and social drivers. Researchers
10 will specifically seek discussion on activity within participants' residential neighborhood and
11 school environments as well as alternative activity spaces in their everyday lives, including
12 those outside of their geographical suburbs. Maps of local environments to prompt discussion
13 on where youth are active (and where they avoid), types of activity, and travel routes will be
14 used. Interviews will be digitally recorded and transcribed by group, with all individual
15 identifying information removed.
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19 Qualitative Analyses

20
21 Following transcription a coding framework will be developed using NVivo software to
22 organise data generated by the project research questions (deductive) and emergent topics
23 (inductive) [88]. Using data extracted from codes, thematic analyses will be conducted to
24 examine issues with regard to the built environment and physical activity. Analyses will be
25 conducted across and within groups to examine commonalities and differences by built
26 environment settings and individual factors (i.e., sex, age, and culture). Concurrent analyses
27 of qualitative and quantitative data will allow insightful integration and triangulation of
28 findings across the study components, allowing us to draw inferences about how youth
29 interact with and manage their lived environments, and what that means for their physical
30 activity and wellbeing [89,90].
31
32

33 Ethics and dissemination

34
35 All adolescents will be required to provide assent to participate in the study. An information
36 sheet will be designed specifically for adolescents in a manner that it will be easy to
37 understand. Additionally, all parents of the assenting adolescents will be required to provide
38 parental consent. Parents will also receive a detailed information sheet outlining the study and
39 its requirements.
40
41

42 Data will be entered and stored into a secure (password protected) database. Only the named
43 researchers will have access to the data. Data will be stored for 10 years and permanently
44 destroyed thereafter.
45

46 It is unlikely that participants will experience discomfort or embarrassment during data
47 collection. However, as body measures of weight and height will be objectively assessed,
48 there is the potential of concern around body weight and size. The institution's counselling
49 services will be accessed if a situation arises. All body measurements will be taken behind a
50 portable screen with gender appropriate research officers. All data will be kept private and
51 confidential.
52

53 At the completion of the study, results will be provided to key stakeholders and organisations
54 (e.g., high schools, adolescents, and parents). Results will be disseminated by means of a
55 written report to schools that have participated in the study. Adolescents and/or their
56 parents/legal guardians will receive a report detailing the individual results collected.
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3 Government organizations, health boards, and councils, will be able to access key findings
4 and recommendations resulting from the project through seminar presentations and report
5 distribution. Research findings will also be circulated to the scientific community in the form
6 publications in refereed journals.
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10 Discussion

11
12 We have described the methods for the BEANZ study which seeks to estimate strengths of
13 association between objective measures of the local environment with accelerometer-derived
14 and self-reported physical activity and sedentary behaviour in youth. A novel aspect of this
15 study is the exploration of detailed and multilevel relationships of interaction between the
16 social and physical environments specific to the NZ adolescents. This will be achieved
17 through additional measures (e.g., GPS, VERITAS, focus groups, NDAI) which collectively
18 serve to advance knowledge in this important area of health research, policy advocacy, and
19 ultimately youth health outcomes. Particularly, the use of GPS/VERITAS to identify the
20 locations that adolescents visit on a daily basis, defining their geographical context, will
21 provide us with accurate estimates of location in which physical activity takes place.
22
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25 International evidence shows that the most consistent environmental attributes positively
26 associated with reported physical activity in youth were land use mix and residential density,
27 but inconsistent findings have been observed for parks, recreation facilities, and street
28 connectivity [41]. Others found that proximity to parks, recreation facilities and proximity to
29 school [32,43,91,92] along with transport infrastructure were positively associated with
30 physical activity in adolescents [92]. Traffic hazards (number of roads to cross, traffic speed)
31 and local conditions (crime, area deprivation) were negatively associated with physical
32 activity [44,92]. Obesogenic environmental attributes of homes, neighborhoods, and schools
33 are believed to promote sedentary behaviour among youth [93] and there is growing evidence
34 that being socially connected with others contributes to adolescent wellbeing [46]. While
35 some evidence exists to show the importance of the built environment for adolescent physical
36 activity and well-being, the use of different methods and limited physical variability within
37 any given environment may serve to consistently underestimate the associations observed. In
38 this study, variance is maximised in two ways. Two major cities in New Zealand are sampled,
39 and these data are subsequently combined with nine other countries through the IPEN-
40 Adolescent study. The larger study will improve our understanding of the nature of the
41 relationships that exist between adolescent physical activity, sedentary behaviour and body
42 weight with specific features of the built environment related to walkability, commuting and
43 access to facilities for recreation.
44
45

46
47 Individuals (or at least parents) may self-select neighborhoods, therefore associations
48 between built environment and walkability may in part be a reflection of neighborhood self-
49 selection bias. Mixed results have been found when investigating neighborhood self-selection
50 and walkability [94-98]. The relationship is a complex one and prospective studies are needed
51 to study the effects of neighborhood self-selection on neighborhood walkability. When
52 reviewing 38 empirical studies that used different approaches to explore the influence of self-
53 selection, Cao and colleagues [99] established that all studies reviewed found a statistically
54 significant influence of the built environment after accounting for self-selection. While
55 exploring this particular relationship is not the focus of the present study, parents'
56 neighborhood preference and self-selection will be accounted for in the analysis.
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3 When conducting spatial analyses on aggregated data, errors affecting the validity of results
4 may be introduced [100]. The problem has been referred to as the Modifiable Areal Unit
5 Problem defined as the ‘geographic manifestation of the ecological fallacy in which
6 conclusions based on data aggregated to a particular set of districts may change if one
7 aggregates the same underlying data to a different set of districts’ [101]. In other words, the
8 way spatial data are aggregated may result in different findings. There has been disagreement
9 in the literature on the best solution for this problem; however, it has been suggested that the
10 only appropriate resolution is to use individual-level data that are geocoded based on
11 residential location [102]. Indeed, our selection strategy uses geo-coded data and we are
12 employing techniques (GPS and VERITAS) to gain a more accurate understanding of
13 neighborhood boundaries for youth. This will substantially advance our knowledge in this
14 field.
15

16
17 This study will contribute to national and international scientific knowledge by forming the
18 NZ arm of the international IPEN-Adolescents collaboration, whereby adolescents’ physical
19 activity and sedentary behaviour data are collected using a common methodology across
20 multiple countries (Australia, Belgium, Brazil, China, Denmark, Malaysia, New Zealand,
21 Portugal and USA). Furthermore the larger study will improve our understanding of the
22 nature of the relationships that exist between adolescent physical activity, sedentary
23 behaviour and body weight with specific features of the built environment related to
24 walkability, commuting and access to facilities for recreation.
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26

27 Ultimately, by showing the relationships between health outcomes and the neighborhood
28 built environment, we aim to influence and inform policy and city planning practices. City
29 planners, policy makers and government agencies will be engaged early [103] [104]. Results
30 will also be shared with other sustainable transport advocacy, urban planners, and public
31 health organisations. Dissemination of findings to NZ secondary schools and students
32 themselves will maximise the potential impact of the findings.
33
34

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37
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42 43 **Authors’ contributions**

44
45 EH developed the first draft of the manuscript. EH, SD, MO, SM, EC, HB, VI, JM, and GS
46 contributed to the conception and the design of the study. All authors provided feedback
47 during manuscript development. Each author has read and approved the final manuscript.
48
49

50 51 **Competing interests**

52
53 The authors declare that they have no competing interests.
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For peer review only

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation
Title and abstract	1	<p>✓ (a) Indicate the study's design with a commonly used term in the title or the abstract</p> <p>✓ (b) Provide in the abstract an informative and balanced summary of what was done and what was found</p>
Introduction		
Background/rationale	2	✓ Explain the scientific background and rationale for the investigation being reported
Objectives	3	✓ State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	✓ Present key elements of study design early in the paper
Setting	5	✓ Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	✓ (a) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	7	✓ Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	✓ For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	✓ Describe any efforts to address potential sources of bias
Study size	10	✓ Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	<p>✓ (a) Describe all statistical methods, including those used to control for confounding</p> <p>(b) Describe any methods used to examine subgroups and interactions</p> <p>(c) Explain how missing data were addressed</p> <p>(d) If applicable, describe analytical methods taking account of sampling strategy</p> <p>(e) Describe any sensitivity analyses</p>
Results		
Participants	13*	<p>(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed</p> <p>(b) Give reasons for non-participation at each stage</p> <p>(c) Consider use of a flow diagram</p>
Descriptive data	14*	<p>(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders</p> <p>(b) Indicate number of participants with missing data for each variable of interest</p>
Outcome data	15*	Report numbers of outcome events or summary measures
Main results	16	<p>(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included</p> <p>(b) Report category boundaries when continuous variables were categorized</p> <p>(c) If relevant, consider translating estimates of relative risk into absolute risk for a</p>

		meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18	✓ Summarise key results with reference to study objectives
Limitations	19	✓ Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	✓ Discuss the generalisability (external validity) of the study results
Other information		
Funding	22	✓ Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.



**BUILT ENVIRONMENT AND PHYSICAL ACTIVITY IN NEW
ZEALAND ADOLESCENTS: A PROTOCOL FOR A CROSS
SECTIONAL STUDY**

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3 **BUILT ENVIRONMENT AND PHYSICAL ACTIVITY IN NEW ZEALAND**
4 **ADOLESCENTS: A PROTOCOL FOR A CROSS SECTIONAL STUDY**
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14 Running title: Built environment and physical activity in NZ adolescents

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18 Key words: Accelerometer, accessibility, GPS, neighborhood, walkability

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22 Word Count: 5,702

Abstract

Introduction: Built-environment interventions have the potential to provide population-wide effects and provide the means for a sustained effect on behavior change. Population-wide effects for adult physical activity have been shown with selected built environment attributes; however, the association between the built environment and adolescent health behaviors is less clear. This New Zealand study is part of an international project across 10 countries (International Physical Activity and the Environment Network– Adolescents) that aims to characterize the links between built environment and adolescent health outcomes.

