

What explains variability in blood pressure readings?

Multilevel analysis of data from 8,731 older adults in 20 Ontario Communities

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Abstract

Title:

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Objectives:

Despite universal healthcare and drug coverage for adults aged 65 and over in Ontario, hypertension, a treatable condition, remains uncontrolled among many older adults. Moreover, there are geographic disparities in blood pressure and hypertension within and across Canadian provinces and territories. Using baseline data collected on 8,731 older adults participating in the Cardiovascular Health Awareness Program (CHAP) in 20 randomly selected Ontario communities, we investigated associations between systolic blood pressure (SBP) and individual- and community-level characteristics, controlling for self-reported use of blood pressure medications.

Method:

Older adults were recruited via invitation by local family physicians, public advertising and word of mouth to attend community pharmacy sessions. During the sessions, trained older adult volunteers assisted participants to complete a cardiovascular disease risk factor questionnaire and blood pressure assessments using an automated blood pressure measuring device. The Postal Code Conversion File Plus was used to confirm residence within one of the 20 study communities. A multilevel linear regression analysis with participants nested within communities was used to determine which individual- and/or community-level characteristics were associated with measured systolic blood pressure level controlling for self-reported use of blood pressure medication.

Results:

4,706 participants (53.9%) reported the use of blood pressure medication. Mean systolic blood pressure (SBP) levels varied among the 20 communities from 128.1 mmHg to 134.7 mmHg for participants not using blood pressure medication and from 131.9 mmHg to 139.0 mmHg for participants using blood pressure medication. The intraclass correlation coefficients were very small: less than 0.2% of the total variance was between communities. Among participants not using blood pressure medication, SBP was associated with the following individual-level characteristics: age, sex, body mass index, smoking, physical activity, stress, fruit/vegetable intake, and alcohol consumption and the following community-level characteristics: community size, community growth and the Rurality Index. Among participants using blood pressure medication, SBP was associated with the following individual-level characteristics: age, sex, body mass index, diabetes, fruit/vegetable intake, alcohol intake and one community-level characteristic: community size. The significance and magnitude of these associations were modified by the use of blood pressure medication.

Conclusion:

The majority of the variability in blood pressure occurs at the individual-level. There are specific individual- and community-level factors that explain variability in blood pressure readings among communities. These results can be used to inform health promotion strategies to decrease mean levels of blood pressure among older adults.

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1.0 Introduction

Despite universal health care in Canada, some populations are significantly less healthy than others; geographic health disparities in Canada have been documented both across and within the provinces and territories (1, 2).

Hypertension (high blood pressure) is a chronic condition that increases a person's risk of stroke, dementia, coronary heart disease, heart and kidney failure and premature death (3). The risk of hypertension increases with age (4), which combined with the increasing rate of population aging, will put significant pressure on the health care system in Canada (5).

There are geographic disparities across Canada and within its provinces and territories. In Canada, the prevalence of self-reported hypertension varies from 14.7% in Alberta to 20.4% in Nova Scotia (1) while the prevalence of self-reported hypertension across geographic areas within the province of Ontario varies from 11.6% to 18.7% (6).

Health Indicators 2010 is a report prepared by the Canadian Institute for Health Information (CIHI) and Statistics Canada focused on health disparities associated with geography, socioeconomic groups, age and sex (1). According to this report, the measurement and reporting of health disparities is important due to the potential to reduce or prevent these disparities and thereby improve the health status of the Canadian population.

Community-level characteristics may explain some of the geographic disparities in the prevalence of hypertension. Individuals from the same community share a number of demographic, socioeconomic, health care access, and lifestyle factors which may be referred to as 'contextual' factors. Therefore, although blood pressure is an individual-level characteristic (with multiple risk factors at the individual-level), there may be additional risk factors at the

community-level which independently influence blood pressure, resulting in a clustering of blood pressure values within the community. It is also possible that the clustering of blood pressure values within communities could be a result of the varying ‘composition’ of the community in terms of individual-level characteristics.

Multilevel analyses can be used to detect the presence of clustering of blood pressure within communities by partitioning the between-community and within-community variance. Unobserved community-level effects are modelled as ‘random’ effects, while the observed individual- and community-level characteristics can be modeled as ‘fixed effects’. The addition of individual-level characteristics describing the ‘composition’ of the communities can allow one to detect whether the presence of clustering of blood pressure values in the community is explained in part or in full by the characteristics and behaviours of the individuals residing in the communities. In addition, such multilevel analyses can be used to estimate the presence, magnitude and statistical significance of associations between individual-level and community-level characteristics and blood pressure, referred to as ‘fixed’ effects.

The aim of this study is to use multilevel, multivariable analyses to explore the differential impact of individual- and community-level characteristics on blood pressure among older adults in Ontario.

1.1. Geographic disparities in hypertension.

Differences in the prevalence of hypertension exist among countries (7) , within countries (1) and within provinces (6). In Canada, the prevalence of self-reported hypertension varies from 14.7% in Alberta to 20.4% in Nova Scotia (1) while the prevalence of self-reported

hypertension across geographic areas within the province of Ontario varies from 11.6% to 18.7% (6).

1.2 Hypertension as a priority public health issue

Criteria can be used by governmental and non-governmental organizations to decide whether to intervene on a health issue with population-level policies and other interventions. While the exact criteria used to allocate resources to one health issue over another differs among organisations, some are commonly considered. These include: the risk of disease; the magnitude of the disease burden such as mortality, disability, morbidity, costs to individuals and organizations; the availability, effectiveness and cost of control measures; and the availability of resources to respond to the issue. Hypertension is a health condition which affects a large proportion of the population (4, 8, 9), contributes heavily to the burden of disease (10), is safe and painless to diagnose and for which there are known safe and effective treatments (11).

1.2.1 Prevalence of hypertension

Hypertension is a prevalent condition and the prevalence increases sharply with age. The Ontario Survey on the Prevalence and Control of Hypertension found that 52% of adults 60-79 years of age were hypertensive compared to 3% of adults 20–39 (4). The combination of the aging of the population and the increased risk of hypertension with age will result in a large increase in the prevalence of hypertension and the corresponding burden of disease. The Canadian Chronic Disease Surveillance System uses administrative databases to estimate the prevalence of hypertension. Based on current age and sex trends, a 25.5% increase in prevalence between 2006/2007 and 2011/2012 is anticipated, representing an additional 1.3 million Canadians living with hypertension (8).

1.2.2 Burden of disease associated with hypertension

Hypertension contributes heavily to the burden of disease. Hypertension is a leading risk factor for stroke, cardiovascular disease and kidney failure, dementia and all-cause mortality (3). Worldwide, 54% of stroke and 47% of ischemic heart disease can be attributed to high blood pressure (12) and thus it is ranked as the third leading cause of the global burden of disease (13) responsible for 7.6 million premature deaths (13.5% of global total) (12). Known as the ‘silent killer’, hypertension is a leading modifiable risk factor for cardiovascular disease and mortality.

1.2.3 Diagnosis of hypertension

Hypertension can be detected by a safe, painless and non-invasive test which is simple to administer and is routinely available in medical clinics and increasingly available in public places such as pharmacies. Blood pressure can be measured by a trained professional using a manual sphygmomanometer; however increasingly automated blood pressure measuring devices which do not require professional training to use are being made available for self-assessment (14).

1.2.4 Prevention and management of hypertension

Known, safe and effective treatments are available to treat, control and prevent hypertension. The prevention and management of hypertension can take two approaches: a ‘high-risk’ approach, focused on the detection, diagnosis and medical treatment of individuals at high risk of hypertension, and a ‘population health’ approach, focused on decreasing the mean level of blood pressure in the entire population. Population health approaches may include promoting healthier lifestyles, instituting healthy public policies and reducing barriers to health care (15). Rose uses the following analogy to distinguish the two approaches: “(The individual

strategy) is analogous to sending emergency aid for famine relief in the Third World: it is ethically compelling and it saves lives, but famines will continue to occur until there are changes in their underlying causes, which are economic, social and agricultural. These radical changes are analogous to the population strategy of prevention”(16).

1.2.4.1 The high-risk approach to hypertension

The concern of the clinician is the individual. The clinician seeks to identify, diagnose and treat those individuals who may be at unusual risk of hypertension. As a necessity, diagnosis depends on dichotomous thinking, that is ‘Is this patient hypertensive or not?’ Study designs aimed at informing the high-risk approach to hypertension would typically define hypertension as a dichotomous outcome, that is, to define a cut-off point and identify study participants as either hypertensive or not hypertensive.

The most common approach to the treatment of hypertension is pharmacological. Significant efforts to increase physician and public awareness of available and effective pharmacological treatment for hypertension (such as the Canadian Hypertension Education Program initiated in 1999) may have contributed to the dramatic increases in the pharmacological treatment and control of hypertension between the Canadian Heart Health Survey (1986-1992) and the Ontario Survey on the Prevalence and Control of Hypertension in 2006. Among participants with diagnosed hypertension ($SBP \geq 140$ mmHg and/or $DBP \geq 90$ mmHg or use of anti-hypertensive medication), 82% versus 33% were treated with anti-hypertensive medication in the 2006 survey and 65.7% versus 14.7% successfully controlled (4). Despite these improvements, approximately one-fifth of hypertensive participants in 2006 were not receiving any treatment (4). There are significant costs associated with the pharmacological

treatment and management of hypertension which will continue to rise exponentially with the projected increase in the prevalence of hypertension outlined in the Public Health Agency of Canada's report, *Hypertension in Canada 2010* (8). The direct cost estimated in 2003 in Canada for physician visits, pharmaceuticals and laboratory work associated with hypertension exceeded 2.3 billion dollars (IMS Health Canada as referenced in (17)).

1.2.4.2 Population health approach to hypertension

The aim of a population health approach to hypertension is to seek ways to promote a downward shift of the distribution of blood pressure in the population by tackling the underlying causes of the incidence of disease. Differences in the population mean blood pressure are secondary to shifts in the distribution of risk factors associated with blood pressure. These in turn are influenced by changes in behaviour by large portions of the population.

