TITLE: Sampling Design and Data Collection for the NEWPATH Survey

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ABSTRACT

The design of sampling and data collection for the NEWPATH survey, conducted in the Region of Waterloo, Ontario, are presented as a case study in design of a complex survey of health behaviors, including travel patterns, objectively- and subjectively-measured physical activity behaviors, diet-related behaviors, and health outcomes. Features of this design include stratification of the sample with respect to neighborhood walkability, household income and household size with allocation to achieve high statistical power, and carrying out sampling in phases to achieve cost efficiencies. The final data set is approximately representative of the population in terms of demographic measures, and survey weights compensate for biases introduced by oversampling of high- and low-walkability areas as well as differential non-response.

INTRODUCTION

The NEWPATH study is a cross-sectional survey of households in the Region of Waterloo, Ontario, that has broken new ground in collecting data on travel patterns, activity and diet simultaneously. In brief, the objectives of the NEWPATH project are the following: to establish a model to integrate dietary, transportation, physical activity, built environment, and body weight data; to evaluate the impact of dietary behavior (energy in) versus physical activity levels (energy out) in explaining obesity across a range of income, age, and walkability levels; and to use the model to inform policy development within land use and transportation planning in the Region of Waterloo.

Key questions include whether neighborhood walkability is associated with activity levels and transportation choices, and whether access to healthy food is associated with diet quality, and thus whether aspects of the built environment can predict overweight and obesity.

Thus, besides the survey itself, two important ingredients of this study are constructed measures of the environment. One is a walkability surface, in which each six-digit postal code is associated with a walkability index score which takes into account residential density, connectivity (road and pedestrian), land use mix and ratio of retail floor area (*1*). The other is a set of objective measures of food access, food availability, food affordability, and food quality , obtained from a census of food stores and restaurants. A variety of food environment assessment tools were applied in one of each chain restaurant, convenience store, gas station and pharmacy; every grocery store; and every independently-owned restaurant, convenience store, gas station and pharmacy in the three cities that comprise the Region of Waterloo (Kitchener, Cambridge, and Waterloo) (*2*), (*3*).

In addition to the unique combination of travel, activity and diet data, the study has two notable features in its sampling design and methodology. The first is the *stratification* of the population, and the *allocation* of the sample among strata defined by walkability and other variables, in order to ensure high statistical power to detect the hypothesized effects of walkability. The second is a process akin to that of a *responsive design* in the sense of (*4*), in which the progress of fieldwork was monitored for sample composition and productivity, and sampling was carried out in phases corresponding to changes in protocol designed to reduce costs and increase representativity of the sample.

The organization of this paper is as follows. The survey data collection protocols and the measures collected for households and individuals are described. Then the study population and the sampling design are specified, and the principles for the allocation of the sample to strata are justified. The next section deals with the division of the sampling design into phases, and the consequences for the computation of survey weights. The results of the sampling design are presented in terms of conditional response rates and the representativity of the sample. The final section contains discussion and conclusions.

SURVEY DATA COLLECTION PROTOCOLS AND INSTRUMENTS

Each respondent household was assigned to one of two groups, in a manner to be described in the next section. In the first group (the Complex group) every member of the household was asked to complete a travel diary, which included food records, for two days, and one household member wore an accelerometer during the same two days. Households in the second group (the Simple group) were to complete diary information pertaining to travel only, without including food eaten, and no one was assigned to wear an accelerometer. Both types of households completed a recruitment questionnaire by telephone, and mailed attitude and behavior questionnaires which asked about neighborhood preferences and food shopping patterns. The remuneration was $25 for the Complex group households (later increased to $30 for larger households) and $15 for the Simple group households. Remuneration was pre-paid for the Simple group, since pre-payment generally increases response rates (*5*), but post-paid for the Complex group, to increase the chances of retrieving the accelerometers.

The telephone recruitment questionnaire contained questions pertaining to all members of the household, concerning personal information, schools, workplaces, vehicles; this was responded to by an available adult knowledgeable about the household, often the person who had answered the telephone. This informant was labeled Person #1 in the household. The paper neighborhood preference questionnaire was also filled out by Person #1. The paper food shopping questionnaire was completed by the person in the household responsible for the majority of food purchases. The two-day diary, either Simple or Complex, was to be filled out for every individual aged 11 or older in the household. The two days for a household were randomly chosen from pairs of consecutive days of the week. In Complex group households, Person #1 was asked to wear the accelerometer.