Methods and Analyses: An observational, cross-sectional study of the associations between measures of the built environment with physical activity, sedentary behavior, body size, and social connectedness in 1,600 New Zealand adolescents aged 12-18 years will be conducted in 2013-2014. Walkability and neighborhood destination accessibility indices will be objectively measured using Geographic Information Systems (GIS). Physical activity and sedentary behaviors will be objectively measured using accelerometers over seven consecutive days. Body mass index will be calculated as weight divided by squared height. Demographics, socioeconomic status, active commuting behaviors, and perceived neighborhood walkability will be assessed using the Neighborhood Environment Walkability Scale for Youth and psychosocial indicators. A web-based computer-assisted personal interview (CAPI) tool (VERITAS) and Global Positioning System (GPS) receivers will be used in a subsample of 300 participants. A qualitative research component will explore barriers and facilitators for physical activity in adolescents with respect to the built and social environment in a subsample of 80 participants.

Ethics and dissemination: The study received ethical approval from the Auckland University of Technology Ethics Committee (12/161). Data will be entered and stored into a secure (password protected) database. Only the named researchers will have access to the data. Data will be stored for 10 years and permanently destroyed thereafter. The results papers will be submitted for publication in peer-reviewed journals.

Strengths and limitations of this study

- Limited data exists on detailed and multilevel relationships of interaction between the social and physical environments specific to the NZ adolescents.
- The use of GPS/VERITAS will define the adolescents' geographical context and will provide accurate estimates of location in which physical activity takes place.
- The study forms the NZ arm of the international IPEN-Adolescents collaboration, whereby adolescents' physical activity and sedentary behavior data are collected using a common methodology across multiple countries.
- Parents may self-select neighborhoods, therefore associations between built environment and walkability may in part be a reflection of neighborhood self-selection bias. Parents' neighborhood preference and self-selection will be accounted for in the analysis.
- When conducting spatial analyses on aggregated data, errors affecting the validity of results may be introduced. Geo-coded data and other techniques will assist in gaining a more accurate understanding of neighborhood boundaries for adolescents.

Built environment and physical activity in New Zealand adolescents: A cross sectional study

Introduction

The benefits of physical activity in youth are well documented [1-5]. Regular moderate-to-vigorous physical activity (MVPA) is positively associated with musculoskeletal health, cardiovascular wellbeing (e.g., healthy blood pressure, lipid and lipoprotein levels, cardiovascular autonomic tone), metabolic health, maintenance of a healthy weight, psychological wellbeing (e.g., improved self-concept, reduced anxiety and depression), and reduced risk of type 2 diabetes [6,7]. The accumulation of at least 60 minutes of MVPA per day is recommended for youth; however, accumulating physical activity below this threshold is still beneficial, especially for those whose health is at risk (e.g., overweight or obese youth) [6]. Despite awareness of the well-established benefits of physical activity, rapid changes in technology and the habitual environment over the last 50 years may have caused an increase in sitting, passive travel, and subsequently a reduction in incidental physical activity [8]. Furthermore, over the course of adolescence, physical activity typically decreases by 60-70% [9], while sedentary behavior remains high at 7-14 hours per day [10-12]. The latter trend is particularly concerning given that emerging evidence suggests that sedentary behavior has negative effects on health that are independent of the beneficial effects of physical activity [13-15]. Additionally, levels of activity during school age years significantly predict activity levels [16] and health outcomes [17] into adulthood.

Behavioral modification programmes have only achieved limited and mostly short term physical activity improvements [18-20]. For sustainable changes that optimise positive behaviors, it is important to understand that physical activity and sedentary behaviors occur within a broader ecological framework [21]. It is recognised that in order to be effective, complex integrated interventions are required that include supportive policies and social and physical environments [22,23]. Manipulating social and physical environments to be more health promoting will likely have sustainable and far-reaching impacts on population health behaviors and outcomes. We have previously examined the relationship of objective built environment measures (i.e., destination access, street connectivity, dwelling density, land use mix) with accelerometer-derived and self-reported physical activity in adults [24]. The work was part of a larger international study (IPEN-International Physical activity and Environment Network) with 12 participating countries. The potential of walkable neighborhoods for supporting health-enhancing increases in physical activity, at least for adults, was high [24]. A one standard deviation increase in neighborhood walkability variables yielded a 7-13% increase in physical activity. This effect is likely to be much higher than effects achieved through behavioral intervention alone [25,26].

While the evidence base for associations between the built environment and physical activity in adults has been steadily accumulating [24,27,28], our understanding of this relationship in adolescents is at its infancy [29-38], and at times non-intuitive [33,39]. Adolescents were consistently identified in our adult focus groups in our previous study as a sub-group whose changing needs for independent mobility and age- and culturally-appropriate forms of physical activity are less likely to be met, particularly in more suburban built environment forms [40]. In a recent review, land-use mix and residential density were the most highly correlated built environment variables with overall physical activity in youth [41]. However,

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3 the review did not find any environmental variables that consistently correlated with physical
4 activity in adolescents. Nonetheless, latest research indicates that adolescents' physically
5 activity tends to occur close to their homes [42,43], and that strong associations exist between
6 inactivity with lower neighborhood walkability, amount of public open space, and
7 neighborhood safety [44], as well as higher densities of cul-de-sac networks [36]. MVPA is
8 significantly lower for rural adolescents compared to those living in urban environments,
9 however these differences between neighborhood type are not seen for BMI [45]. Geospatial
10 data indicate that adolescent girls engage in higher intensity physical activity in places with
11 parks, schools, and higher population density, and accumulate lower levels of physical
12 activity in places with more roads and food outlets [32]. Low-income adolescents were
13 physically active at fields/courts, indoor recreation facilities, small and large parks, and
14 swimming pools [43] but reduced accessibility of physical activity facilities and food outlets
15 was associated with being overweight [34].
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18 In the Built Environment and Adolescent New Zealanders (BEANZ) study, we seek to
19 understand the relationship of physical activity, sedentary behavior, and body size with
20 neighborhood-level built environment features in New Zealand (NZ) adolescents. We
21 hypothesise that neighborhood walkability and neighborhood destination accessibility indices
22 will be positively associated with minutes of MVPA, and inversely associated with minutes
23 of sedentary time and body mass index (BMI). We will also investigate associations between
24 the built environment and social connectedness to the community [46], the moderating effects
25 of ethnicity and mediating effects of active commuting, neighborhood mobility, and
26 perceived neighborhood walkability. A novel aspect of this study is the use of portable
27 global positioning system (GPS) receivers together with web-based interactive mapping and
28 geocoding software to examine adolescents' mobility and access to regular destinations.
29 These ancillary data will enable the shape and scale of environmental exposure to be defined
30 in considerable detail.
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33 Our study forms part of the IPEN-Adolescent collaboration, using comparable data
34 collection, management, and protocol sharing across 10 countries. By comparing diverse
35 countries, built environmental heterogeneity can be captured (and therefore generate robust
36 estimates of the real effects) while facilitating intra- and inter-country comparisons. The goal
37 is to generate credible evidence to guide long-term town planning, policy change, and
38 redesign of existing urban environments to maximise physical activity and community
39 connectedness and minimise sedentary behavior and body size, all key determinants of
40 human health.
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44 **Method and analysis**

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46 The standardized checklist for the Strengthening the Reporting of Observational Studies in
47 Epidemiology (STROBE) recommendations was used to ensure that all elements
48 recommended were address within this section [47].
49

50 **Design**

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52 BEANZ will be based on an observational, cross-sectional design that examines the
53 associations of objective and subjective measures of the built environment with physical
54 activity, sedentary behavior, body size, and social connectedness in 1,600 NZ adolescents
55 aged 12-18 years from eight secondary schools (approximately 200 participants per school).
56 Moreover, differences between non-Māori and Māori population groups will be explored.
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3 Demographics, socioeconomic status, active commuting, psychosocial indicators, and
4 perceptions of the built environment will be measured in the full sample. Data will be
5 collected in the 2013-2014 academic school years for the southern hemisphere. A GPS and
6 interactive mapping sub-study of approximately 300 participants will assess neighborhood
7 mobility by geolocating participants' destinations, modes of travel, activity locations,
8 walking/cycling area, and perceived neighborhood boundaries. Focus groups will explore
9 barriers and facilitators for physical activity with respect to neighborhood built and social
10 environment in a subsample of approximately 80 participants. Data will be collected from
11 two major cities in New Zealand: Auckland and Wellington. Auckland is the largest city in
12 New Zealand with a population of approximately 1.4 million residents (one third of the
13 country's population) [48], with a population density comparable to Los Angeles and
14 Helsinki [49]. Wellington, the capital city of New Zealand, is located on the southern part of
15 the North Island and has a population density comparable to Vancouver and Honolulu [49].
16 Ethical approval was received by the Institution's Ethics Committee (AUTEC, 12/161).
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19 Neighborhood, school and participant selection

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21 Associations between exposure and outcome variables are estimated based on data collected
22 using a multistage sampling strategy. This strategy maximises heterogeneity in the exposure
23 variables (built environment) while allowing comparisons to be made between those of low
24 and high socioeconomic status (SES). In the first instance, GIS will be used to calculate three
25 built environment measures – street connectivity, residential density, and land use mix –for
26 each meshblock (smallest census tract units available in New Zealand) [40]. Street
27 connectivity will be calculated by dividing the number of 3-or-more-way intersections by the
28 area in square kilometres. To avoid edge effects associated with meshblocks delineated by
29 street centrelines, street connectivity will be calculated for 20 m meshblock buffers.
30 Intersections will be extracted from 2013 street network datasets provided by territorial
31 authorities. Residential density will be calculated by dividing the number of dwellings by the
32 residential land area. The number of dwellings will be obtained from the 2006 census data
33 provided at the meshblock level. Residential land area will be derived from 2013 zoning
34 datasets provided by territorial authorities. Land use mix will be calculated using the area of
35 five land use categories (residential, commercial, industrial, open space, other) in an entropy
36 equation [50]. Land uses will be determined using 2013 zoning datasets provided by
37 territorial authorities. The raw scores for these three built environment measures will be
38 normalised (converted to deciles) and summed to create a basic walkability index. This basic
39 meshblock level walkability index will only be used in school and participant selection. The
40 GIS-based built environment indices that will be created for each participant and used in
41 analyses are described in a later section.
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45 The raw scores for these built environment measures will be normalised and summed to
46 create a basic walkability index. Next the basic walkability index and and pre-existing
47 deprivation data (NZ Dep 2006) will be used to classify all Auckland and Wellington urban
48 meshblocks) into one of four strata: (1) higher walkable, higher SES; (2) higher walkable,
49 lower SES; (3) lower walkable, higher SES; and (4) lower walkable, lower SES. Meshblocks
50 with the top four walkability/SES deciles are classified as higher walkable/SES, and
51 meshblocks with the bottom four walkability/SES deciles are classified as lower
52 walkable/SES. Meshblocks with walkability or SES in deciles 5 and 6 are excluded.
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55 School selection will be based on convenience and close proximity to large numbers of
56 meshblocks in each of the four strata. Within each school, all potential participants will be
57 sampled, regardless of the quadrant they reside, and for each participant walkability will be
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calculated: all students will be assigned to the strata of the meshblock they primarily reside in. This procedure will take place prior to the consent process. Adolescents living in one of the four meshblock strata will be invited to participate in the study. Participation in the study will require written, informed consent from a parent or caregiver and written assent from the adolescent. At the time of consent parents will be asked to rate the importance of a variety of reasons for choosing to live in their neighbourhood. Subsequent schools will be selected on the basis of the quadrants that need to be balanced. In addition to this approach, care will be taken to balance student numbers across the four strata both within and across schools. A similar sampling strategy was used in our previous study of the environmental correlates of physical activity in adults; the heterogeneity generated by this technique permitted several meaningful associations to be detected [40]. A sub-sample of approximately 40 participants will be randomly selected from each school for the GPS and interactive mapping measurements.