Knowledge about community-level characteristics associated with blood pressure can inform a population-based approach to reduce geographic disparities, aimed at shifting downward the population mean level of blood pressure. Rose (1981) states that 'a large number of people exposed to a low risk is likely to produce more cases than a small number of people exposed to a high risk'. Rose goes on to estimate that a downward shift of 2-3 mmHg in average population blood pressure level would match the life-saving benefits achieved by antihypertensive treatment of individuals (15). Although Rose's claim is now nearly 30 years old, the recent Institute of Clinical Evaluative Sciences (ICES) publication on the population risk of diabetes offers support for Rose's theory. The ICES report found that although very obese people (BMI>35) are at the greatest risk of developing diabetes, the largest number of new diabetic cases will come from the overweight population (BMI 25-30) (18). Accordingly, while

people with very high levels of blood pressure (for example >140/90 mmHg) are at the greatest risk for stroke, many strokes occur among those with blood pressure in the high-normal or mild hypertension category (for example 115-139 mmHg systolic and/or 80-89 mmHg diastolic).

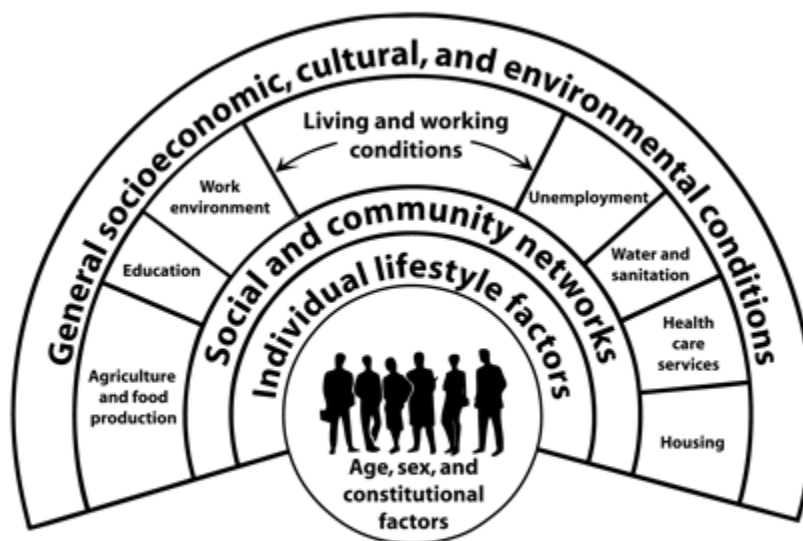
According to a meta-analysis of individual data for one million middle-aged and older adults in 61 studies, the risk for stroke and ischemic heart disease increases linearly with blood pressure with no evidence of a threshold below 115/75 mm Hg (19). These results demonstrate that risk does not commence at an arbitrarily defined cut-off such as 140/90 mmHg. For this reason, study designs aiming to inform a population health approach to blood pressure should model blood pressure as a continuous measure. By identifying individual and community-level characteristics associated with blood pressure, population health interventions can be designed and implemented to reduce the incidence of hypertension by shifting the population distribution of blood pressure to a lower level.

1.3 The effects of 'place' on health

Interest is growing in Canada about the effects of 'place' on health. The recently released report *Health Indicators 2010* focused on geographic and socioeconomic health disparities on the rates of heart attack in Canada and found a greater than three-fold difference between the provinces with the highest and lowest rates of heart attack (1). The study authors suggest further research is required to determine the full extent of health disparities in Canada and to determine the extent to which these disparities are influenced by individual behaviours compared to the contexts in which people live. Multilevel studies can quantify the extent to which geographic disparities are compositional, that is, a function of the characteristics and behaviours of the individuals comprising the population, or contextual, that is, a function of group level characteristics.

Dahlgren and Whitehead (1991) developed a theoretical model demonstrating how an individual's health is affected, either positively or negatively, by layers of influence including community context (Figure 1)(20) . External factors, such as those at the community level, can either directly influence health or can enable or constrain an individual's lifestyle decisions that

Figure 1. Main Determinants of Health Model (Dahlgren and Whitehead, 1991)



in turn affect their health. At the centre of the model are non-modifiable individual characteristics such as sex, age and hereditary factors. In the next layer are the modifiable individual behaviours that influence health such as diet, physical activity and smoking. These individual influences are nested within the shared wider determinants of health which arise from social, environmental and economic conditions. These include living and working conditions

which are shared by members of the same community such as education levels, unemployment and access to health care.

Many studies have used multilevel regression analyses to demonstrate neighbourhood and community socioeconomic effects on adult health status including blood pressure (21), cardiovascular risk (22) cognitive and functional impairment (23), general health (24), and mortality (25). In addition to socioeconomic conditions, community demographic variables such as the proportion of residents 65 and over (26, 27), access to health care; (28, 29), ratio of physicians to patients (30) residential stability (27), community growth (31), and community size (32) have been linked to health outcomes among older adults.

Community context has been shown to be influential in the health of older adults (26, 33). However, there has been a dearth of studies examining contextual effects among older adults in Canada. In a recently published systematic review of neighbourhood influence in the health of older adults, a total of 33 studies published between January 1997 and December 2007 met the following review criteria: published in English, average age of study population greater than 55 years of age, and neighbourhood as the exposure (34). The health outcomes investigated in the 33 studies included mortality, self-reported health or quality of life, mental health, disability, cognition, physical activity, obesity and morbidity. Since nearly half (15/33) of the studies did not use multilevel analyses to account for clustering within neighbourhoods, the validity of the inferences reported in these studies are suspect. No multilevel studies in the review examined blood pressure as an outcome. The systematic review concluded that neighbourhood environment is important in the health and functioning of older adults.

Of the 33 studies included in the systematic review, 26 were conducted in the U.S. and the remaining seven in Australia or Europe (34). There are political, economic, health care and racial differences between Canada and the U.S, Australia and Europe which limit the generalizability of these findings to the Canadian population of older adults.

Based on this systematic review, there is a gap in the research literature about the ways the health of older adults in Canada may be associated with the areas in which they live; in particular no studies examining area-level effects on the blood pressure of older adults were identified in this review (34).

2.0 Study Objectives and Rationale

This study was focused on Ontario adults, aged 65 and over, the most rapidly increasing demographic group in the province (35). The overall aims of this study were to estimate the extent and the source(s) of geographic disparity in blood pressure values across 20 Ontario communities, to differentiate the contribution of compositional effects and contextual effects and to quantify the associations between individual-level and community-level characteristics and blood pressure.

Several strategies were used to control for factors that may have introduced systemic biases in this study. In order to control for political, economic and health care system differences across the Canadian provinces and territories, this study was limited to communities within the province of Ontario. In order to limit bias associated with financial need as a barrier to the use of blood pressure medication, this study was limited to adults 65 and over, the age of eligibility for the Ontario Drug Benefit program. In order to adjust for the modifying effect of blood pressure medication on blood pressure values, older adults reporting the use of blood pressure medication were analyzed separately from those who did not report the use of blood pressure medication.

Systolic blood pressure (SBP) was selected as the outcome measure in this study since it is identified as a more important cardiovascular disease risk factor than diastolic blood pressure (DBP) for adults over 50 years of age according to the findings of the *Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure* (3).

The specific objectives of this study were:

- A. To describe and quantify the extent of variability across 20 Ontario communities in (i) the distribution of individual systolic blood pressure measurements, (ii) the distribution of individual-level characteristics that may be associated with hypertension, and (iii) the distribution of community-level characteristics that may be associated with hypertension among older adults reporting using and not using blood pressure medication;
- B. To examine the extent to which geographic disparities in blood pressure are explained by community composition versus community context among older adults reporting using and not using blood pressure medication;
- C. To identify individual-level and community-level characteristics independently associated with differences in systolic blood pressure measurements among older adults using and not using blood pressure medication.

3.0 Literature Review

3.1 Literature review research question

What evidence is presented in the published scientific literature about the association between geographic area-level characteristics and blood pressure or hypertension among adults in developed countries?

3.2 Literature review methods

3.2.1 Inclusion and exclusion criteria

Studies were included in the review if they employed multilevel statistical analysis investigating area-level effects on either blood pressure level or risk of hypertension in an adult population.

Studies whose primary aim was to investigate racial differences associated with geography or for which the population was limited to a racial subset of the population were excluded as the investigation of racial differences was not a primary aim of the current study. Studies set in developing countries were excluded as the access to health care for the diagnosis and treatment of high blood pressure was not comparable. In addition, studies published in a language other than French or English were excluded as translation services were not available.

3.2.2. Search methods

Electronic database search strategies were developed with the assistance of a Health Services Research Liaison librarian from the University of Ottawa. Using these search strategies, outlined in Appendix A, the MEDLINE and EMBASE databases were searched for studies

matching the inclusion criteria between 1995 and the present. In addition, a Google search was conducted using the same search strategy keywords. Search result study titles were screened to identify studies matching the eligibility criteria. If a study's title suggested a match, the study's abstract was read. If the study abstract also suggested a match, the full-text version of the study was read to determine whether the study met the inclusion or exclusion criteria for the review.

Alerts were set in both databases (MEDLINE and EMBASE) to repeat the search on a biweekly schedule. Automated e-mails were generated including the titles and abstracts of any newly indexed studies meeting the search strategy criteria. This ensured the review was updated until January 1, 2011.

In order to ensure a thorough search of the published literature, studies identified from the electronic database searches meeting the inclusion criteria were used to identify other potentially relevant studies. For each included study, the study's references were searched, the 'related articles' feature in PubMed was used, and Scopus, a search engine that identifies studies that have cited the study of interest, was used to identify any additional studies meeting the inclusion criteria for the literature review.

3.2.3. Critical appraisal of studies

In order to devise a strategy for appraising the quality of the studies included in this review, the published scientific literature was searched to identify quality assessment tools and reviews of methodological issues pertaining specifically to multilevel analysis. The information from this investigation was used to develop a critical appraisal checklist to assess the quality of the studies included in the review.