Households were recruited by telephone. The questionnaire and diary materials were sent to recruited households by courier, with instructions for mailing them back. One reminder call was made to each recruited household just before the diaries were to be used, and follow-up calls were made after the diaries were to be used.

Household-level background measures include data on income, number of persons, language, ethnicity, detailed information on household vehicles, ownership or rental of dwelling, factors in the decision to move into the neighborhood, whether or not moving is being considered, aspects of neighborhood walkability, and other local characteristics.

Household-level measures related to food include a fruit and vegetable frequency questionnaire (adapted from the Canadian Community Health Survey, Cycle 2.2), perceptions of the neighborhood food environment (related to food access, food availability, food quality, and food affordability), frequency of different type of food outlet use (stores and restaurant) and respondents' reasons for patronizing different kinds of food outlets, and the Rapid Risk Factor Surveillance Survey (RRFSS) food security questionnaire (www.rrfss.ca).

Individual-level measures include gender and age, length of time living in Canada, possession of a driver's license, work situation and primary occupation, work or school address, educational achievement, and presence of a medical condition affecting travel habits; chronic conditions and self-perceived health were also obtained for Person #1. Data were collected on travel and physical activity (habitual and over the previous 7 days for Person #1, and over the two diary days for everyone).

Self-reported body mass index (BMI=kg/m^2) and waist circumference (WC) have been considered adequate proxies for measured BMI and WC in previous studies (*6*). In both Simple and Complex diaries, participants were asked their height and weight, and were provided with a paper tape measure and explicit instructions to measure WC. BMI was calculated from self-reported height and weight. Participants reported two measures of WC; mean WC (cm) was used as an individual-level outcome variable. For participants who completed Complex diaries, the Healthy Eating Index adapted for Canada (HEI-C) (*7*) was used to define diet quality. Participants' food record data were entered into the ESHA Food Processor SQL program, which analysed micro- and macro-nutrient content of the food reportedly eaten. The Canadian Nutrient File database (2007) was linked to the micro- and macro-nutrient datafile to determine the number of servings of different food groups based on Canada's Food Guide to Healthy Eating. The HEI-C reflects Canadian food intake recommendations based on participants' age and sex, and ranges from 0 to 100, where scores less than 50 represent a poor diet; scores between 50 and 80 represent a diet in need of improvement, and scores above 80 represent a good quality diet (*7*). Mean HEI-C over the two days was used as an individual-level indicator of dietary quality. Finally, Complex participants also reported each time they bought food prepared away from home for immediate or for home consumption.

STUDY POPULATION AND SAMPLE

The survey was undertaken to document travel, food environment, food purchasing patterns, and dietary consumption, body weight, urban form, and demographic measures, for an initial target of approximately 2400 households, 1400 in the Simple group and 1000 in the Complex group. In the end, budget constraints forced the reduction of the intended Complex group sample size to 750. At the completion of fieldwork, diary data were obtained from 2228 households: 1473 in the Simple group and 755 in the Complex group. Accelerometer data for at least one day were obtained from 746 individuals, while 716 provided complete accelerometer and diary data.

The sample was stratified by variables known to be predictors of the outcomes and relationships of interest, and allocated in such a way as to give high power to comparisons across walkability levels. As was observed by Frank et al (*8*), P. 69, "without a stratification strategy it would be impossible to get enough variation to allow for sophisticated and rigorous statistical analysis of the effect of land use patterns on travel behavior". The design was similar to the "orthogonal" approach for neighborhood level sampling in (*9*), where high- and low-walkability and high- and low-income categories were crossed to form strata of "blockgroups" (the building blocks of "neighborhoods").

The household population consisted of households defined to be families and one-person units living alone or with unrelated people, in the three major cities of the Region of Waterloo, Ontario: Cambridge, Kitchener and Waterloo. The walkability index and surface were to be used to classify postal codes in the three cities as being of high, medium and low walkability. The high- and low-walkability areas consisted, respectively, of postal codes with walkability scores more than one standard deviation higher than, and more than one standard deviation lower than, the mean of the walkability scores for postal codes. At the time of the 2006 Census of Canada, the proportions of households in the Region of Waterloo in the high-, medium- and low-walkability areas were 4%, 85% and 11%. The sampling design was to oversample the high- and low-walkability areas, and within each walkability area, to stratify proportionally according to three ranges of household income (< \$35K, \$35K-\$85K, >\$85K), and three levels of household size (1 person, 2 persons, 3+persons).