Sample size

In adjusted multilevel models, it has been estimated that a sample of 1,600 adolescents recruited from two schools within each stratum (eight in total) would allow the detection of a small effect size (i.e., 1.4% of explained outcome variance found in similar studies conducted elsewhere [51]) with 80% power. The calculated sample size assumes a two-tailed probability level of 5%, a conservative clustering effect equivalent to an intra-class correlation coefficient of 0.10, and a regression model with 25 background covariates explaining 25% of the outcome variance (comparable to what might be expected from the selected variables). With an anticipated sample size of 320 Māori adolescents (our smallest sub-group comparison), the corresponding detectable effect size will be 7% of explained outcome variance (medium effect size).

Exposure, outcomes and covariates

Exposures

GIS data provide multiple spatially-referenced layers that can be used to create meaningful and objective exposure measures of the built environment. They are used to objectively characterise the built environment surrounding the primary home address of each participant and can be applied across a range of road network buffers (e.g., 500 m, 800 m, 1000 m, and 1600 m) in order to evaluate differences between various limits of exposure. Road network buffers can be created to define areas that can be reached on the street network system, but exclude areas that are not accessible due to major barriers (motorway, river, lake). Two main indices, each a composite function of 2-8 other variables, are used to assess physical environmental features: walkability index [52] and neighborhood destination accessibility index [53]. These are described in more detail below. All exposure measures (Table 1) follow the common protocols established for the international IPEN-Adolescents collaboration.

Table 1. Summary of study exposure, outcomes, and covariate

Exposure	Covariates
Detailed walkability index	Demographics
- Net residential density	- Age
- Land use mix	- Sex
- Retail density	- Ethnicity
- Street connectivity	- School

<ul style="list-style-type: none"> - Street discontinuity <p>Neighborhood destination accessibility index</p> <ul style="list-style-type: none"> - Education destinations - Transport destinations - Recreation destinations - Social and cultural destinations - Food retail destinations - Financial destinations - Health destinations - Other retail 	<p>Socioeconomic status</p> <ul style="list-style-type: none"> - Parent education - Parent occupation - Family car ownership - Household crowding <p>Active commuting</p> <ul style="list-style-type: none"> - Frequency of active commuting - Duration of active commuting <p>Neighborhood mobility</p> <ul style="list-style-type: none"> - Frequency and location of regular destinations - Frequency and location of activity <p>Physical activity behavior</p> <ul style="list-style-type: none"> - Total walking area - Total cycling area <p>Sedentary behavior</p> <ul style="list-style-type: none"> - Perceived neighborhood boundary <p>Perceived neighborhood walkability</p> <ul style="list-style-type: none"> - Perceived residential density - Perceived land use mix - Perceived traffic/crime safety - Perceived aesthetics <p>Body size</p> <ul style="list-style-type: none"> - Body mass index - Waist circumference <p>Psychosocial indicators</p> <ul style="list-style-type: none"> - Self-efficacy - Cons/barriers - Family support - Peer support <p>Weather</p> <ul style="list-style-type: none"> - Total rainfall - Mean temperature - Hours of daylight
<p>Outcomes</p> <p>Physical activity behavior</p> <ul style="list-style-type: none"> - Minutes of MVPA - Minutes of light activity <p>Sedentary behavior</p> <ul style="list-style-type: none"> - Minutes of overall sedentary activity - Minutes of television watching <p>Body size</p> <ul style="list-style-type: none"> - Body mass index - Waist circumference 	

Detailed walkability

The detailed walkability index is a summary score of five distinct variables calculated within GIS: net residential density, land use mix, retail density, street connectivity, and street discontinuity. This protocol was created for the US-based Neighborhood Quality of Life Study project, [52] and has been subsequently implemented in the US-based TEAN study [54], the Australian PLACE study, [50] and all IPEN Adult country study sites [55].

Neighborhood Destination Accessibility

Pedestrian access to destinations will be calculated using the Neighborhood Destination Accessibility Index (NDAI) [53]. The NDAI is an objective measure of pedestrian access to neighborhood destinations; it characterises the distribution of urban infrastructure within an 800m street network distance from residence. The NDAI has an advantage over most previous area-level measures of the urban environment in that it captures the range and intensity of everyday destinations such as schools, supermarkets and cafes, which may encourage active travel and enhance recreational physical activity at the population level. As well, the NDAI has been specifically designed for the New Zealand environment. The eight

domains captured in the NDAI are education, transport, recreation and play, social and cultural, food retail, financial, health, and other retail.

Outcomes

Physical Activity

Minutes of MVPA will be objectively measured using hip-mounted triaxial accelerometers (Actigraph GT3X+) over seven consecutive days. The GT3X+ is a small, durable, and water resistant device worn on an elastic belt that records the frequency, duration, and intensity of physical activity with a high level of accuracy and precision [56]. Participants are asked to wear the Actigraph during all waking hours (except when bathing or swimming) for seven days; however, at least five complete days (including at least one weekend day) will be required for analysis to ensure reliable estimates of MVPA [57]. Consistent with previous research, a valid day will be defined as at least 10 hours of data for weekdays and 8 hours for weekend days; non-wear time will be defined as 60 minutes of consecutive zero counts [58,59]. In addition, each participant will be given a seven-day compliance log to complete daily, which assists with identifying non-wear periods. Upon collection of the accelerometer, data are downloaded and screened for completeness and possible malfunction using the Meterplus software (www.meterplussoftware.com). Accelerometer count data will be classified into minutes of light, moderate, and vigorous activity using thresholds developed by Evenson and colleagues [60]; these have performed well in a recent comparison of accelerometer count thresholds for youth [61].

Sedentary Behavior

Minutes of sedentary activity will be objectively assessed using the GT3X+ accelerometer over the seven-day measurement period. The aforementioned cut-points established by Evenson and colleagues [60] will be used to define sedentary time (< 100 counts per minute).

Body Size

Height, weight, and waist circumference of each participant will be measured by trained field researchers using a stadiometer, calibrated scales, and a tape measure. These procedures occur immediately before the researchers distribute the accelerometers; participants wear light clothing and shoes are removed. BMI will be calculated as weight divided by squared height. Participants are classified into weight status categories using age- and sex-specific BMI thresholds [62].

Covariates

Demographics and socioeconomic status

Age, sex, ethnicity, and SES will be collected from the participants. Consistent with the IPEN-adolescents protocol, household income will be the preferred SES indicator, but highest level of parental education will be used when income is unavailable.

Active commuting

The frequency, distance, duration, and mode of all active commuting trips to or from the home address in the previous six months will be assessed with the CAPI. The recall of each trip will be aided by a basic travel log (time, location, and mode of transport only) to be

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2
3 completed nightly with the accelerometer compliance log. Participants will be asked to bring
4 this information with them to the subsequent CAPI.
5

6 *Neighborhood Mobility* 7

8 The majority of studies investigating the built environment and health have focused
9 exclusively on residential neighborhoods as a predictor of exposure [63,64], and overlooked
10 the prospect that a large proportion of activity choices may be influenced by additional
11 environments that are experienced during daily routines. This may reduce the accuracy of
12 environmental exposure assessment [65] and introduce errors that may confound research
13 results. It has been suggested that investigating aspects of daily mobility (regular destinations
14 and the movement between them) will be important to enhance the assessment of exposure
15 [66] and resolve the Uncertain Geographic Context Problem [67]. Using GPS and interactive
16 activity destination questionnaires, we aim to accurately capture the full extent of daily
17 mobility, and its mediating built environment effect on health.
18
19