The search for reviews of multilevel modelling netted two studies. Schreiber and Griffin (2004) provided an introduction to methodological issues in multilevel model and presented a framework to critically appraise eight multilevel studies published in the *Journal of Educational Research* between 1992 and 2002 (36). Schreiber and Griffin (2004) recommended multilevel studies explicitly report the research questions, estimation method, one-way random effects analysis of variance results in addition to reporting the partitioned variance of all estimated models. According to Schreiber and Griffin (2004), all estimated models should report regression coefficients and standard errors, variance/covariance components, inferential test results and detailed interpretation of coefficients and variance components and model fit statistics. In the application of their framework to eight published multilevel studies, Schreiber and Griffin (2004) determined that while research questions and coefficients and inferential tests were consistently reported, there was inconsistent reporting of model equations, variance and covariance components, estimation methods, fit statistics and the use of centering (36).

More recently, Dedrick et al. (2009) sought to replicate and extend the work published by Schreiber and Griffin (2004) by means of an updated review of the methodological literature on multilevel modeling which was used to inform the development of a checklist (37). The authors applied the checklist to 99 articles from 13 peer-reviewed journals in social sciences and education. The authors found that many of these 99 studies failed to report adequate information for a reader to critique the analyses. In conclusion, the authors suggested seven guidelines for quality reporting of studies employing multilevel modeling (37). These guidelines include reporting clear description of all models specified including choice of predictors and covariance structure, use of centering including type of centering used and variables that were centered, evaluation of distributional assumptions and outliers including methods and results,

consideration of missing data, analysis methods including software and version used, method of estimation, convergence and admissibility of variance and covariance estimates, complete list of parameter estimates for all interpreted models and standard errors or confidence intervals for parameters of interest.

The two reviews of multilevel studies (36, 37) were used to guide the development of a critical appraisal checklist for this literature review. This checklist was used to assess whether or not the studies included in this review had considered and reported on each of the checklist items. The reliability of the checklist was not evaluated as no secondary reviewer was available to perform this check. The eight items on the checklist and a brief explanation of each item are listed below:

1. Are the research questions explicitly reported?

The research questions, driven by theory or logic, should drive the analysis, the number of models and the order of inclusion of the variables.

2. Was the dependent variable assessed using measured blood pressure?

Self-report is known to underestimate the prevalence of hypertension due to the significant proportion of the population who are unaware of their hypertension status. The use of administrative data to determine hypertensive status will also underestimate the prevalence of hypertension in persons with undiagnosed hypertension.

3. Is the model building process clearly described?

A statement of the covariates included at each level of the model and a description of the model building process helps the reader to interpret the presented models (37). The description

of the model building process should include the number of models estimated, the order of covariate entry and the criteria for model reduction.

4. Are one-way random effects reported?

The estimation of a baseline model, also often referred to as an empty or unconditional model, is a model which does not include any level 1 (participant-level) or level 2 (area-level) characteristics. The baseline model is used to partition the variance at each level of the multilevel model, that is, the level 1 or within-area variance and the level 2 or between-area variance. The partitioned variance can be used to calculate the intraclass correlation coefficient to quantify the proportion of the total variance accounted for by the between-area variance.

5. Was an evaluation of distributional assumptions reported?

All inferential statistics have inherent assumptions which support the validity of the results. In order to consider whether or not these assumptions are met or violated, the assumptions must be checked. For multilevel models, assumptions are made about the errors at both level 1, that is the individual-level, and level 2, the area-level. Errors at both of these levels are assumed to be independent and normally distributed with a mean of zero. These assumptions must be verified by the examination of residual plots at each level.

6. Were the amount and pattern of missing data reported?

Missing data on one or more level 1 and/or level 2 covariates is possible. It is important to report not only the frequency of missing data but also the pattern of missing data; that is, whether or not the missing data appear at random in the data, and are thus not associated with either the outcome or independent covariates. Since participants who are missing data on any covariate included in a model are deleted from the analysis, it is important to investigate whether any systematic patterns exist with the missing data. If these patterns are identified, a

consideration of ways to minimize the bias introduced by the deletion of these participants must be considered.

7. Was the software used reported?

The statistical software and version used should always be reported in the study as the description of the methods should allow for reproducibility of the analysis.

8. Were regression coefficients reported with standard errors or confidence intervals?

It is important to provide the reader with the regression coefficient point estimate, standard error or confidence interval as well as the inferential test to allow for interpretation of the effect.

3.3 Literature review results

3.3.1 Description of the studies included in the review

The literature review search strategies netted a total of fourteen studies meeting the inclusion criteria. The description of the studies is presented in Table 1, including the study location, the age range of the sample, the sample size, how the clusters were defined, the number of clusters, the outcome variable (systolic blood pressure and/or diastolic blood pressure or hypertension), and the method used to determine blood pressure level or hypertension status.

The fourteen studies included participants from developed countries in North America, South America, Europe, Asia, and Australia. One of the fourteen studies was an international comparison of blood pressure distributions in 39 study populations from 21 countries (7). Four studies took place in the United States; one was a comparison of 44 states (38), and the three others used data collected in Oregon, Maryland, Illinois, North Carolina, New York, Minnesota and Mississippi states (39-41). Three studies took place in Canada; one was a national

Table 1. Description of Fourteen Multilevel Studies Investigating the Association Between Area-level Characteristics and Blood Pressure

Study	Study Location	Age (years)	Sample size	Cluster definition	Number of Clusters	Outcome measure	Method used to Assess BP
Diez-Roux (1997)(39)	United States	45-64	12,601	Census Block Groups	567	SBP ¹	Measured
Hart (1997)(42)	Scotland	40-59	10,178	Government Districts	22	DBP ²	Measured
Diez-Roux (2000)(38)	United States	18+	70,534	State	44	HTN ³	Self-report
Merlo (2001)(43)	Sweden	45-73	15,569	'Urban divisions'	17	DBP	Measured
Merlo (2004) (7)	International	35-64	48,752	Study sites	39	SBP	Measured
Veugelers (2004) (44)	Canada	18+	3,094	Census Subdivisions	64	HTN	Measured
Breckenkamp (2007) (45)	Germany	25-69	11,548	Regions	7	SBP/DBP	Measured
Dragano (2007) (22)	Czech Republic/ Germany	45-69	11,554	Neighbourhoods	326	HTN	Measured
Chaix (2008) (46)	France	50-59	7,838	Neighbourhoods	1387	SBP	Measured
Mujahid (2008) (40)	United States	45-85	2,612	Census Tracts	576	HTN	Measured
Li (2009) (41)	United States	50-75	1,145	Census Block Groups	120	SBP/DBP	Measured
Chaix (2010) (47)	France	30-79	5,941	Neighbourhoods	1824	SBP	Measured
Matheson (2010) (48)	Canada	18+	103,419	Census Tracts	3663	HTN	Self-report
Menec (2010) (49)	Canada	65+	77,930	Enumeration area	25	HTN	Administrative Data

1. SBP=Systolic blood pressure, 2. DBP= Diastolic Blood Pressure, 3. HTN= Hypertension,

sample (48), one was a provincial sample from Nova Scotia (44), and one was a population-based study from the city of Winnipeg, Manitoba (49).

Six of the fourteen studies modeled hypertension as a dichotomous outcome and the definition of hypertension varied between the studies. The two studies using self-report to classify participants as hypertensive were based on whether the participant had ever been told by a doctor, nurse or other health professional that they had high blood pressure (38, 48). One study used administrative data to classify participants' hypertensive status based on the presence of an ICD-9-CM diagnostic code of hypertension used in one or more hospitalizations or two or more physician visits for more than three years (49). Three studies used measured blood pressure to classify participants as hypertensive and the cut-off value to define hypertension differed between the three studies. Dragano (2007) classified participants as hypertensive if they had $SBP \geq 160$ mmHg or $DBP \geq 90$ mmHg or were taking blood pressure medication (22). Muhajid (2008) classified participants as hypertensive if they had $SBP \geq 140$ mmHg or $DBP \geq 90$ mmHg or were taking blood pressure medication (40). Veugelers (2004) classified participants as hypertensive if they had $DBP \geq 90$ mmHg (44).

3.3.2 Critical appraisal of studies

The application of the critical appraisal checklist confirmed there were important gaps in the reporting and consideration of the checklist items among the fourteen studies included in the review. As summarized in Table 2, some items on the checklist were consistently discussed and reported such as a description of the research questions driving the study and the model building process. Thirteen of the fourteen studies reported regression coefficients with either 95% confidence limits or standard errors. There were, however, some items on the checklist that were

Table 2. Critical Appraisal of Fourteen Multilevel Studies Investigating the Association Between Area-level Characteristics and Blood Pressure

Checklist Item	Study														# of studies meeting checklist item criteria
	Diez-Roux (1997) (39)	Hart (1997) (42)	Diez-Roux (2000) (38)	Merlo (2001) (43)	Merlo (2004) (7)	Veuglers (2004) (44)	Breckenkamp (2007) (45)	Dragano (2007) (22)	Chaix (2008) (46)	Mujahid (2008) (40)	Li (2009) (41)	Chaix (2010) (47)	Matheson (2010) (48)	Menec (2010) (49)	
1. Are research questions explicitly reported?	X ²	X	X	X	X	X	X	X	X	X	X	X	X	X	14
2. Unbiased measurement of outcome?	X	X		X	X			X	X	X	X	X			9
3. Description of model building process?	X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
4. One-way random effects reported?		X		X	X								X	X	5
5. Evaluation of model distributional assumptions?			X												1
6. Reporting and consideration of missing data?							X								1
7. Reporting of software used?	X	X	X	X	X	X	X	X			X			X	10
8. Reporting of regression coefficients with standard errors or 95% confidence intervals?	X	X	X	X	X	X	X	X	X	X	X	X	X		13
Study checklist score¹	5	6	5	6	6	4	5	5	4	4	5	4	4	4	

1. Sum of items meeting checklist criteria for each study

2. X=Meets checklist item criteria

seldom discussed and reported such as whether the study models met the distributional assumptions inherent in multilevel modelling and a consideration of the impact of missing data. These results were congruent with the Dedrick et al. (2009) and Schreiber and Griffin (2004) reviews, demonstrating that many studies fail to consider and/or report important methodological details (36, 37).

Five of the fourteen studies estimated one-way random effects (an empty or unconditional model) to partition the between-area and within-area variance.