The theory behind the allocation to high- and low- walkability areas in the NEWPATH study is as follows. For a regression model of form $Y = X\beta + \varepsilon$, the least squares estimator for β is

$$\hat{\beta} = (X^T X)^{-1}(X^T Y),$$

and the covariance matrix for $\hat{\beta}$ is $\sigma^2(X^T X)^{-1}$. The greatest precision for estimation of a component of β is obtained when the corresponding element of the diagonal of $(X^T X)^{-1}$ is largest. Therefore the detection of a case where a component of β is non-zero is expected to be more powerful, the greater the variability in the relevant explanatory variables. Maximum variability subject to bounds is generally obtained when the explanatory variable corresponding to β is orthogonal to the others and equally likely to be its lowest and its highest possible value (*10*).

At the same time, for close examination of the relationships between walkability and important outcomes, it is desirable to have representation from the medium-walkability areas. The theory just described assumes a linear relationship between walkability and outcome, but this linearity may not hold for all outcomes. For example, for some outcomes there may be thresholds of walkability below which no dependence of (say) vehicle use on walkability exists. Thus a substantial number of households in the Simple group were eventually recruited from medium-walkability areas. This part of the allocation also meant that, with appropriate weighting, results of the survey could be generalized to the whole population of the cities in the Region of Waterloo.

Once the walkability scores for postal codes were available, the Region of Waterloo obtained tabulations from the 2006 Census of Canada by city and income group, by walkability level and income group, by city and household size, and by walkability level and household size. (Three-way cross tabulations were not available.) The targets for numbers of households were then set by walkability level and income group, and by walkability level and household size. For the Simple group, the allocations to low-, medium- and high-walkability areas were 400, 600 and 400 households respectively. For the Complex group, the allocations to low- and high-walkability areas were to be equal, with 500 households in each; these target allocations were later reduced to 375 households in each. Within walkability areas, targets were proportional to sizes of the income group and household size strata from the 2006 census. The low-, medium- and high- income group target proportions were approximately 25%, 41% and 34% in each of the walkability areas, so that the walkability and income group allocations would be approximately orthogonal.

Because the targets were not available at the beginning of fieldwork, and because it typically took two to four weeks to determine whether a recruited household would become a completely responding household, the targets were not achievable precisely; continual assessments of the sample composition resulted in the phased structure of the design discussed in the next section, and survey weights were constructed to calibrate the sample to the 2006 Census of Canada tabulations.

The target and achieved numbers of households are given in Tables 1 to 4.

TABLE 1 Sample sizes (upper) and targets (lower) for the Simple group, by walkability area and income group

Walkability	Income Groups							
	<$35K	%of Target	$35K-$85K	%of Target	>$85K	%of Target	TOTAL	%of Target
Low	71	177.5%	178	107.9%	235	120.5%	484	121.0%
	40		165		195		400	
Medium	131	93.5%	264	101.5%	214	107.0%	609	101.5%
	140		260		200		600	
High	105	63.6%	174	108.8%	101	134.7%	380	95.0%
	165		160		75		400	
OVERALL	307	89.0%	616	105.3%	550	117.0%	1473	105.2%
	345		585		470		1400	

TABLE 2 Sample sizes (upper) and targets (lower) for the Simple group, by walkability area and household size

Walkability	Household Size							
	1 person	%of Target	2 person	%of Target	3+ person	%of Target	TOTAL	%of Target
Low	58	145.0%	180	144.0%	246	104.7%	484	121.0%
	40		125		235		400	
Medium	153	102.0%	207	103.5%	249	99.6%	609	101.5%
	150		200		250		600	
High	148	72.2%	139	120.9%	93	116.3%	380	95.0%
	205		115		80		400	
OVERALL	359	90.9%	526	119.5%	588	104.1%	1473	105.2%
	395		440		565		1400	