20 The Visualization and Evaluation of Route Itineraries, Travel Destinations, and Activity
21 Spaces (VERITAS) is a web-based CAPI tool integrating interactive mapping capacities
22 (based on Google Maps) and has the potential to explore destinations both inside and outside
23 the residential neighborhood. VERITAS was initially developed and tested for the RECORD
24 Cohort Study, a major longitudinal study of over 7,200 French adults [68-71]. The
25 applicability and feasibility of this method to an adolescent population is detailed elsewhere
26 (manuscript under review but available on request). While we will be using GIS to provide an
27 objective assessment of the surrounding environment (i.e., exposure measures), VERITAS
28 will allow the research team to search and geolocate participants' regular destinations (visited
29 within the previous 6 months), activity locations, walking/cycling area, routes and modes of
30 travel between locations, travel companions, and perceived or experienced neighborhood
31 boundaries (i.e., neighborhood mobility). The VERITAS programme will run through an
32 internet browser on a laptop computer, and will be designed to automatically upload all
33 participant responses to our secure database when connected to a wireless network. Spatio-
34 temporal data will be collected using the Qstarz BT-Q1000XT GPS receiver (Qstarz
35 International, Taipai, Taiwan) which has been deemed one of the more accurate portable GPS
36 receivers on the market [72]. The GPS will be worn in a pouch alongside the accelerometer.
37 GPS data will be cleaned, filtered and merged with accelerometer data using the Personal
38 Activity Location Measurement System (PALMS, refer to: [https://ucsd-palms-
39 project.wikispaces.com](https://ucsd-palms-project.wikispaces.com)) [73]. The merged data streams retrieved from PALMS will be
40 disaggregated into discrete trips and imported into ArcGIS for further analysis. Data obtained
41 from GPS and VERITAS differ both temporally (previous 1 week and 6 months,
42 respectively) and spatially (a continuous sequential polyline compared with point data).
43 Although VERITAS will be able to obtain data for extended periods, it lacks the temporal
44 sequence of events available from GPS tracking. However, as short periods of GPS
45 monitoring may not truly represent destinations visited over extended periods, the
46 combination of both has been recommended to create complementary and more robust
47 measures of environmental exposure [70].
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51 The neighborhood mobility data will allow the demarcation of the territorial range by active
52 travel modes. A spatial 'polygon' will be created consisting of a multisided geometric shape
53 surrounding the home address that connects the various locations to which participants claim
54 to have walked or cycled. The area (m²) within these polygons will be calculated and used to
55 define separate shapes based on the travel modes. In situations where participants walk or
56 cycle to only one location (e.g., school) the polygon area will be the distance between the
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3 location and home addresses multiplied by 1 m. As with the active commuting assessment,
4 the recall of visited locations and trips will be aided by the travel log that will be completed
5 daily. Finally, using VERITAS, each participant will be able to map their perceived
6 neighborhood boundary, allowing us to isolate the effects of their self-defined neighborhood
7 environment on the outcome measures.
8

9 *Perceived Neighborhood Walkability*

10
11 In order to understand the mediating effect of individual perceptions of the neighborhood on
12 the relationship between the objectively-measured built environment and physical activity
13 behavior, the Neighborhood Environment Walkability Scale for Youth (NEWS-Y) will be
14 administered as a self-completion hard copy survey. NEWS-Y is based on the NEWS, which
15 has demonstrated good reliability and validity [74-78]. In addition to the GIS-based
16 walkability index variables (residential density, land use mix, street connectivity), NEWS-Y
17 assesses pedestrian/cycle facilities, aesthetics, traffic safety, and crime safety. The ten
18 NEWS-Y subscales have acceptable test-retest reliability (ICC: 0.56-0.87) and specific
19 subscales were correlated significantly with physical activity for adolescents [79].
20
21

22 *Psychosocial Indicators*

23
24 A small number of psychosocial variables associated with adolescent physical activity will be
25 measured in the study. These include: self-efficacy; perceived barriers to being physically
26 activity; family support; and peer support [79]. These variables have shown the most
27 consistent psychosocial correlations with adolescent physical activity in the literature [80].
28 Further, by including such items we are able to examine our findings within a multilevel
29 framework thereby accounting for and separating the various layers of influence (i.e.,
30 individual, social, and physical environments) [81].
31

32 Self-reported physical activity, sedentary behavior and commuting to school

33
34 In addition to perceived neighbourhood walkability and psychosocial indicators, participants
35 will be asked to report on commuting (to and from school, walking and biking, barriers to
36 walking and cycling) [82-84], physical activity (at and outside of school, places for, barriers
37 in the neighbourhood, decisions about, confidence about, enjoyment of, social support,
38 workout equipment, activity rules, and athletic ability) [85-87], and sedentary behavior
39 (during school and weekend days, things in the bedroom and personal electronics) [88]. The
40 scales have shown to be reliable and valid in the adolescent population [82-84,88].
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43 *Weather*

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45 We have previously demonstrated the significant impact of inclement weather conditions on
46 physical activity in New Zealand children [89]. To monitor these potential confounding
47 effects we will obtain hourly rainfall, mean temperature, and hours of daylight statistics from
48 the New Zealand Met Service for each data collection day and use these as covariates in the
49 models.
50

51 *Procedures*

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53 Data will be collected from participants within the school setting in school hours. During the
54 measurement session, the NEWS-Y [79] questionnaire will be administered, anthropometric
55 measures will be taken and accelerometers and compliance logs will be distributed. Text
56 messages will be sent to adolescents/parents before data collection session as a reminder to
57 attend. A random sub-sample of 40 adolescents per school will be allocated a GPS receiver to
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3 wear in conjunction with the accelerometer, and will complete the VERITAS interview. All
4 participants will be instructed on the correct use, wear-time, and care of the equipment.
5 Participants will be issued with a \$20 shopping voucher upon completion of data collection
6 and return of the monitors and compliance logs.
7

8 **Quantitative Analyses**

9
10 The proposed dataset will have a hierarchical independent variable structure which consists
11 of person-level observations nested within neighborhoods and schools. The main aim of the
12 study is to examine confounder-adjusted associations of environmental variables with
13 physical activity and body size outcomes. For this purpose, cross-classified (by
14 neighborhoods and schools) generalized linear mixed models (MGLM) with random
15 intercepts will be used. These can account for multiple sources of dependency (schools and
16 neighborhoods) and different types of data (e.g., continuous or binary) following a Normal or
17 other types of distributions (e.g., negative binomial, Poisson) [90]. MGLMs perform well
18 when the number of observations across areas is highly unbalanced, [91] which will be
19 relevant to this project as the number of participants may vary substantially across schools
20 and neighborhoods. Given the relatively small number of strata included in the study,
21 MGLMs will be estimated using Restricted Maximum Likelihood (REML) or Bayesian
22 Markov chain Monte Carlo (MCMC) methods with non-informative priors, [92] the latter
23 appropriate for binary (e.g., overweight/obese vs. normal weight) [92,93] or non-normally
24 distributed outcomes [90]. Non-linear relationship will be examined using restricted cubic
25 splines [94]. A probability level of 0.05 will be adopted.
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31 **Qualitative Methodology**

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33 A total of 16 focus groups, with approximately 5-8 participants, will be conducted at eight
34 participating schools. One researcher (VI) will conduct all the focus groups and at least one
35 of the co-researchers will assist. Variability in walkability will be sought by recruiting two
36 schools in Auckland (representing relatively low walkability) and Wellington (relatively high
37 walkability). However students within focus groups will be selected to represent a range of
38 neighborhood settings to facilitate discussion on differing experiences of the built
39 environment. Participants will also take part in the quantitative component and completed all
40 data collection. To aid open discussion and allow meaningful comparisons separate focus
41 groups will be conducted by age, with younger students (approximately 12-14 years) further
42 stratified by sex, and older students (approximately 15-18 years) in mixed sex groups [43].
43 Focus groups will be conducted using 40 min school periods to accommodate school
44 timetables semi-structured interview. The focus groups are designed to examine the enablers
45 and barriers to being physically active, particularly with regard to active transport,
46 engagement in formal and informal physical activity, safety, and social drivers. Researchers
47 will specifically seek discussion on activity within participants' residential neighborhood and
48 school environments as well as alternative activity spaces in their everyday lives, including
49 those outside of their geographical suburbs. Maps of local environments to prompt discussion
50 on where youth are active (and where they avoid), types of activity, and travel routes will be
51 used. Interviews will be digitally recorded and transcribed by group, with all individual
52 identifying information removed.
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57 **Qualitative Analyses**

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3 Initially, two of the researchers will independently read the transcripts, code and extract
4 themes. The themes will be presented to the team. Disagreement will be resolved through
5 discussion and themes will be confirmed. A coding framework will be developed using
6 NVivo software to organise data generated by the project research questions (deductive) and
7 emergent topics (inductive) [95]. Analyses will be conducted across and within groups to
8 examine commonalities and differences by built environment settings and individual factors
9 (i.e., sex, age, and culture). Concurrent analyses of qualitative and quantitative data will
10 allow insightful integration and triangulation of findings across the study components,
11 allowing us to draw inferences about how youth interact with and manage their lived
12 environments, and what that means for their physical activity and wellbeing [96,97].
13
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15 **Ethics and dissemination**

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17 All adolescents will be required to provide assent to participate in the study. An information
18 sheet will be designed specifically for adolescents in a manner that it will be easy to
19 understand. Additionally, all parents of the assenting adolescents will be required to provide
20 parental consent. Parents will also receive a detailed information sheet outlining the study and
21 its requirements.
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24 Data will be entered and stored into a secure (password protected) database. Only the named
25 researchers will have access to the data. Data will be stored for 10 years and permanently
26 destroyed thereafter.
27

28 It is unlikely that participants will experience discomfort or embarrassment during data
29 collection. However, as body measures of weight and height will be objectively assessed,
30 there is the potential of concern around body weight and size. The institution's counselling
31 services will be accessed if a situation arises. All body measurements will be taken behind a
32 portable screen with gender appropriate research officers. All data will be kept private and
33 confidential.
34

35 At the completion of the study, results will be provided to key stakeholders and organisations
36 (e.g., high schools, adolescents, and parents). Results will be disseminated by means of a
37 written report to schools that have participated in the study. Adolescents and/or their
38 parents/legal guardians will receive a report detailing the individual results collected.
39 Government organizations, health boards, and councils, will be able to access key findings
40 and recommendations resulting from the project through seminar presentations and report
41 distribution. Research findings will also be circulated to the scientific community in the form
42 publications in refereed journals.
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47 **Discussion**