A variety of statistical software packages were used in the multilevel analyses. SAS (50) was used in four studies, MLwiN (51) in two studies and Mplus (52), Mln (53), R (54), and HLM (55) were used in one study respectively.

3.3.3 Individual-level and area-level characteristics included in the studies

The 33 unique individual-level characteristics included in the multilevel models in the fourteen studies are summarized in Table 3. Age and sex (with the exception of the two studies that included only one sex) were covariates in all fourteen studies. The next most frequently used individual-level covariates were education level (11/14), household income (7/14), body mass index (7/14), smoking status (5/14) and antihypertensive medication use (5/14).

The 22 unique area-level characteristics included in the fourteen studies investigating area-level associations with blood pressure are summarized in Table 4.

Table 3. Individual-level Characteristics Included in Fourteen Multilevel Studies Investigating the Association Between Area-level Characteristics and Blood Pressure

Individual-level Characteristic	Study														Studies Including characteristic	Current Study
	Diez-Roux (11997) (39)	Hart (1997) (42)	Diez-Roux (2000) (38)	Merlo (2001) (43)	Merlo (2004) (7)	Veuglers (2004) (44)	Breckenkamp (2007) (45)	Dragano (2007) (22)	Chaix (2008) (46)	Mujahid (2008) (40)	Li (2009) (41)	Chaix (2010) (47)	Matheson (2010) (48)	Menec (2010) (49)		
Age	X	X	X	X	X	X	X	X	X	X	X	X	X	X	14	†
Gender	X	X	X	n/a	X	X	X	X	n/a	X	X	X	X	X	12	†
Education level	X	X		X	X	X		X	X	X	X	X	X		11	
Body mass index		X			X	X	X		X			X	X		7	†
Household income	X		X			X				X	X	X	X		7	
Smoking status					X	X					X	X	X		5	†
Antihypertensive meds		X			X				X		X	X			5	†
Marital Status									X			X	X	X	4	†
Occupation level	X	X							X			X			4	
Physical activity			X								X	X	X		4	†
Alcohol use											X	X	X		3	†
Employment status								X	X			X			3	
Housing tenure		X							X			X			3	
Waist circumference									X			X			2	
Race/ethnicity										A	X				2	
SES index							X								1	
CVD or diabetes						X									1	†
Self-rated health						X									1	
Dependent children													X		1	
Citizenship									X						1	
Parent's Education												X			1	
Material wealth									X						1	
Individual income			X												1	
Financial strain												X			1	
Fruit/vegetable intake											X				1	†
Perceived stress													X		1	†
Fast Food intake											X				1	†
Resting heart rate												X			1	
Physician visit this year													X		1	
Family history of HTN												X			1	
Diagnosed with HTN			X												1	
Social isolation								X							1	

X=included as an individual-level covariate in the literature review study

†= included as in individual-level characteristic in the current study

Table 4. Area-level Characteristics Included in Fourteen Multilevel Studies Investigating the Association Between Area-level Characteristics and Blood Pressure

Area-level Characteristic	Study														Current Study
	Diez-Roux (1997) (39)	Hart (1997) (42)	Diez-Roux (2000) (38)	Merlo (2001) (43)	Merlo (2004) (7)	Veugelaers (2004) (44)	Breckenkamp (2007) (45)	Dragano (2007) (22)	Chaix (2008) (46)(21)	Mujahid (2008) (40)	Li (2009) (41)	Chaix (2010) (47)	Matheson (2010) (48)	Menec (2010) (49)	
Poverty rate							X								†
Education level	X			X					X			X			†
Population Density									X		X				†
Median household income	X					X					X	X		X	†
Mean Value of dwellings sold	X											X			
Occupation categories	X														
Unemployment rate								X							†
Overcrowding (living space in m ² /inhabitants)								X							
Income inequality			X												
Walkability										X	X				
Access to Healthy Foods										X					
Density of Fast Food Restaurants											X				
Safety										X					
Social Cohesion										X					
Deprivation Index													X		
Race distribution											X				
BP measurement instrument					X										
Population variation in BP					X										
Life expectancy						X									
Number of physician visits per resident						X									†
Population over 65 years														X	†
Residential stability														X	†

X=included as an area-level characteristic in the literature review study

†=an area-level characteristic with similarities included in the current study

3.3.4 Literature review study findings

Table 5 summarizes the measures of between-area variation reported by seven of the fourteen studies. Five of the seven studies quantified the proportion of variation attributed to the area-level using the intraclass correlation coefficient (ICC) and two of the studies use the median odds ratio (MOR). The median odds ratio translates area-level variance into an odds ratio scale meaning that if there is no area-level variation, the MOR=1 and if there is area-level variation, the MOR>1 (56).

Table 5. Summary of Area-level Variation Reported in Seven of Fourteen Studies Investigating the Association between Area-level Characteristics and Blood Pressure

Study	Intraclass correlation coefficient (%)	Median Odds Ratio
Hart (1997) (42)		
Male	2.5	
Female	2.6	
Merlo (2001) (43)		
Female	0.3	
Merlo (2004) (7)		
Male	6.0	
Female	8.0	
Breckenkamp (2007) (45)		
Male SBP	2.6	
Male DBP	4.6	
Female SBP	3.8	
Female DBP	3.7	
Mujahid (2008) (40)		1.47
Matheson (2010) (48)	2.1	
Menec (2010) (49)		1.05

Table 6 summarizes the results of the fourteen literature review studies including the magnitude, direction and statistical significance of the area-level effects on blood pressure or hypertension.

Table 6. Summary of Results of Fourteen Studies Investigating the Association Between Area-level Characteristics and Blood Pressure

Study	Outcome	Area-level Characteristic	Magnitude of effect	Direction of effect (+ or -)	Statistical significance Y=p<0.05 N=p≥0.05	Comment
Diez-Roux (1997)(39)	SBP ¹					Mean difference (mmHg) for 90 th vs. 10 th percentile
		Occupation (Male)	$\beta^2 = 1.8$	-	Y	
		Occupation (Female)	$\beta = 3.2$	-	Y	
		Education (Male)	$\beta = 1.4$	-	N	
		Education (Female)	$\beta = 1.6$	-	N	
		Income (Male)	$\beta = 0.3$	-	N	
		Income (Female)	$\beta = 1.0$	-	N	
		House value (Male)	$\beta = 0.8$	-	N	
		House value (Female)	$\beta = 0.9$	-	N	
Hart (1997) (42)	DBP ³					No area-level characteristics
Diez-Roux (2000) (38)	HTN ⁴					
		Income inequality (Male-low income)	OR ⁵ =1.22	+	N	
		(Male-high income)	OR=0.78	-	N	
		(Female- low income)	OR=1.61	+	Y	
		(Female-high income)	OR=0.79	-	N	
Merlo (2001) (43)	DBP					
		Education (Female)	$\beta = 2.97$	-	Y	
Merlo (2004) (7)	SBP					
		SBP standard deviation	$\beta = 1.08$	+	Y	

Exploring individual and community-level effects on blood pressure in adults 65 and over in Ontario

Veugelers (2004) (44)	HTN					
		Physician visit rates	OR=1.04	+	N	Odds of diagnosed HTN for above vs. below average physician visit rates
Breckenkamp (2007) (45)	SBP/DBP			-	N	
		Poverty-SBP (Male)	$\beta=0.33$			
		Poverty-SBP (Female)			N	No coefficient estimated
		Poverty-DBP (Male)	$\beta=0.43$	-	Y	
		Poverty-DBP (Female)	$\beta=0.29$	-	N	
Dragano (2007) (22)	HTN					Odds of HTN for Q ⁶ 4 vs Q1
		Unemployment (Czech)	OR=0.89	-	N	Czech=Czechoslovakia
		Unemployment (Germ)	OR=1.14	+	N	Germ=Germany
		Overcrowding (Czech)	OR=1.04	+	N	
		Overcrowding (Germ)	OR=1.06	+	N	
Chaix (2008) (46)	SBP					Mean difference (mmHg) Q1 vs Q4
		Population Density (Male)	$\beta=2.50$	-	Y	Male only sample
		Education (Male)	$\beta=3.30$	-	Y	
Mujahid (2008) (40)	HTN					Odds of HTN of 90 th vs. 10 th percentile
		Walkability	OR=0.81*	-	Y	
		Safety	OR=0.80*	-	Y	*These significant effects
		Access to healthy food	OR=0.77*	-	Y	were attenuated when
		Social cohesion	OR=0.80*	-	Y	models were adjusted for race/ethnicity.
Li (2009) (41)	SBP/DBP					
		Fast food density (high walkability)-SBP	$\beta =0.17$	-	N	Mean difference (mmHg) high vs. low density

Exploring individual and community-level effects on blood pressure in adults 65 and over in Ontario

		Fast food density (low walkability)-SBP	$\beta=8.65$	+	Y	of fast food restaurants
		Fast food density (high walkability)-DBP	$\beta=0.17$	-	N	
		Fast food density (low walkability)-DBP	$\beta=4.07$	+	Y	
Chaix (2010) (47)	SBP					Mean difference (mmHg) Q1 vs. Q4
		Education	$\beta=0.86$	-	N	
		Income			N	No coefficient estimated
		Mean value dwellings sold			N	No coefficient estimated
Matheson (2010) (48)	HTN					
		Deprivation index (Male)	OR=1.00		N	
		Deprivation index (Female)	OR=1.07	+	Y	
Menec (2010) (49)	HTN					
		Income	OR=1.19	-	Y	Odds of HTN Q1 vs.Q5
		Proportion aged 65 +	$\beta=0.003$	+	N	
		Residential Stability	$\beta=0.003$	-	N	

1. SBP=Systolic Blood Pressure 2. β =Beta coefficient 3. DBP= Systolic Blood Pressure 4.HTN=hypertension 5.OR= Odds Ratio
5. Q=Quartile

Nine of the fourteen studies investigated the associations between area-level socioeconomic characteristics and blood pressure. When individual-level characteristics were taken into account in the multilevel models, three studies reported significant effects of area-level socioeconomic characteristics (21, 43, 49), two studies reported non-significant effects (22, 47), and four had a combination of significant and non-significant effects (38, 39, 45, 48).