TABLE 3 Sample sizes (upper) and targets (lower) for the Complex group, by walkability area and income group

Walkability	Income Groups							
	<$35K	%of Target	$35K-$85K	%of Target	>$85K	%of Target	TOTAL	%of Target
Low	54	108.0%	133	64.9%	224	91.4%	411	82.2%
	50		205		245		500	
High	126	61.5%	119	59.5%	99	104.2%	344	68.8%
	205		200		95		500	
OVERALL	180	70.5%	252	62.2%	323	95.0%	755	75.5%
	255		405		340		1000	

TABLE 4 Sample sizes (upper) and targets (lower) for the Complex group, by walkability area and household size

Walkability	Household Size							
	1 person	%of Target	2 person	%of Target	3+ person	%of Target	TOTAL	%of Target
Low	41	82.0%	124	80.0%	246	83.4%	411	82.2%
	50		155		295		500	
High	165	64.7%	84	57.9%	95	95.0%	344	68.8%
	255		145		100		500	
OVERALL	206	67.5%	208	69.3%	341	86.3%	755	75.5%
	305		300		395		1000	

The reduction in Complex group sample size resulted in some reduction of expected statistical power, as in the following examples. Suppose standardized measures of physical activity variables, are used as the predictors in a logistic regression of obesity, having overall prevalence of about 23%. With walkability included as a variable, and the use of weights which sum to sample size within walkability areas, assume a survey design effect of 1.3 (factor by which variances are inflated over those for a simple random sample, using the variance inflation factor described in (*11*)). From power calculations using simulations of the logistic regression model, a sample size of 750 individuals from different households should give 80% power to detect an effect size (increase in log odds of obesity vs 1 unit increase in a predictor) of 0.28 (odds ratio 1.32), using a two-sided hypothesis test of size 5%. The corresponding effect size for 1000 individuals is 0.24. A sample size of 2228 individuals from different households would give 80% power to detect an effect size of 0.165 (odds ratio 1.18), using a two-sided test of size 5%. The corresponding effect size for 2400 individuals is 0.155.

The achieved allocation of the sample to high- and low-walkability areas is close to equal: it includes 895 households in the low-walkability areas and 724 households in the high-walkability areas. Assuming an average of 1.7 respondents per household, this division yields 80% power to detect a difference of 5.8 percentage points in the overweight/obesity rates of the two groups, with a two-sided hypothesis test of size 5%, and assuming a survey design effect of 1.5. If the sample had allocated in proportion to the numbers of households in the walkability areas, the numbers of households would have been about 90 for high walkability and 245 for low walkability, and the power to detect such a difference would have been about 22%.

RESPONSIVE DESIGN OF THE SURVEY

Complex household surveys are planned using assumptions of response rates and respondent effort which may not be realized in practice. Often, preliminary costing of the fieldwork is required before the instruments are fully developed, or before the sampling frames are available. Once fieldwork is underway, it is necessary to monitor the progress of fieldwork carefully, keeping track not only of sample sizes in categories (for households and for individuals) but also of productivity of field staff, and costs being incurred. At certain points, the frames, the targets, and sometimes the protocols, may need to be adjusted. These decisions divide the survey fieldwork into phases (Groves and Heeringa, 2006), which must later be taken into account in estimation, principally through calculation of the weights.

In the NEWPATH study, it was initially expected that data collection would occur in a spring wave and a fall wave, but the complexity of the data collection and the time required to develop the walkability surface meant that the time period had to be extended significantly. Difficulty in recruiting in certain categories resulted in the adjustment of targets in the last part of the time period. Thus the NEWPATH study had six phases in all.

Data collection began in the Spring of 2009, and was suspended for the summer months. Through the periods of May 14 – June 16, 2009 and August 28 – November 27, 2009, recruitment for the Simple form and the Complex form of the survey was carried on using a randomly ordered telephone sampling frame (listed numbers with postal codes). Complex group recruitment was also carried out from February 23 – April 11, 2010. Finally, a UW student sample was added using the University's student email address frame, to address an under-representation of the student-age population. The student group was recruited from March to May, 2010.

The six phases may be termed Spring 2009 Simple, Spring 2009 Complex, Fall 2009 Simple, Fall 2009 Complex, Winter-Spring 2010 Complex General, and Winter-Spring 2010 Complex Student.