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49 We have described the methods for the BEANZ study which seeks to estimate strengths of
50 association between objective measures of the local environment with accelerometer-derived
51 and self-reported physical activity and sedentary behavior in youth. A novel aspect of this
52 study is the exploration of detailed and multilevel relationships of interaction between the
53 social and physical environments specific to the NZ adolescents. This will be achieved
54 through additional measures (e.g., GPS, VERITAS, focus groups, NDAI) which collectively
55 serve to advance knowledge in this important area of health research, policy advocacy, and
56 ultimately youth health outcomes. Particularly, the use of GPS/VERITAS to identify the
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3 locations that adolescents visit on a daily basis, defining their geographical context, will
4 provide us with accurate estimates of location in which physical activity takes place.
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6 International evidence shows that the most consistent environmental attributes positively
7 associated with reported physical activity in youth were land use mix and residential density,
8 but inconsistent findings have been observed for parks, recreation facilities, and street
9 connectivity [41]. Others found that proximity to parks, recreation facilities and proximity to
10 school [32,43,98,99] along with transport infrastructure were positively associated with
11 physical activity in adolescents [99]. Traffic hazards (number of roads to cross, traffic speed)
12 and local conditions (crime, area deprivation) were negatively associated with physical
13 activity [44,99]. Obesogenic environmental attributes of homes, neighborhoods, and schools
14 are believed to promote sedentary behavior among youth [100] and there is growing evidence
15 that being socially connected with others contributes to adolescent wellbeing [46]. While
16 some evidence exists to show the importance of the built environment for adolescent physical
17 activity and well-being, the use of different methods and limited physical variability within
18 any given environment may serve to consistently underestimate the associations observed. In
19 this study, variance is maximised in two ways. Two major cities in New Zealand are sampled,
20 and these data are subsequently combined with nine other countries through the IPEN-
21 Adolescent study. The larger study will improve our understanding of the nature of the
22 relationships that exist between adolescent physical activity, sedentary behavior and body
23 weight with specific features of the built environment related to walkability, commuting and
24 access to facilities for recreation.
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28 Individuals (or at least parents) may self-select neighborhoods, therefore associations
29 between built environment and walkability may in part be a reflection of neighborhood self-
30 selection bias. Mixed results have been found when investigating neighborhood self-selection
31 and walkability [101-105]. The relationship is a complex one and prospective studies are
32 needed to study the effects of neighborhood self-selection on neighborhood walkability.
33 When reviewing 38 empirical studies that used different approaches to explore the influence
34 of self-selection, Cao and colleagues [106] established that all studies reviewed found a
35 statistically significant influence of the built environment after accounting for self-selection.
36 While exploring this particular relationship is not the focus of the present study, parents'
37 neighborhood preference and self-selection will be accounted for in the analysis. As
38 mentioned earlier, parents will be asked to rank the importance of a variety of reasons for
39 choosing to reside in the particular neighbourhood. The reasons (that address self-selection)
40 could be: easy access to services, walkable environment, and/or access to recreational and
41 sporting facilities. This information will be used in the analysis.
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45 When conducting spatial analyses on aggregated data, errors affecting the validity of results
46 may be introduced [107]. The problem has been referred to as the Modifiable Areal Unit
47 Problem defined as the 'geographic manifestation of the ecological fallacy in which
48 conclusions based on data aggregated to a particular set of districts may change if one
49 aggregates the same underlying data to a different set of districts' [108]. In other words, the
50 way spatial data are aggregated may result in different findings. There has been disagreement
51 in the literature on the best solution for this problem; however, it has been suggested that the
52 only appropriate resolution is to use individual-level data that are geocoded based on
53 residential location [109]. Indeed, our selection strategy uses geo-coded data and we are
54 employing techniques (GPS and VERITAS) to gain a more accurate understanding of
55 neighborhood boundaries for youth. This will substantially advance our knowledge in this
56 field.
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4 This study will contribute to national and international scientific knowledge by forming the
5 NZ arm of the international IPEN-Adolescents collaboration, whereby adolescents' physical
6 activity and sedentary behavior data are collected using a common methodology across
7 multiple countries (Australia, Belgium, Brazil, China, Denmark, Malaysia, New Zealand,
8 Portugal and USA). Furthermore the larger study will improve our understanding of the
9 nature of the relationships that exist between adolescent physical activity, sedentary behavior
10 and body weight with specific features of the built environment related to walkability,
11 commuting and access to facilities for recreation.
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14 Ultimately, by showing the relationships between health outcomes and the neighborhood
15 built environment, we aim to influence and inform policy and city planning practices. City
16 planners, policy makers and government agencies will be engaged early [110] [111]. Results
17 will also be shared with other sustainable transport advocacy, urban planners, and public
18 health organisations. Dissemination of findings to NZ secondary schools and students
19 themselves will maximise the potential impact of the findings.
20
21

22 23 **Acknowledgements**

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25 New Zealand (12/329).
26
27

28 29 **Authors' contributions**

30 EH developed the first draft of the manuscript. EH, SD, MO, SM, EC, HB, VI, JM, and GS
31 contributed to the conception and the design of the study. All authors provided feedback
32 during manuscript development. Each author has read and approved the final manuscript.
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38 39 **Competing interests**

40 The authors declare that they have no competing interests.
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**BUILT ENVIRONMENT AND PHYSICAL ACTIVITY IN NEW ZEALAND
ADOLESCENTS: A PROTOCOL FOR A CROSS SECTIONAL STUDY**

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Abstract

Introduction: Built-environment interventions have the potential to provide population-wide effects and provide the means for a sustained effect on behavior change. Population-wide effects for adult physical activity have been shown with selected built environment attributes; however, the association between the built environment and adolescent health behaviors is less clear. This New Zealand study is part of an international project across 10 countries (International Physical Activity and the Environment Network– Adolescents) that aims to characterize the links between built environment and adolescent health outcomes.

Methods and Analyses: An observational, cross-sectional study of the associations between measures of the built environment with physical activity, sedentary behavior, body size, and social connectedness in 1,600 New Zealand adolescents aged 12-18 years will be conducted in 2013-2014. Walkability and neighborhood destination accessibility indices will be objectively measured using Geographic Information Systems (GIS). Physical activity and sedentary behaviors will be objectively measured using accelerometers over seven consecutive days. Body mass index will be calculated as weight divided by squared height. Demographics, socioeconomic status, active commuting behaviors, and perceived neighborhood walkability will be assessed using the Neighborhood Environment Walkability Scale for Youth and psychosocial indicators. A web-based computer-assisted personal interview (CAPI) tool (VERITAS) and Global Positioning System (GPS) receivers will be used in a subsample of 300 participants. A qualitative research component will explore barriers and facilitators for physical activity in adolescents with respect to the built and social environment in a subsample of 80 participants.

Ethics and dissemination: The study received ethical approval from the Auckland University of Technology Ethics Committee (12/161). Data will be entered and stored into a secure (password protected) database. Only the named researchers will have access to the data. Data will be stored for 10 years and permanently destroyed thereafter. The results papers will be submitted for publication in peer-reviewed journals.

Strengths and limitations of this study

- Limited data exists on detailed and multilevel relationships of interaction between the social and physical environments specific to the NZ adolescents.
- The use of GPS/VERITAS will define the adolescents' geographical context and will provide accurate estimates of location in which physical activity takes place.
- The study forms the NZ arm of the international IPEN-Adolescents collaboration, whereby adolescents' physical activity and sedentary behavior data are collected using a common methodology across multiple countries.
- Parents may self-select neighborhoods, therefore associations between built environment and walkability may in part be a reflection of neighborhood self-selection bias. Parents' neighborhood preference and self-selection will be accounted for in the analysis.
- When conducting spatial analyses on aggregated data, errors affecting the validity of results may be introduced. Geo-coded data and other techniques will assist in gaining a more accurate understanding of neighborhood boundaries for adolescents.

Built environment and physical activity in New Zealand adolescents: A cross sectional study

Introduction

The benefits of physical activity in youth are well documented [1-5]. Regular moderate-to-vigorous physical activity (MVPA) is positively associated with musculoskeletal health, cardiovascular wellbeing (e.g., healthy blood pressure, lipid and lipoprotein levels, cardiovascular autonomic tone), metabolic health, maintenance of a healthy weight, psychological wellbeing (e.g., improved self-concept, reduced anxiety and depression), and reduced risk of type 2 diabetes [6,7]. The accumulation of at least 60 minutes of MVPA per day is recommended for youth; however, accumulating physical activity below this threshold is still beneficial, especially for those whose health is at risk (e.g., overweight or obese youth) [6]. Despite awareness of the well-established benefits of physical activity, rapid changes in technology and the habitual environment over the last 50 years may have caused an increase in sitting, passive travel, and subsequently a reduction in incidental physical activity [8]. Furthermore, over the course of adolescence, physical activity typically decreases by 60-70% [9], while sedentary behavior remains high at 7-14 hours per day [10-12]. The latter trend is particularly concerning given that emerging evidence suggests that sedentary behavior has negative effects on health that are independent of the beneficial effects of physical activity [13-15]. Additionally, levels of activity during school age years significantly predict activity levels [16] and health outcomes [17] into adulthood.

Behavioral modification programmes have only achieved limited and mostly short term physical activity improvements [18-20]. For sustainable changes that optimise positive behaviors, it is important to understand that physical activity and sedentary behaviors occur within a broader ecological framework [21]. It is recognised that in order to be effective, complex integrated interventions are required that include supportive policies and social and physical environments [22,23]. Manipulating social and physical environments to be more health promoting will likely have sustainable and far-reaching impacts on population health behaviors and outcomes. We have previously examined the relationship of objective built environment measures (i.e., destination access, street connectivity, dwelling density, land use mix) with accelerometer-derived and self-reported physical activity in adults [24]. The work was part of a larger international study (IPEN-International Physical activity and Environment Network) with 12 participating countries. The potential of walkable neighborhoods for supporting health-enhancing increases in physical activity, at least for adults, was high [24]. A one standard deviation increase in neighborhood walkability variables yielded a 7-13% increase in physical activity. This effect is likely to be much higher than effects achieved through behavioral intervention alone [25,26].