The studies finding a mixture of significant and non-significant effects included those that found some but not all area-level characteristics were associated with blood pressure or hypertension or that the associations were not consistent across the study population. One study found area-level occupation was significantly associated with blood pressure area-level education, while income and house values were not (39). A study of the association between income inequality and blood pressure found a significant association with low-income females only (38). A study of the association between poverty rate and blood pressure found significant associations solely among males and with diastolic blood pressure only (45). A study of neighbourhood deprivation and hypertension found a significant association for females only (48).

Two of the studies investigating area-level socioeconomic characteristics also investigated area-level demographic characteristics (46, 49). Systolic blood pressure was significantly associated with population density (46) but the risk of hypertension was not significantly associated with the proportion of the population over 65 years or residential stability (49).

Two studies investigated associations between social capital and characteristics of the built environment and blood pressure (40, 41). In one study, the risk of hypertension increased significantly with low walkability, lower safety, lower access to healthy food and lower social

cohesion (40) although these significant effects were attenuated by race/ethnicity. In the other study, systolic and diastolic blood pressure increased in areas with a high density of fast food restaurants when the walkability was low, however when walkability was high, no significant associations were detected (41).

A single study investigated the association between the area-level mean number of physician visits per patient and the probability of diagnosed hypertension. No significant association was detected in this study (44).

3.4 Literature review conclusion

The impact of area-level effects on blood pressure has been the topic of several studies over the past twenty years. The heterogeneity across these studies in study populations, definitions of geographic areas for comparison, area-level characteristics studied, and the operational definition of blood pressure make it very challenging to summarize the findings.

The seven studies using an empty model to partition the between-area and within-area variance all agreed that the majority of the total variance occurred at the individual-level. The study comparing 39 international communities reported the highest degree of clustering of blood pressure values with 6-8% of the variance occurring between the study communities (7). This might not be surprising as we might expect important differences between internationally compared communities such as access to health care and anti-hypertensive medication, diet and socioeconomic status.

Ten studies found at least some evidence of significant associations between area-level characteristics and blood pressure including income inequality, socioeconomic characteristics such as occupation and education, built environment characteristics such as walkability and density of fast food restaurants and demographic characteristics such as population density. The

inconsistency of findings both across and within studies makes it difficult to draw definitive conclusions about the association between area-level characteristics and blood pressure.

To date, the Menec et al. (2010) study is the only multilevel examination of area-level effects on blood pressure on a population aged 65 and over published in English or French identified by this extensive literature search (49). The study's use of administrative data is advantageous since it is population-based, that is including all residents of the city of Winnipeg, Manitoba, but the use of administrative data for research also has important limitations. The classification of participants as hypertensive depends on the accurate coding of hospital discharge abstracts and physician billing forms which cannot always be relied upon for accuracy. In addition, only residents of the city who had interactions with the health care system, that is those who had been hospitalized or who had two or more physician visits over a three year period could be classified as hypertensive. This results in a systematic misclassification bias whereby residents who have not interacted with the public healthcare system are classified as not hypertensive, a determination which may or may not be accurate.

This literature review reinforces the unique opportunity to examine the area-level and individual-level characteristics associated with blood pressure in a population of older Canadian adults provided by the data collected on 15,889 older adults by the Cardiovascular Health Awareness Program (CHAP). The CHAP Risk Profile questionnaire collected data on twelve of the same individual-level characteristics used in the reviewed studies, supporting the validity of this questionnaire for the purposes of this study. The outcome measure for this study meets a high standard of validity and reliability due to the fact that the BpTRU is a validated instrument (57) and the process for measurement was standardized across the twenty communities (see *CHAP Implementation Guide* (58)).

4.0 Methods

4.1. Data

4.1.1 Geographic coding of participants to communities

The Postal Code Conversion File Plus (PCCF+) (54) was used to assign geography, in particular the census subdivision, to the 15,889 CHAP participants based on the participant's postal code as collected on the Risk Profile Recording Form. Census subdivision is the general term for municipalities (as determined by provincial/territorial legislation) or areas treated as municipal equivalents for statistical purposes (59). For the purpose of this study, community was defined geographically by the municipal boundaries of the study community.

Of the 20 study communities, 16 communities were assigned a census subdivision which was unique to the community's municipal boundaries. The census subdivision codes assigned to these 16 communities were obtained by referencing Statistics Canada's Standard Geographical Classification (2006)(60). The 16 census subdivision codes were used to match participants who had been geographically coded by PCCF+ to one of these 16 study communities.

Four of the study communities, however, were nested within a census subdivision that included populations outside of the study community's municipal boundaries. Therefore, in order to ensure that only participants who resided within the community of interest were included in the study, a full listing of the postal codes assigned to each of these four communities was obtained from the Postal Code Conversion File. Participants residing in each of these four communities were included in the study based on a match of the participant's postal code to one of the postal codes assigned to one of these four communities.

4.1.2 Individual-level characteristics

The individual-level data analyzed in this study were collected in the CHAP community cluster randomised trial hereafter referred to as C-CHAP.

4.1.2.1 The C-CHAP trial

CHAP is a community-based approach to cardiovascular disease risk awareness and management that is targeted at older adults. In the fall of 2006, CHAP implemented the C-CHAP trial, a community cluster-randomised trial involving 39 Ontario communities; 20 communities were randomised to the CHAP intervention and 19 communities were randomized to control. The aim of the C-CHAP trial was to evaluate the effectiveness of the CHAP program in reducing community morbidity from cardiovascular disease. During a 10-week period in the fall of 2006, 15,889 unique participants in the 20 intervention communities attended a CHAP community pharmacy session where their blood pressure measurements and cardiovascular risk profiles were recorded.

Community eligibility criteria for the C-CHAP trial were as follows:

- A. Ontario communities with a population of 10,000 to 60,000 based on the 2001 Census;
- B. A minimum of five family physicians practicing in the community;
- C. A minimum of two pharmacies in the community;
- D. No recent amalgamation into a major metropolitan centre.

Community exclusion criteria eliminated townships, first nation reserves, and dissolved and amalgamated townships and counties. A total of 41 communities in Ontario met these eligibility criteria; of these two communities were eliminated as they had been pilot-test sites for the CHAP intervention. Of the remaining 39 eligible communities, 20 communities were randomly assigned to the intervention and 19 communities to control arms of the trial. Appendix B has a map of Ontario with markers indicating the location of each of the 20 intervention communities.

Implementation of the CHAP intervention across the 20 communities was standardized by the use of the *CHAP Implementation Guide* (58) which is available online. A brief description of the implementation of CHAP in the intervention communities will be given here.

Implementation of CHAP was initiated by the solicitation of a local lead organisation with an interest in health promotion and experience working with volunteers in each community. The local lead organisation recruited a local CHAP coordinator tasked with gaining the support and participation of local family physicians and pharmacies for CHAP in the community. Participating family physicians sent personalised invitations to patients aged 65 years and over encouraging attendance at CHAP sessions in the community. Participating pharmacies hosted CHAP sessions in the pharmacy, offered pharmacist support during CHAP sessions and encouraged older adult pharmacy clients to participate in CHAP sessions.

In addition to the recruitment of participating physicians, pharmacies and pharmacists, the local CHAP coordinator recruited volunteer peer health educators to assist with the delivery of CHAP sessions in the community pharmacies. The volunteers were trained by a public health nurse using a standardised curriculum to assist CHAP participants in the measurement of blood

pressure using the BpTRU and the collection and recording of cardiovascular risk information using the Risk Profile Recording Form (Appendix C).

The recruitment of participants was achieved by the invitations to CHAP sessions by family physicians, pharmacies and pharmacists, local lead organisations as well as the promotion of CHAP sessions using flyers, posters and advertisements in local media. Participation in CHAP sessions was open to all residents in the 20 intervention communities; however community-dwelling adults (not in hospital or residing in long-term care) aged 65 and over were specifically targeted.

A total of 1265 three-hour long CHAP sessions were held in 129 pharmacies with the assistance of 577 volunteer peer health educators over the 10-week program in the fall of 2006 (61) (full trial details in Appendix D). As the primary aim of the C-CHAP trial was to measure the effectiveness in reducing cardiovascular mortality in the community, population based administrative health data were used to evaluate the C-CHAP trial.

The recording of individual-level CHAP participant cardiovascular risk profile information and blood pressure measurements was a key element of the CHAP since, with participant consent, this information was shared with the participant's family physician and pharmacist. The goal of sharing this information was to 'close the loop' between health care providers. While the participant-level data was not used in the evaluation of the effectiveness of CHAP in the trial, this individual-level data provides a rich source of information on the cardiovascular risk profiles and blood pressure levels of older adults in Ontario. The individual-level data collected on 15,889 participants at the first CHAP session visit were used in this study.

The three principal investigators for the CHAP program, Dr. Janusz Kaczorowski (University of British Columbia), Dr. Lisa Dolowich (McMaster University) and Dr. Larry Chambers (Elisabeth Bruyère Research Institute) endorsed the use of the C-CHAP data for this thesis. Dr. Lisa Sweet, chair of the Research Ethics Board of Bruyère Continuing Care, confirmed the ethics approval granted for the C-CHAP trial permitted the secondary analysis of data proposed for this thesis.

4.1.2.2 C-CHAP measures

Blood pressure was measured in mmHg by participants using the BpTRU (BpTRU Medical Devices, Canada) at the CHAP pharmacy session. Trained volunteer peer health educators assisted participants in fitting the blood pressure cuff. The BpTRU is an automated blood pressure measuring device designed to eliminate the drawbacks associated with auscultation, including inter-reader variability and situational 'white coat' hypertension. The BpTRU has been shown to provide a superior level of accuracy, convenience and value to blood pressure readings in clinical practice (57) and as such was also the instrument used in the 2006 Ontario Survey on the Prevalence and Control of Hypertension (62) and the Canadian Health Measures Survey (63).

The protocol for using the BpTRU followed a two-step process. First, participants received an explanation of how the BpTRU operated and were assisted in putting on the BpTRU arm cuff. Second, once the first blood pressure reading was taken by the BpTRU, the person assisting the participant left the patient alone while the assessment was completed. In total, six blood pressure measurements were taken at one-minute intervals; the BpTRU discards the first reading and the remaining five readings are averaged to yield the measurement recorded on each participant's Risk Profile Recording Form.