In the Spring 2009 Simple phase, sampling began before final targets were set for the quota cells, since determination of the walkability areas and calculations with census data to determine the characteristics of their populations were ongoing. Accordingly, households were recruited effectively randomly for the Simple version of the questionnaire and diary package.

Recruitment for the Spring 2009 Complex phase was intermittent, being subject to the availability of accelerometers. Only 30 devices were available during the short recruitment period before the middle of June.

By the beginning of the Fall 2009 Simple phase, the boundaries of the walkability areas had been delineated, and it became apparent that more of the remaining households for the Simple questionnaire package would have to be recruited from the medium-walkability areas. Where it appeared that quota cells were becoming full, those quotas were closed to recruitment.

In the Fall 2009 Complex phase, households were recruited randomly from high- and low-walkability areas. A serious shortfall in the numbers of larger households in low-walkability areas meant that the Winter-Spring 2010 Complex General phase focused on this group, and the compensation was increased for larger households.

Under-representation of the high-walkability area student-age population in Waterloo led to the introduction of the Winter-Spring 2010 Complex Student phase, in which students were selected randomly from the University of Waterloo frame of student email addresses, and recruited by email. A total of 34,601 students were invited. To be eligible, they had to be living alone or with unrelated roommates, in a high-walkability area. (To assess whether they would have been contactable through the telephone frame, they were asked where they lived in each phase of the recruitment, and whether the dwelling was cell-only, or had a landline connection.) In all, 79 students completed the survey.

Survey weights were constructed for participating households and for individuals. They include “inflation weights”, which are the reciprocals of inclusion probabilities, calibrated to sum to totals in geographic and age-gender categories cities in the Region of Waterloo from the 2006 Census of Canada.

Since the design deliberately under-sampled medium-walkability areas, the inflation weights in those areas are much larger than in the areas of low and high walkability. In regression analyses, if the inflation weights were used, the sample points in the medium-walkability areas would dominate, making inference very inefficient. For regression and logistic regression analyses in which walkability is an explanatory variable, so-called “analytic weights” were also constructed, to sum to sample size within walkability area.

There are separate inflation and analytic weights for each of the instruments in the used in the survey. For example, there are household recruitment weights (inflation and analytic), individual travel diary weights, and so on. Details of their construction and advice on their uses are provided in the technical report of the study, available on request. The basis for the calculation of weights, taking into account the phase structure, is here illustrated for the household recruitment inflation weights.

The recruitment probability of inclusion of a household from the telephone frame is the probability of its being recruited in one of the first five phases. Suppose first that in each phase the probability of a household being recruited is approximately uniform in household size crossed with walkability area. Thus for phase p an approximation to the household inclusion probability is n_{psw}/N_{psw}, where n_{psw} is the number of households in which people were recruited in phase p with household size s in walkability area w, and N_{psw} is the number of households with household size s in walkability area w.

For households of 2 persons or 3+ persons, the N_{psw} were taken from 2006 census data for each phase. For households of 1 person (including single persons in shared accommodation with unrelated others), the N_{psw} were estimated from census data supplemented by information on student enrolment in the universities, which varies considerably from university term to term. (Thus inclusion probabilities for households of 1 person were taken to be different in Fall, Winter and Spring.) For a household consisting of a single person in shared accommodation with unrelated others, n_{psw}/N_{psw} should be further divided by the number of unrelated people in the shared accommodation, assuming them all equally likely to participate. However, this was not possible since by the number of unrelated people in the shared accommodation was not collected. These quantities n_{psw}/N_{psw} were summed over the first five phases to obtain an overall household inclusion probability.

The probability of inclusion of a student recruited in the Winter-Spring 2010 Complex Student phase was assumed to be the same as the probability for a household of 1 person plus n_{61w}/N_{61w}, where n_{61w} is the number of students in the sample in walkability area w and N_{61w} is the estimated number of eligible students in the population in walkability area w.

Basic inflation weights were taken to be the reciprocals of these inclusion probabilities. However, their calculation ignored the fact that there were targets specified for walkability area crossed with income group (low, medium, high). It also ignored differential recruitment rates by city. (Recruiting in Cambridge proved to be more difficult than in Waterloo and Kitchener.) To correct the weights to take these facts into account, the weights were calibrated to sum to assumed totals (from census data) of households within each city crossed with household size, assumed totals of walkability area crossed with income group, and assumed totals of walkability area crossed with household size.