While the evidence base for associations between the built environment and physical activity in adults has been steadily accumulating [24,27,28], our understanding of this relationship in adolescents is at its infancy [29-38], and at times non-intuitive [33,39]. Adolescents were consistently identified in our adult focus groups in our previous study as a sub-group whose changing needs for independent mobility and age- and culturally-appropriate forms of physical activity are less likely to be met, particularly in more suburban built environment forms [40]. In a recent review, land-use mix and residential density were the most highly correlated built environment variables with overall physical activity in youth [41]. However,

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3 the review did not find any environmental variables that consistently correlated with physical
4 activity in adolescents. Nonetheless, latest research indicates that adolescents' physically
5 activity tends to occur close to their homes [42,43], and that strong associations exist between
6 inactivity with lower neighborhood walkability, amount of public open space, and
7 neighborhood safety [44], as well as higher densities of cul-de-sac networks [36]. MVPA is
8 significantly lower for rural adolescents compared to those living in urban environments,
9 however these differences between neighborhood type are not seen for BMI [45]. Geospatial
10 data indicate that adolescent girls engage in higher intensity physical activity in places with
11 parks, schools, and higher population density, and accumulate lower levels of physical
12 activity in places with more roads and food outlets [32]. Low-income adolescents were
13 physically active at fields/courts, indoor recreation facilities, small and large parks, and
14 swimming pools [43] but reduced accessibility of physical activity facilities and food outlets
15 was associated with being overweight [34].
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18 In the Built Environment and Adolescent New Zealanders (BEANZ) study, we seek to
19 understand the relationship of physical activity, sedentary behavior, and body size with
20 neighborhood-level built environment features in New Zealand (NZ) adolescents. We
21 hypothesise that neighborhood walkability and neighborhood destination accessibility indices
22 will be positively associated with minutes of MVPA, and inversely associated with minutes
23 of sedentary time and body mass index (BMI). We will also investigate associations between
24 the built environment and social connectedness to the community [46], the moderating effects
25 of ethnicity and mediating effects of active commuting, neighborhood mobility, and
26 perceived neighborhood walkability. A novel aspect of this study is the use of portable
27 global positioning system (GPS) receivers together with web-based interactive mapping and
28 geocoding software to examine adolescents' mobility and access to regular destinations.
29 These ancillary data will enable the shape and scale of environmental exposure to be defined
30 in considerable detail.
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33 Our study forms part of the IPEN-Adolescent collaboration, using comparable data
34 collection, management, and protocol sharing across 10 countries. By comparing diverse
35 countries, built environmental heterogeneity can be captured (and therefore generate robust
36 estimates of the real effects) while facilitating intra- and inter-country comparisons. The goal
37 is to generate credible evidence to guide long-term town planning, policy change, and
38 redesign of existing urban environments to maximise physical activity and community
39 connectedness and minimise sedentary behavior and body size, all key determinants of
40 human health.
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44 **Method and analysis**

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46 The standardized checklist for the Strengthening the Reporting of Observational Studies in
47 Epidemiology (STROBE) recommendations was used to ensure that all elements
48 recommended were address within this section [47].
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50 **Design**

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52 BEANZ will be based on an observational, cross-sectional design that examines the
53 associations of objective and subjective measures of the built environment with physical
54 activity, sedentary behavior, body size, and social connectedness in 1,600 NZ adolescents
55 aged 12-18 years from eight secondary schools (approximately 200 participants per school).
56 **Moreover, differences between non-Māori and Māori population groups will be explored.**
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3 Demographics, socioeconomic status, active commuting, psychosocial indicators, and
4 perceptions of the built environment will be measured in the full sample. Data will be
5 collected in the 2013-2014 academic school years for the southern hemisphere. A GPS and
6 interactive mapping sub-study of approximately 300 participants will assess neighborhood
7 mobility by geolocating participants' destinations, modes of travel, activity locations,
8 walking/cycling area, and perceived neighborhood boundaries. Focus groups will explore
9 barriers and facilitators for physical activity with respect to neighborhood built and social
10 environment in a subsample of approximately 80 participants. Data will be collected from
11 two major cities in New Zealand: Auckland and Wellington. Auckland is the largest city in
12 New Zealand with a population of approximately 1.4 million residents (one third of the
13 country's population) [48], with a population density comparable to Los Angeles and
14 Helsinki [49]. Wellington, the capital city of New Zealand, is located on the southern part of
15 the North Island and has a population density comparable to Vancouver and Honolulu [49].
16 Ethical approval was received by the Institution's Ethics Committee (AUTEC, 12/161).

19 Neighborhood, school and participant selection

21 Associations between exposure and outcome variables are estimated based on data collected
22 using a multistage sampling strategy. This strategy maximises heterogeneity in the exposure
23 variables (built environment) while allowing comparisons to be made between those of low
24 and high socioeconomic status (SES). In the first instance, GIS will be used to calculate three
25 built environment measures – street connectivity, residential density, and land use mix –for
26 each meshblock (smallest census tract units available in New Zealand) [40]. Street
27 connectivity will be calculated by dividing the number of 3-or-more-way intersections by the
28 area in square kilometres. To avoid edge effects associated with meshblocks delineated by
29 street centrelines, street connectivity will be calculated for 20 m meshblock buffers.
30 Intersections will be extracted from 2013 street network datasets provided by territorial
31 authorities. Residential density will be calculated by dividing the number of dwellings by the
32 residential land area. The number of dwellings will be obtained from the 2006 census data
33 provided at the meshblock level. Residential land area will be derived from 2013 zoning
34 datasets provided by territorial authorities. Land use mix will be calculated using the area of
35 five land use categories (residential, commercial, industrial, open space, other) in an entropy
36 equation [50]. Land uses will be determined using 2013 zoning datasets provided by
37 territorial authorities. The raw scores for these three built environment measures will be
38 normalised (converted to deciles) and summed to create a basic walkability index. This basic
39 meshblock level walkability index will only be used in school and participant selection. The
40 GIS-based built environment indices that will be created for each participant and used in
41 analyses are described in a later section.

45 The raw scores for these built environment measures will be normalised and summed to
46 create a basic walkability index. Next the basic walkability index and and pre-existing
47 deprivation data (NZ Dep 2006) will be used to classify all Auckland and Wellington urban
48 meshblocks) into one of four strata: (1) higher walkable, higher SES; (2) higher walkable,
49 lower SES; (3) lower walkable, higher SES; and (4) lower walkable, lower SES. Meshblocks
50 with the top four walkability/SES deciles are classified as higher walkable/SES, and
51 meshblocks with the bottom four walkability/SES deciles are classified as lower
52 walkable/SES. Meshblocks with walkability or SES in deciles 5 and 6 are excluded.

55 School selection will be based on convenience and close proximity to large numbers of
56 meshblocks in each of the four strata. Within each school, all potential participants will be
57 sampled, regardless of the quadrant they reside, and for each participant walkability will be
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calculated: all students will be assigned to the strata of the meshblock they primarily reside in. This procedure will take place prior to the consent process. Adolescents living in one of the four meshblock strata will be invited to participate in the study. Participation in the study will require written, informed consent from a parent or caregiver and written assent from the adolescent. At the time of consent parents will be asked to rate the importance of a variety of reasons for choosing to live in their neighbourhood. Subsequent schools will be selected on the basis of the quadrants that need to be balanced. In addition to this approach, care will be taken to balance student numbers across the four strata both within and across schools. A similar sampling strategy was used in our previous study of the environmental correlates of physical activity in adults; the heterogeneity generated by this technique permitted several meaningful associations to be detected [40]. A sub-sample of approximately 40 participants will be randomly selected from each school for the GPS and interactive mapping measurements.

Sample size

In adjusted multilevel models, it has been estimated that a sample of 1,600 adolescents recruited from two schools within each stratum (eight in total) would allow the detection of a small effect size (i.e., 1.4% of explained outcome variance found in similar studies conducted elsewhere [51]) with 80% power. The calculated sample size assumes a two-tailed probability level of 5%, a conservative clustering effect equivalent to an intra-class correlation coefficient of 0.10, and a regression model with 25 background covariates explaining 25% of the outcome variance (comparable to what might be expected from the selected variables). With an anticipated sample size of 320 Māori adolescents (our smallest sub-group comparison), the corresponding detectable effect size will be 7% of explained outcome variance (medium effect size).

Exposure, outcomes and covariates

Exposures

GIS data provide multiple spatially-referenced layers that can be used to create meaningful and objective exposure measures of the built environment. They are used to objectively characterise the built environment surrounding the primary home address of each participant and can be applied across a range of road network buffers (e.g., 500 m, 800 m, 1000 m, and 1600 m) in order to evaluate differences between various limits of exposure. Road network buffers can be created to define areas that can be reached on the street network system, but exclude areas that are not accessible due to major barriers (motorway, river, lake). Two main indices, each a composite function of 2-8 other variables, are used to assess physical environmental features: walkability index [52] and neighborhood destination accessibility index [53]. These are described in more detail below. All exposure measures (Table 1) follow the common protocols established for the international IPEN-Adolescents collaboration.

Table 1. Summary of study exposure, outcomes, and covariate

Exposure	Covariates
Detailed walkability index	Demographics
- Net residential density	- Age
- Land use mix	- Sex
- Retail density	- Ethnicity
- Street connectivity	- School

<ul style="list-style-type: none"> - Street discontinuity Neighborhood destination accessibility index <ul style="list-style-type: none"> - Education destinations - Transport destinations - Recreation destinations - Social and cultural destinations - Food retail destinations - Financial destinations - Health destinations - Other retail 	Socioeconomic status <ul style="list-style-type: none"> - Parent education - Parent occupation - Family car ownership - Household crowding Active commuting <ul style="list-style-type: none"> - Frequency of active commuting - Duration of active commuting Neighborhood mobility <ul style="list-style-type: none"> - Frequency and location of regular destinations
Outcomes	<ul style="list-style-type: none"> - Frequency and location of activity
Physical activity behavior <ul style="list-style-type: none"> - Minutes of MVPA - Minutes of light activity Sedentary behavior <ul style="list-style-type: none"> - Minutes of overall sedentary activity - Minutes of television watching Body size <ul style="list-style-type: none"> - Body mass index - Waist circumference 	<ul style="list-style-type: none"> - Total walking area - Total cycling area - Perceived neighborhood boundary Perceived neighborhood walkability <ul style="list-style-type: none"> - Perceived residential density - Perceived land use mix - Perceived traffic/crime safety - Perceived aesthetics Psychosocial indicators <ul style="list-style-type: none"> - Self-efficacy - Cons/barriers - Family support - Peer support Weather <ul style="list-style-type: none"> - Total rainfall - Mean temperature - Hours of daylight

Detailed walkability

The detailed walkability index is a summary score of five distinct variables calculated within GIS: net residential density, land use mix, retail density, street connectivity, and street discontinuity. This protocol was created for the US-based Neighborhood Quality of Life Study project, [52] and has been subsequently implemented in the US-based TEAN study [54], the Australian PLACE study, [50] and all IPEN Adult country study sites [55].