Self-reported data collected on each participant at the CHAP pharmacy sessions included demographic information, history of cardiovascular disease and risk factors for cardiovascular disease.

The following individual-level characteristics were self-reported on the Risk Profile Recording form: name, postal code, age, sex, living alone status (yes/no), height and weight, eating five or more servings of fruits and vegetables daily (yes/no) and frequency of eating high fat or fast foods weekly (0, 1-2, or 3 or more times per week); salt intake, which was assessed by how often participants reported adding salt to foods during cooking or at the table (rarely/sometimes/ often); stress level, which was assessed by the frequency of feeling overwhelmed or stressed in a typical week(rarely/sometimes/often); physical activity, which was assessed by whether participants reported being physically active for 30-60 minutes most days of the week (yes/no); current smoking status (yes/no); and consuming 2 or more alcoholic drinks daily (yes/no). Participants self-reported whether they had ever had a transient ischemic attack, stroke, heart attack, been diagnosed by a physician with high cholesterol, diabetes or high blood pressure or were currently using blood pressure medication. The response choice for each of these items was yes/no/not sure.

4.1.3 Community-level characteristics

In addition to the individual-level characteristics collected in C-CHAP, a set of community-level characteristics were abstracted for this study. The selection of the specific community-level characteristics was informed by the literature review as well as other studies investigating area-level effects on health outcomes other than blood pressure such as mortality, cardiovascular morbidity and self-reported health among older adults.

Due to the financial and time constraints involved in completing a thesis, the selection of community-level characteristics was limited to those routinely collected at the community-level and publicly available. Nine community-level characteristics were selected in three broad categories: access to health care, demographic characteristics and socioeconomic characteristics. Figure 4 is a graphical representation of the individual-level and community-level characteristics included in the study, adapted from Li et al.(64) .

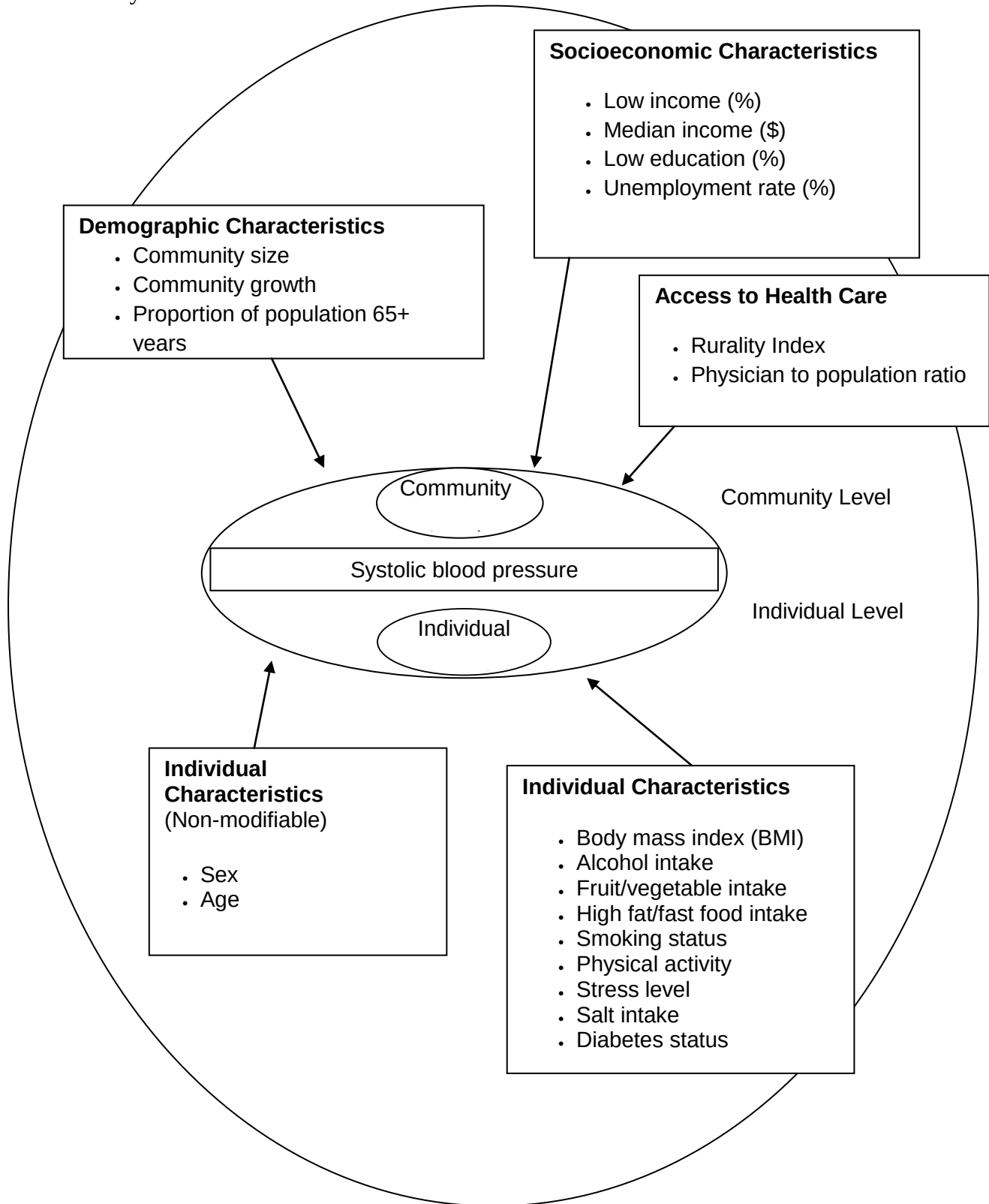
4.1.3.1 Access to medical care

Access to medical care in a community is important since the measurement of blood pressure and treatment of high blood pressure is a cornerstone of blood pressure management (65). Since blood pressure measurement frequently takes place at the family physician's office and pharmaceutical treatment of blood pressure medication requires a physician's prescription, access to medical care may be related to blood pressure level. The following community-level characteristics were used to investigate the association between access to health care and blood pressure:

A. Rurality Index.

Geographic proximity is a function of distance or travel time and is considered an important aspect of health service accessibility (66). As distance or travel time to health services increases, health service utilization may decrease. Arcury et al. (2005) found an association between distance to health care and chronic disease management and preventative measures (29). As an acknowledgement that access to health care professionals and distance to care varies significantly between Ontario communities, Kralj (2000) set out to quantify the 'rurality' of

Figure 2. Graphical Representation of the Individual-level and Community-level Characteristics Included in the Study



Ontario communities as a continuous measure (67). The Rurality Index for Ontario (RIO2008_Basic) has been supported and used by both the Ontario Medical Association and the Ministry of Health and Long-Term Care (68). The RIO2008_Basic is derived from three components: community population and density, measure of time travel to nearest basic referral centre and measure of time travel to the nearest advanced referral centre. The RIO2008_Basic scores were transformed to a 0 to 100 scale reflecting relative ranking with higher scores indicating higher rurality. The RIO2008 scores were abstracted for each of the twenty communities by using the on-line look-up tool hosted by the Ontario Medical Association on their website <https://www.oma.org/PublicApp/nlp/NLPWF003.aspx> using a postal code from each study community.

B. Family physician to population ratio

Since blood pressure measurement frequently takes place at the family physician's office, access to primary care may be related to blood pressure level. In an attempt to quantify the availability of family physicians in each community a family physician to population ratio was calculated.

The family physician to population ratio was derived by dividing the number of family physicians practicing in the community in 2006 by the 2006 Census community population. The number of family physicians practicing in each of the study communities in 2006 was documented by the CHAP program manager in 2006 with data obtained from the College of Physicians and Surgeons website. The website has an All Doctor Search (<http://www.cpso.on.ca/docsearch/>) capability allowing searches by specified community. The College is obliged under the *Regulated Health Professions Act (RHPA)* to maintain a list of the medical doctors authorized to practise medicine in Ontario. The information for the website

is obtained at registration with the College and updated annually (69). For each of the 20 study communities, the number of family physicians practicing in the community in 2006 was divided by the community's 2006 census population. The result was standardized to a ratio of family physicians per 100,000 population to allow for a meaningful comparison among the twenty communities.

4.1.3.2 Community demographic characteristics

Several studies have included community demographic characteristics in studies of the effects of place on health including community size (70), community growth (31) and the proportion of the population 65 years and over (49). These same three characteristics were among those included by Statistics Canada studies investigating regional disparities in self-rated health and disability-free life expectancy (71, 72).

The following community demographic characteristics were abstracted for each of the 20 communities in the study from the Statistics Canada Census 2006:

- A. Community population size in 2006;
- B. Population growth: 2001 to 2006 population growth (%);
- C. Proportion of community population 65 years and over: calculated by summing the number of residents in the age categories 65 years and over and dividing by the total community population.

The Statistics Canada Community Profile 2006 website (<http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E>) was used to obtain values for the community demographic characteristics for the 16 communities with community subdivision boundaries which were equivalent to the community population of interest. In the case of the

four communities which were nested within larger census subdivisions, Statistics Canada Census 2006 data at the Urban Area level including only the population of interest was obtained from the data librarian at the Geographic, Statistical and Government Information Centre of the University of Ottawa.

4.1.3.3 Community socioeconomic characteristics

Area-level socioeconomic characteristics were associated with blood pressure in several of the studies included in the literature review and were therefore included as community-level socioeconomic characteristics in this study.

- A. Below low-income cut-off before tax adjustments: percent of individuals in the community who spend 20 percentage points more of their before-tax income than the average family on food, shelter and clothing;
- B. Median income: the median income of persons 15 and over in the community;
- C. Low education: percent of the total community population aged 15 and over with no certificate, diploma or degree which was calculated by dividing the number of residents 15 and over with no certificate, diploma or degree by the total community population aged 15 and over;
- D. Unemployment rate: the unemployed expressed as a percentage of the labour force in the week (Sunday to Saturday) prior to Census Day (May 16, 2006).