SAMPLE CHARACTERISTICS

For a household to be eligible to be recruited for the survey, the informant had to assert that the household would be willing and able to complete the survey tasks in the required time frame. Thus in absolute terms, response rates were low, as is common for recruitment by random digit dialing (RDD). Conditional response rates were measured in terms of the number of households which completed the survey, once recruited. These rates can be summarized as follows.

The conditional response rates for households varied little across the six phases, ranging from 56% in the Fall 2009 Complex phase to 64% in the Winter-Spring 2010 Complex General phase (where compensation was increased for larger households). The rates were highest for Waterloo and lowest for Cambridge. They were fairly consistent across walkability levels. Before the Winter-Spring 2010 Complex General phase, they tended to be lower for households with 3+ persons than for households of smaller size. The conditional response rates also tended to be higher for households of low-walkability areas and high income, and for households of high-walkability areas.

The composition of the sample of individual respondents who completed the travel diaries is compared with composition of the population of residents of the three cities combined (the Kitchener Census Metropolitan Area) from the 2006 census. The census population numbers and percentages are given in Table 5, along with the unweighted percentages (equivalent to sample percentages) from the NEWPATH sample. (The weighted percentages from the NEWPATH sample are equivalent to the census percentages.) The unweighted percentages are fairly close to the census percentages, with some underrepresentation in the younger age groups, particularly for males.

TABLE 5 Population numbers and percentages from the 2006 Census of Canada, and [unweighted percentages] from the NEWPATH study

Age group	Male	Female
11-17	21489 5.5% [6.0%]	20533 5.3% [5.4%]
18-24	23730 6.1% [3.9%]	22979 5.9% [5.0%]
25-34	31865 8.2% [6.7%]	31880 8.2% [7.6%]
35-44	35815 9.2% [8.8%]	36270 9.3% [9.4%]
45-54	32515 8.4% [8.8%]	33435 8.6% [10.5%]
55-64	22105 5.7% [7.6%]	23105 6.0% [8.2%]
65+	22365 5.8% [5.5%]	29900 7.7% [6.7%]

DISCUSSION AND CONCLUSIONS

This paper has described a case study in complex household data collection with emphasis on two features of the sampling design and their implications.

The first feature was a considerable oversampling of households in high- and low-walkability areas, with enough sampling of households in medium-walkability areas to produce general population estimates. The oversampling in high- and low-walkability areas allows for more powerful statistical analyses of differences in outcomes at extremes of walkability, controlling for important confounders related to socioeconomic status and household composition. The oversampling also renders the "inflation weights" (needed for estimation of descriptive attributes of the general population) very highly variable. For regression and logistic regression analyses, "analytic weights" which are rescaled to sum to walkability level sample sizes are required, and with the use of these weights walkability level must always be included in the regression model.

The second feature was the conduct of the survey in phases, defined in effect by the two types of task (simple and complex), the timing of availability of walkability data and targets, the length of time required to recruit, the need to adjust effort and compensation to reach larger households in the last few months of the survey, and the decision to recruit a separate sample of students. As indicated in the section on Responsive Design, it is still possible under such circumstances to calculate basic and calibrated weights to support a wide variety of analyses.

As originally envisaged, the survey would have taken place over two periods, one in the spring and one in the fall, avoiding the "atypical" summer months, and the harsh conditions of winter. Ultimately, there were effectively three periods, with Simple group surveys being carried out approximately half in Spring 2009 and half in Fall 2009, and Complex group surveys being carried out approximately two-thirds in Spring and Fall 2009 and one third in late Winter and early Spring of 2010. Fortunately, the period in the Winter of 2010 was relatively mild, with very little snow, and March of 2010 was warmer than average.

This paper is provides a concrete example of theoretical bases for designing studies on the built environment. Built environment research is becoming more popular, as urban planners and public health practitioners are increasingly interested in creating livable and healthy communities, with ample opportunities for physical activity and healthy eating. This kind of research is important because the built environment can be modified, or designed to incorporate improvements. Studies like the NEWPATH survey can provide an evidence base for planning healthy livable communities.

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