Neighborhood Destination Accessibility

Pedestrian access to destinations will be calculated using the Neighborhood Destination Accessibility Index (NDAI) [53]. The NDAI is an objective measure of pedestrian access to neighborhood destinations; it characterises the distribution of urban infrastructure within an 800m street network distance from residence. The NDAI has an advantage over most previous area-level measures of the urban environment in that it captures the range and intensity of everyday destinations such as schools, supermarkets and cafes, which may encourage active travel and enhance recreational physical activity at the population level. As well, the NDAI has been specifically designed for the New Zealand environment. The eight

domains captured in the NDAI are education, transport, recreation and play, social and cultural, food retail, financial, health, and other retail.

Outcomes

Physical Activity

Minutes of MVPA will be objectively measured using hip-mounted triaxial accelerometers (Actigraph GT3X+) over seven consecutive days. The GT3X+ is a small, durable, and water resistant device worn on an elastic belt that records the frequency, duration, and intensity of physical activity with a high level of accuracy and precision [56]. Participants are asked to wear the Actigraph during all waking hours (except when bathing or swimming) for seven days; however, at least five complete days (including at least one weekend day) will be required for analysis to ensure reliable estimates of MVPA [57]. Consistent with previous research, a valid day will be defined as at least 10 hours of data for weekdays and 8 hours for weekend days; non-wear time will be defined as 60 minutes of consecutive zero counts [58,59]. In addition, each participant will be given a seven-day compliance log to complete daily, which assists with identifying non-wear periods. Upon collection of the accelerometer, data are downloaded and screened for completeness and possible malfunction using the Meterplus software (www.meterplussoftware.com). Accelerometer count data will be classified into minutes of light, moderate, and vigorous activity using thresholds developed by Evenson and colleagues [60]; these have performed well in a recent comparison of accelerometer count thresholds for youth [61].

Sedentary Behavior

Minutes of sedentary activity will be objectively assessed using the GT3X+ accelerometer over the seven-day measurement period. The aforementioned cut-points established by Evenson and colleagues [60] will be used to define sedentary time (< 100 counts per minute).

Body Size

Height, weight, and waist circumference of each participant will be measured by trained field researchers using a stadiometer, calibrated scales, and a tape measure. These procedures occur immediately before the researchers distribute the accelerometers; participants wear light clothing and shoes are removed. BMI will be calculated as weight divided by squared height. Participants are classified into weight status categories using age- and sex-specific BMI thresholds [62].

Covariates

Demographics and socioeconomic status

Age, sex, ethnicity, and SES will be collected from the participants. Consistent with the IPEN-adolescents protocol, household income will be the preferred SES indicator, but highest level of parental education will be used when income is unavailable.

Active commuting

The frequency, distance, duration, and mode of all active commuting trips to or from the home address in the previous six months will be assessed with the CAPI. The recall of each trip will be aided by a basic travel log (time, location, and mode of transport only) to be

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3 completed nightly with the accelerometer compliance log. Participants will be asked to bring
4 this information with them to the subsequent CAPI.
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6 *Neighborhood Mobility*

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8 The majority of studies investigating the built environment and health have focused
9 exclusively on residential neighborhoods as a predictor of exposure [63,64], and overlooked
10 the prospect that a large proportion of activity choices may be influenced by additional
11 environments that are experienced during daily routines. This may reduce the accuracy of
12 environmental exposure assessment [65] and introduce errors that may confound research
13 results. It has been suggested that investigating aspects of daily mobility (regular destinations
14 and the movement between them) will be important to enhance the assessment of exposure
15 [66] and resolve the Uncertain Geographic Context Problem [67]. Using GPS and interactive
16 activity destination questionnaires, we aim to accurately capture the full extent of daily
17 mobility, and its mediating built environment effect on health.
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20 The Visualization and Evaluation of Route Itineraries, Travel Destinations, and Activity
21 Spaces (VERITAS) is a web-based CAPI tool integrating interactive mapping capacities
22 (based on Google Maps) and has the potential to explore destinations both inside and outside
23 the residential neighborhood. VERITAS was initially developed and tested for the RECORD
24 Cohort Study, a major longitudinal study of over 7,200 French adults [68-71]. The
25 applicability and feasibility of this method to an adolescent population is detailed elsewhere
26 (manuscript under review but available on request). While we will be using GIS to provide an
27 objective assessment of the surrounding environment (i.e., exposure measures), VERITAS
28 will allow the research team to search and geolocate participants' regular destinations (visited
29 within the previous 6 months), activity locations, walking/cycling area, routes and modes of
30 travel between locations, travel companions, and perceived or experienced neighborhood
31 boundaries (i.e., neighborhood mobility). The VERITAS programme will run through an
32 internet browser on a laptop computer, and will be designed to automatically upload all
33 participant responses to our secure database when connected to a wireless network. Spatio-
34 temporal data will be collected using the Qstarz BT-Q1000XT GPS receiver (Qstarz
35 International, Taipai, Taiwan) which has been deemed one of the more accurate portable GPS
36 receivers on the market [72]. The GPS will be worn in a pouch alongside the accelerometer.
37 GPS data will be cleaned, filtered and merged with accelerometer data using the Personal
38 Activity Location Measurement System (PALMS, refer to: [https://ucsd-palms-
39 project.wikispaces.com](https://ucsd-palms-project.wikispaces.com)) [73]. The merged data streams retrieved from PALMS will be
40 disaggregated into discrete trips and imported into ArcGIS for further analysis. Data obtained
41 from GPS and VERITAS differ both temporally (previous 1 week and 6 months,
42 respectively) and spatially (a continuous sequential polyline compared with point data).
43 Although VERITAS will be able to obtain data for extended periods, it lacks the temporal
44 sequence of events available from GPS tracking. However, as short periods of GPS
45 monitoring may not truly represent destinations visited over extended periods, the
46 combination of both has been recommended to create complementary and more robust
47 measures of environmental exposure [70].
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51 The neighborhood mobility data will allow the demarcation of the territorial range by active
52 travel modes. A spatial 'polygon' will be created consisting of a multisided geometric shape
53 surrounding the home address that connects the various locations to which participants claim
54 to have walked or cycled. The area (m²) within these polygons will be calculated and used to
55 define separate shapes based on the travel modes. In situations where participants walk or
56 cycle to only one location (e.g., school) the polygon area will be the distance between the
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3 location and home addresses multiplied by 1 m. As with the active commuting assessment,
4 the recall of visited locations and trips will be aided by the travel log that will be completed
5 daily. Finally, using VERITAS, each participant will be able to map their perceived
6 neighborhood boundary, allowing us to isolate the effects of their self-defined neighborhood
7 environment on the outcome measures.
8

9 *Perceived Neighborhood Walkability*

10
11 In order to understand the mediating effect of individual perceptions of the neighborhood on
12 the relationship between the objectively-measured built environment and physical activity
13 behavior, the Neighborhood Environment Walkability Scale for Youth (NEWS-Y) [81] will
14 be administered as a self-completion hard copy survey. NEWS-Y is based on the NEWS,
15 which has demonstrated good reliability and validity [74-78]. In addition to the GIS-based
16 walkability index variables (residential density, land use mix, street connectivity), NEWS-Y
17 assesses pedestrian/cycle facilities, aesthetics, traffic safety, and crime safety. The ten
18 NEWS-Y subscales have acceptable test-retest reliability (ICC: 0.56-0.87) and specific
19 subscales were correlated significantly with physical activity for adolescents [79].
20
21

22 *Psychosocial Indicators*

23
24 A small number of psychosocial variables associated with adolescent physical activity will be
25 measured in the study. These include: self-efficacy; perceived barriers to being physically
26 activity; family support; and peer support [79]. These variables have shown the most
27 consistent psychosocial correlations with adolescent physical activity in the literature [80].
28 Further, by including such items we are able to examine our findings within a multilevel
29 framework thereby accounting for and separating the various layers of influence (i.e.,
30 individual, social, and physical environments) [81].
31

32 **Self-reported physical activity, sedentary behavior and commuting to school**

33
34 In addition to perceived neighbourhood walkability and psychosocial indicators, participants
35 will be asked to report on commuting (to and from school, walking and biking, barriers to
36 walking and cycling) [82-84], physical activity (at and outside of school, places for, barriers
37 in the neighbourhood, decisions about, confidence about, enjoyment of, social support,
38 workout equipment, activity rules, and athletic ability) [85-87], and sedentary behavior
39 (during school and weekend days, things in the bedroom and personal electronics) [88]. The
40 scales have shown to be reliable and valid in the adolescent population [82-84,88].
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43 *Weather*

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45 We have previously demonstrated the significant impact of inclement weather conditions on
46 physical activity in New Zealand children [89]. To monitor these potential confounding
47 effects we will obtain hourly rainfall, mean temperature, and hours of daylight statistics from
48 the New Zealand Met Service for each data collection day and use these as covariates in the
49 models.
50

51 *Procedures*

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53 Data will be collected from participants within the school setting in school hours. During the
54 measurement session, the NEWS-Y [79] questionnaire will be administered, anthropometric
55 measures will be taken and accelerometers and compliance logs will be distributed. Text
56 messages will be sent to adolescents/parents before data collection session as a reminder to
57 attend. A random sub-sample of 40 adolescents per school will be allocated a GPS receiver to
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3 wear in conjunction with the accelerometer, and will complete the VERITAS interview. All
4 participants will be instructed on the correct use, wear-time, and care of the equipment.
5 Participants will be issued with a \$20 shopping voucher upon completion of data collection
6 and return of the monitors and compliance logs.
7

8 **Quantitative Analyses**

9
10 The proposed dataset will have a hierarchical independent variable structure which consists
11 of person-level observations nested within neighborhoods and schools. The main aim of the
12 study is to examine confounder-adjusted associations of environmental variables with
13 physical activity and body size outcomes. For this purpose, cross-classified (by
14 neighborhoods and schools) generalized linear mixed models (MGLM) with random
15 intercepts will be used. These can account for multiple sources of dependency (schools and
16 neighborhoods) and different types of data (e.g., continuous or binary) following a Normal or
17 other types of distributions (e.g., negative binomial, Poisson) [90]. MGLMs perform well
18 when the number of observations across areas is highly unbalanced, [91] which will be
19 relevant to this project as the number of participants may vary substantially across schools
20 and neighborhoods. Given the relatively small number of strata included in the study,
21 MGLMs will be estimated using Restricted Maximum Likelihood (REML) or Bayesian
22 Markov chain Monte Carlo (MCMC) methods with non-informative priors, [92] the latter
23 appropriate for binary (e.g., overweight/obese vs. normal weight) [92,93] or non-normally
24 distributed outcomes [90]. Non-linear relationship will be examined using restricted cubic
25 splines [94]. A probability level of 0.05 will be adopted.
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31 **Qualitative Methodology**