The Statistics Canada Community Profile 2006 website (<http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/index.cfm?Lang=E>) was used to abstract values for the four community-level socioeconomic characteristics in the 16 communities with community subdivisions equivalent to the community population of interest. In the case of the 4

communities which were nested within larger census subdivisions, Statistics Canada data at the urban area level including only the population of interest was obtained from the data librarian at the Geographic, Statistical and Government Information Centre of the University of Ottawa.

4.2 Statistical analyses

The dataset was reduced by excluding participants under 65 years of age. In addition, those participants missing data on systolic blood pressure, use of blood pressure medication or postal code and those who did not complete the questionnaire on the Risk Profile Recording Form were excluded. In addition, participants who did not reside in one of the 20 study communities (based on postal code match to geography) were excluded from the analysis.

Body mass index was derived using self-reported height and weight. The responses to the adding salt, consuming high fat/fast foods and feeling stressed items were dichotomized into ‘often’ versus ‘sometimes or rarely’. In cases where participants responded ‘not sure’ to one of the risk profile questions, the response was recoded as ‘no’.

The sample was stratified into two groups based on the self-reported use of blood pressure medication. The association between individual-level and community-level characteristics and blood pressure was hypothesized to be modified by the use of blood pressure medication. Two options were identified to account for this possibility: 1) divide the sample into two groups, that is those reporting using and those reporting not using blood pressure medication and analyze the groups separately or 2) include interaction terms with the individual-level and community-level characteristics in the analysis. The first option, dividing the sample into groups based on blood pressure medication use, was selected in order to simplify the analysis and due to the fact the large sample sizes remained with over 4,000 participants in each of the two groups.

Power in multilevel models is limited more by the number of groups in the study (communities in this case) than the number of participants per group (73, 74).

4.2.1 Descriptive statistics

Descriptive statistics were calculated for the dependent variable systolic blood pressure, and individual- and community-level characteristics. Continuous variables were assessed for normality, using visual inspection of histograms and normal probability plots. Variables with a normal distribution were described using the mean and standard deviation, while variables with a skewed distribution were described using the median and interquartile range; categorical variables were described using frequencies and proportions.

Comparisons of individual-level characteristics were made between the two groups: participants reporting and not reporting the use of blood pressure medication. In order to compare the two groups while adjusting for the community-level clustering, each individual-level characteristic was specified as the dependent variable with blood pressure medication status as the sole predictor variable. General linear mixed models were specified for continuous variables and generalized mixed models for the dichotomized variables.

4.2.2. Quantifying the extent of variability among communities (Objective A)

4.2.2.1 Variability in individual- and community-level characteristics

To quantify the extent of variability across communities in the individual-level characteristics, aggregated community means for body mass index and proportions for all other individual-level characteristics were calculated for each of the twenty communities for the two study groups, participants reporting using and not using blood pressure medication. The coefficient of variation, a normalized measure of dispersion calculated by dividing the standard

deviation by the mean and expressed as a percentage, allows direct comparison of the variability among the individual-level characteristics by community. The coefficient of variation was also used to quantify the extent of variability across communities in the community-level characteristics.

4.2.2.2 Variability in systolic blood pressure

Community means were calculated for each of the 20 study communities. In addition, the total variability in blood pressure was decomposed into between-community and within-community components. An empty multilevel model was used to partition the individual and community components of variance in systolic blood pressure in the sample. The level 1 variance (within-community differences) and the level 2 variance (between-community differences) were used to calculate the intraclass correlation coefficient, an estimate of the proportion of the total variability in systolic blood pressure that can be attributed to differences between communities.

4.2.3 Multilevel multivariable analysis

Multilevel, multivariable models were used to quantify the associations between individual- and community-level characteristics and systolic blood pressure. The dependent variable specified in all models was systolic blood pressure level. General linear mixed models, SAS 9.2 PROC MIXED (50), were used to accommodate the hierarchical structure of the data with individuals (level 1) nested in communities (level 2). The correlation between observations within each of the 20 community clusters was taken into account by specifying the community identifier as a ‘random effect’ in the regression model. A compound symmetry covariance structure was specified to account for the clustering of the observations within communities. The

individual- and community-level risk factors were specified as ‘fixed effects’ in the model. Age and body mass index were centred about the grand mean. Restricted Maximum Likelihood estimation was selected as it typically provides less biased estimates of the variance components of the model compared to full information maximum likelihood estimation, particularly since this study was limited to 20 communities and included numerous covariates. Kenward-Rogers adjustment for degrees of freedom was used to reduce the potential for Type 1 error (75).

Three multilevel models were developed incrementally for each group (i.e., participants reporting using and not using blood pressure). The first model, called the “empty model” was fitted with no explanatory variables. The “empty model” was used to partition the between-community and within-community variance allowing for the calculation of the intraclass correlation coefficient. (Objective A).

The second model, called the “individual model”, included all of the individual-level characteristics: age, sex, living alone status, diabetes status, body mass index, smoking status, alcohol intake, fruit/vegetable intake, high fat/fast food intake, physical activity, stress and adding salt to food. Backward selection was used to reduce the “individual model” removing variables with a statistical significance level of $p > 0.10$. The intraclass correlation coefficient was recalculated to determine the extent to which the between-community variance was explained by the community’s composition (Objective B). The “individual model” was also used to quantify the association between individual-level characteristics and systolic blood pressure (Objective C).

The third model, called the “final model” included all of the variables retained in the ‘individual model’ with the addition of all of the community-level characteristics: physician to population ratio, Rurality index, community population, community growth, proportion of

population 65 years and over, proportion of population without secondary education, proportion of population below the low income cut-off, median income and unemployment rate. Backward selection was used to reduce the ‘final model’ removing variables with a statistical significance level of $p > 0.10$. The intraclass correlation coefficient was recalculated to determine the extent to which the between-community variance was explained by the retained community-level characteristics (Objective B). The ‘final model’ was also used to quantify the association between community-level characteristics and systolic blood pressure (Objective C) and assess whether the regression coefficients between individual-level characteristics and systolic blood pressure were changed by the addition of community-level characteristics in the final model.

4.2.3.1 Missing data

The impact of missing data was investigated by calculating the percentage of participants with missing values on each of the individual-level risk factors; moreover, the distribution of blood pressure measurements for participants with missing or non-missing risk factors were compared to determine whether missingness was random or non-random.

A list-wise deletion of participants with missing data on any covariates used to estimate models occurs in SAS PROC MIXED (50). As a result, it was essential to determine whether there was any systematic bias introduced by the deletion of these participants from the analysis. The pattern of missing covariates was investigated to determine whether missing values were associated with any of the individual-level characteristics under study.

To investigate the pattern of missing covariates, a binary variable was assigned to all participants to indicate whether or not the participant had complete data. A logistic regression model was fitted using the binary outcome (complete data yes/no) as the dependent variable.

Each of the individual-level characteristics and the dependent variable were included separately in the model to determine whether any of these characteristics were significantly associated with the probability of having a missing variable at $p < 0.05$. Any individual-level characteristics systematically associated with the probability of having a missing variable were forced into the final multilevel model to adjust for the impact of missing variables.

4.2.3.2 Model Diagnostics

Model diagnostics for the mixed models included plotting residuals against predicted mean response as well as residuals against covariates to check for violation of model assumptions. If there was a systematic trend evident in the residual scatterplots, transformation of the covariates was indicated. A histogram of the studentized residuals was used to determine whether residuals were normally distributed and normal quantile plots of residuals were used to identify the presence of outliers. Histograms of the random effects were used to verify whether the random effects were normally distributed.

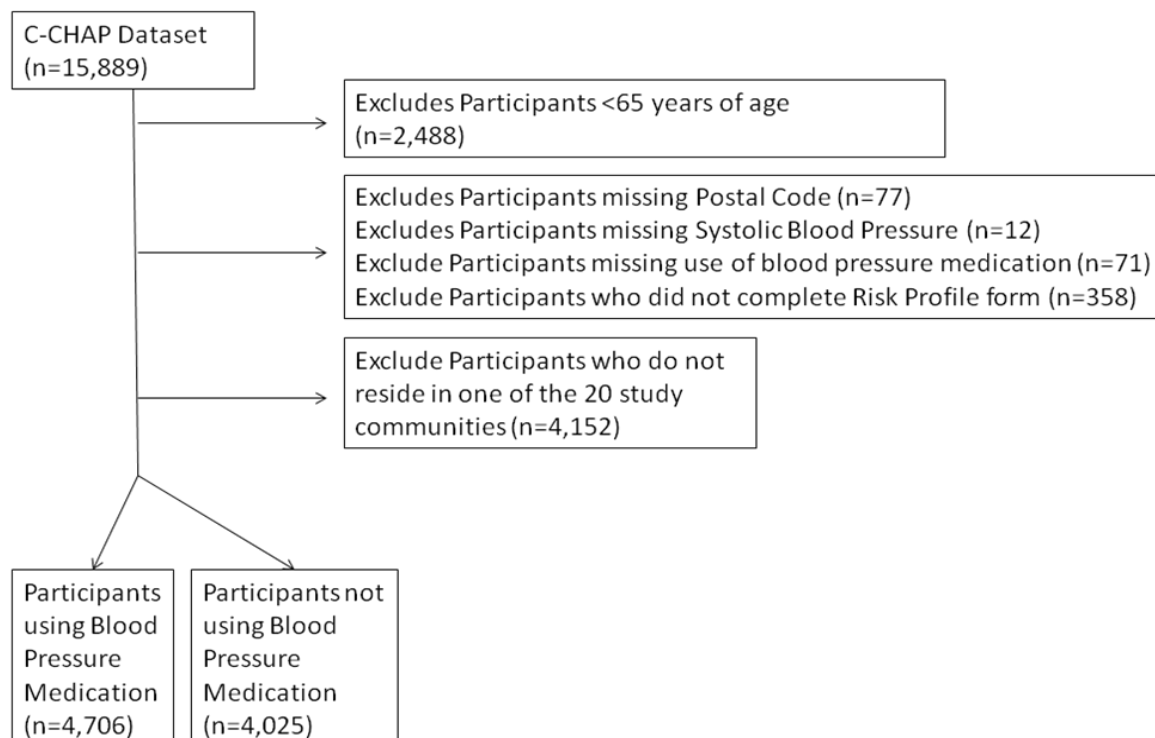
Collinearity between the individual-level characteristics was investigated by calculating the variance inflation factor. Variance inflation factor values greater than 10 may merit further investigation (76). A Spearman correlation matrix was used to investigate collinearity between the community-level variables.