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33 A total of 16 focus groups, with approximately 5-8 participants, will be conducted at eight
34 participating schools. One researcher (VI) will conduct all the focus groups and at least one
35 of the co-researchers will assist. Variability in walkability will be sought by recruiting two
36 schools in Auckland (representing relatively low walkability) and Wellington (relatively high
37 walkability). However students within focus groups will be selected to represent a range of
38 neighborhood settings to facilitate discussion on differing experiences of the built
39 environment. Participants will also take part in the quantitative component and completed all
40 data collection. To aid open discussion and allow meaningful comparisons separate focus
41 groups will be conducted by age, with younger students (approximately 12-14 years) further
42 stratified by sex, and older students (approximately 15-18 years) in mixed sex groups [43].
43 Focus groups will be conducted using 40 min school periods to accommodate school
44 timetables semi-structured interview. The focus groups are designed to examine the enablers
45 and barriers to being physically active, particularly with regard to active transport,
46 engagement in formal and informal physical activity, safety, and social drivers. Researchers
47 will specifically seek discussion on activity within participants' residential neighborhood and
48 school environments as well as alternative activity spaces in their everyday lives, including
49 those outside of their geographical suburbs. Maps of local environments to prompt discussion
50 on where youth are active (and where they avoid), types of activity, and travel routes will be
51 used. Interviews will be digitally recorded and transcribed by group, with all individual
52 identifying information removed.
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58 **Qualitative Analyses**

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3 Initially, two of the researchers will independently read the transcripts, code and extract
4 themes. The themes will be presented to the team. Disagreement will be resolved through
5 discussion and themes will be confirmed. A coding framework will be developed using
6 NVivo software to organise data generated by the project research questions (deductive) and
7 emergent topics (inductive) [95]. Analyses will be conducted across and within groups to
8 examine commonalities and differences by built environment settings and individual factors
9 (i.e., sex, age, and culture). Concurrent analyses of qualitative and quantitative data will
10 allow insightful integration and triangulation of findings across the study components,
11 allowing us to draw inferences about how youth interact with and manage their lived
12 environments, and what that means for their physical activity and wellbeing [96,97].
13
14

15 **Ethics and dissemination**

16
17 All adolescents will be required to provide assent to participate in the study. An information
18 sheet will be designed specifically for adolescents in a manner that it will be easy to
19 understand. Additionally, all parents of the assenting adolescents will be required to provide
20 parental consent. Parents will also receive a detailed information sheet outlining the study and
21 its requirements.
22

23
24 Data will be entered and stored into a secure (password protected) database. Only the named
25 researchers will have access to the data. Data will be stored for 10 years and permanently
26 destroyed thereafter.
27

28 It is unlikely that participants will experience discomfort or embarrassment during data
29 collection. However, as body measures of weight and height will be objectively assessed,
30 there is the potential of concern around body weight and size. The institution's counselling
31 services will be accessed if a situation arises. All body measurements will be taken behind a
32 portable screen with gender appropriate research officers. All data will be kept private and
33 confidential.
34

35 At the completion of the study, results will be provided to key stakeholders and organisations
36 (e.g., high schools, adolescents, and parents). Results will be disseminated by means of a
37 written report to schools that have participated in the study. Adolescents and/or their
38 parents/legal guardians will receive a report detailing the individual results collected.
39 Government organizations, health boards, and councils, will be able to access key findings
40 and recommendations resulting from the project through seminar presentations and report
41 distribution. Research findings will also be circulated to the scientific community in the form
42 publications in refereed journals.
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45 **Discussion**

46
47 We have described the methods for the BEANZ study which seeks to estimate strengths of
48 association between objective measures of the local environment with accelerometer-derived
49 and self-reported physical activity and sedentary behavior in youth. A novel aspect of this
50 study is the exploration of detailed and multilevel relationships of interaction between the
51 social and physical environments specific to the NZ adolescents. This will be achieved
52 through additional measures (e.g., GPS, VERITAS, focus groups, NDAI) which collectively
53 serve to advance knowledge in this important area of health research, policy advocacy, and
54 ultimately youth health outcomes. Particularly, the use of GPS/VERITAS to identify the
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3 locations that adolescents visit on a daily basis, defining their geographical context, will
4 provide us with accurate estimates of location in which physical activity takes place.
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6 International evidence shows that the most consistent environmental attributes positively
7 associated with reported physical activity in youth were land use mix and residential density,
8 but inconsistent findings have been observed for parks, recreation facilities, and street
9 connectivity [41]. Others found that proximity to parks, recreation facilities and proximity to
10 school [32,43,98,99] along with transport infrastructure were positively associated with
11 physical activity in adolescents [99]. Traffic hazards (number of roads to cross, traffic speed)
12 and local conditions (crime, area deprivation) were negatively associated with physical
13 activity [44,99]. Obesogenic environmental attributes of homes, neighborhoods, and schools
14 are believed to promote sedentary behavior among youth [100] and there is growing evidence
15 that being socially connected with others contributes to adolescent wellbeing [46]. While
16 some evidence exists to show the importance of the built environment for adolescent physical
17 activity and well-being, the use of different methods and limited physical variability within
18 any given environment may serve to consistently underestimate the associations observed. In
19 this study, variance is maximised in two ways. Two major cities in New Zealand are sampled,
20 and these data are subsequently combined with nine other countries through the IPEN-
21 Adolescent study. The larger study will improve our understanding of the nature of the
22 relationships that exist between adolescent physical activity, sedentary behavior and body
23 weight with specific features of the built environment related to walkability, commuting and
24 access to facilities for recreation.
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28 Individuals (or at least parents) may self-select neighborhoods, therefore associations
29 between built environment and walkability may in part be a reflection of neighborhood self-
30 selection bias. Mixed results have been found when investigating neighborhood self-selection
31 and walkability [101-105]. The relationship is a complex one and prospective studies are
32 needed to study the effects of neighborhood self-selection on neighborhood walkability.
33 When reviewing 38 empirical studies that used different approaches to explore the influence
34 of self-selection, Cao and colleagues [106] established that all studies reviewed found a
35 statistically significant influence of the built environment after accounting for self-selection.
36 While exploring this particular relationship is not the focus of the present study, parents'
37 neighborhood preference and self-selection will be accounted for in the analysis. As
38 mentioned earlier, parents will be asked to rank the importance of a variety of reasons for
39 choosing to reside in the particular neighbourhood. The reasons (that address self-selection)
40 could be: easy access to services, walkable environment, and/or access to recreational and
41 sporting facilities. This information will be used in the analysis.
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45 When conducting spatial analyses on aggregated data, errors affecting the validity of results
46 may be introduced [107]. The problem has been referred to as the Modifiable Areal Unit
47 Problem defined as the 'geographic manifestation of the ecological fallacy in which
48 conclusions based on data aggregated to a particular set of districts may change if one
49 aggregates the same underlying data to a different set of districts' [108]. In other words, the
50 way spatial data are aggregated may result in different findings. There has been disagreement
51 in the literature on the best solution for this problem; however, it has been suggested that the
52 only appropriate resolution is to use individual-level data that are geocoded based on
53 residential location [109]. Indeed, our selection strategy uses geo-coded data and we are
54 employing techniques (GPS and VERITAS) to gain a more accurate understanding of
55 neighborhood boundaries for youth. This will substantially advance our knowledge in this
56 field.
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4 This study will contribute to national and international scientific knowledge by forming the
5 NZ arm of the international IPEN-Adolescents collaboration, whereby adolescents' physical
6 activity and sedentary behavior data are collected using a common methodology across
7 multiple countries (Australia, Belgium, Brazil, China, Denmark, Malaysia, New Zealand,
8 Portugal and USA). Furthermore the larger study will improve our understanding of the
9 nature of the relationships that exist between adolescent physical activity, sedentary behavior
10 and body weight with specific features of the built environment related to walkability,
11 commuting and access to facilities for recreation.
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14 Ultimately, by showing the relationships between health outcomes and the neighborhood
15 built environment, we aim to influence and inform policy and city planning practices. City
16 planners, policy makers and government agencies will be engaged early [110] [111]. Results
17 will also be shared with other sustainable transport advocacy, urban planners, and public
18 health organisations. Dissemination of findings to NZ secondary schools and students
19 themselves will maximise the potential impact of the findings.
20
21

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25 New Zealand (12/329).
26
27

28 29 **Authors' contributions**

30 EH developed the first draft of the manuscript. EH, SD, MO, SM, EC, HB, VI, JM, and GS
31 contributed to the conception and the design of the study. All authors provided feedback
32 during manuscript development. Each author has read and approved the final manuscript.
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38 39 **Competing interests**

40 The authors declare that they have no competing interests.
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STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation
Title and abstract	1	✓ (a) Indicate the study's design with a commonly used term in the title or the abstract ✓ (b) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2	✓ Explain the scientific background and rationale for the investigation being reported
Objectives	3	✓ State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	✓ Present key elements of study design early in the paper
Setting	5	✓ Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	✓ (a) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	7	✓ Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	✓ For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	✓ Describe any efforts to address potential sources of bias
Study size	10	✓ Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	✓ (a) Describe all statistical methods, including those used to control for confounding ✓ (b) Describe any methods used to examine subgroups and interactions ✓ (c) Explain how missing data were addressed ✓ (d) If applicable, describe analytical methods taking account of sampling strategy ✓ (e) Describe any sensitivity analyses
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest
Outcome data	15*	Report numbers of outcome events or summary measures
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a

		meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18	✓ Summarise key results with reference to study objectives
Limitations	19	✓ Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	✓ Discuss the generalisability (external validity) of the study results
Other information		
Funding	22	✓ Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.