5.0 Results

5.1. Individual- and community-level characteristics

The reduction of the original C-CHAP dataset to the analytical dataset for this study is summarized in Figure 3. 99.0% (15,726 of 15,889) of all participants were successfully geographically coded including the assignment of Census Subdivision (CSD) by the Postal Code Conversion File Plus (PCCF+) (77). Of the 15,889 unique C-CHAP participants, 4,152 (26.1%) participants were excluded as they did not reside in one of the twenty study communities. In addition, 2,488 (15.7%) participants were excluded as they were younger than 65 years of age, 77 (0.5%) participants were missing a postal code, 12 (0.08%) were missing systolic blood pressure values, 71 (0.4%) were missing blood pressure medication status and 358 (2.3%) participants did not complete the Risk Profile Recording Form.

Figure 3. Eligible Study Participants from the C-CHAP Study, 2006



The participant characteristics are summarized in Table 7. Participants reporting the use of blood pressure medication have significantly higher mean systolic blood pressure than participants not using blood pressure medication (135.7 mmHg versus 130.8 mmHg, $p<0.0001$).

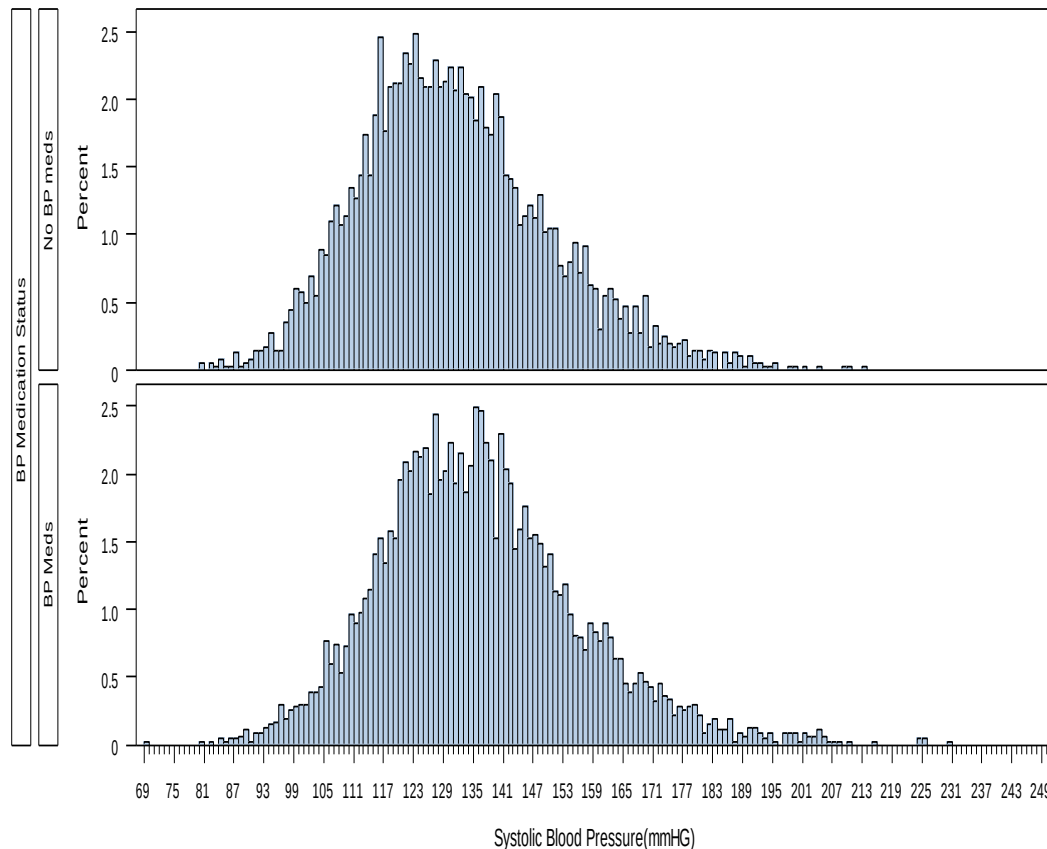
Table 7. Individual-level Characteristics of Participants Not Using BP Medication ($n=4,025$) and Participants Using BP Medication ($n=4,706$). C-CHAP Study, 2006

Individual-level Characteristic	Not Using BP Medication ($n=4,025$)	Using BP Medication ($n=4,706$)	<i>p</i>
Age in years (mean,sd)	74.5 (6.4)	75.3 (6.3)	<0.0001
Sex, % male	43.7	38.7	<0.0001
Systolic Blood Pressure, mmHg (mean, sd)	130.8 (19.0)	135.7 (19.9)	<0.0001
Diastolic Blood Pressure, mmHg (mean, sd)	74.0 (10.6)	73.4 (10.9)	0.0069
History of TIA (%)	5.8	11.1	<0.0001
History of Stroke (%)	2.3	3.9	<0.0001
History of Heart Attack (%)	8.1	14.8	<0.0001
High Cholesterol (%)	32.4	49.1	<0.0001
Diabetic (%)	8.9	21.8	<0.0001
BMI (mean, sd)	25.7 (4.0)	27.4 (4.7)	<0.0001
Current Smoker (%)	7.6	5.8	0.0003
Alcohol > 2drinks/day (%)	10.1	9.7	0.61
Eat ≥ 5 fruit or vegetables/day (%)	63.8	64.4	0.65
Often add salt (%)	18.9	14.2	<0.0001
Often stressed (%)	8.8	10.7	<0.0012
Often eat high fat or fast foods (%)	7.3	7.1	0.70
Physically active (%)	84.0	77.0	<0.0001
Live alone (%)	30.3	32.4	0.035

Figure 4 is a graphical representation of the distribution of systolic blood pressure values by blood pressure medication status. Systolic blood pressure was normally distributed in both groups, those using and not using blood pressure medication. Diastolic blood pressure was slightly lower for participants using blood pressure medication (73.4 mmHg versus 74.0 mmHg, $p=0.0076$). Participants reporting the use of blood pressure medication were older (75.3 versus 74.5 years, $p<0.0001$), more frequently female (61.3 versus 56.3, $p<0.0001$), more frequently diabetic (21.8 versus 8.9%, $p<0.0001$), more frequently overweight and obese (BMI 27.4 versus 25.7, $p<0.0001$), living alone (32.4 versus 30.3, $p=0.04$), more likely to report being stressed or

overwhelmed often each week (10.7% versus 8.8%, $p<0.0001$) and more likely to have a history of high cholesterol (49.1% versus 32.4%, $p<0.0001$) than those not using BP medication.

Figure 4. Systolic Blood Pressure Distribution by Blood Pressure Medication Status, C-CHAP 2006



Participants reporting the use of blood pressure medication were statistically significantly more likely to have experienced cardiovascular disease including transient ischemic attacks (11.1% versus 5.8%, $p<0.0001$), stroke (3.9% versus 2.3%, $p<0.0001$) and heart attack (14.8% versus 8.1%, $p<0.0001$). Participants reporting the use of blood pressure medication were significantly less likely to smoke (5.8% versus 7.6%, $p=0.0012$), less likely to add salt to food (14.2% versus 18.9%, $p<0.0001$), and less likely to be physically active (77.0% versus

84.0%, $p < 0.0001$). There are no significant differences between the groups in the frequency of alcohol, fruit and vegetable or high fat or fast food consumption with approximately 10% of participants reporting they consume two or more alcoholic drinks daily, 64% of participants reporting consuming five or more servings of fruit or vegetables daily and 7% of participants reporting consuming high fat or fast food three or more times per week.

The community-level characteristics are summarized in Table 8. According to the 2006 Statistics Canada census, the 20 communities ranged in population size from 10,703 to 47,629 and the median population size was 16,840. Population growth experienced in study communities between 2001 and 2006 ranged from negative growth (-4.2%) to substantial growth (18.6%); the median growth was 5.2%. The proportion of residents of 65 years of age ranged from 8.9% to 31.6% with a median of 17.2%. The median unemployment rate among the 20 communities was 5.9% and the median income was \$26,433. The proportion of the population over 15 years of age who had not completed secondary education ranged from 15.6% to 44.4% with a median value of 28.2%. The proportion of the population below the low income cut-off (before tax) varied from 6.4% to 21.1% with a median value of 9.9%. Rural Index scores are scaled from 0-100 with higher values indicating increasing rurality. Rural Index scores in the 20 study communities ranged from 5 to 80 with a median value of 25.5. The median physician to population ratio was 141.6 physicians per 100,000 population. The low income cut-off (before tax) varied from 6.4% to 21.1% with a median value of 9.9%.

5.3 Missing data

Of the total 8,731 participants whose data were analyzed, 664 (7.6%) were missing data on one or more of the individual-level covariates. Participants were missing data on smoking

status (32, 0.4%), diabetes (40, 0.5%), living alone (54 ,0.6%), body mass index (160, 1.8%), alcohol (60, 0.7%), use of table salt (98, 1.1%), physical activity (37, 0.4%), high fat or fast food intake (43, 0.5%), fruit/vegetable intake (101, 1.2%) and perceived stress (102, 1.2%). Missing data was distributed across participants in the 20 communities with the frequency of participants missing data ranging from 3.8% to 9.9% per community.

Table 8. Summary of Community-level Characteristics in 20 Ontario, Canada Communities

Community-level Characteristic (n=20)	Median (Q1,Q3)	Minimum	Maximum
Population size	16,840 (13,735,29,546)	10,703	47,629
Population growth 2001-2006 (%)	5.2 (1.2,7.2)	-4.2	18.6
Population $\geq$ 65 years old (%)	17.2 (15.6,21.2)	8.9	31.6
Unemployment rate (%)	5.9 (5.1,6.9)	3.9	13.2
Median income for population 15+ (\$)	26,433 (22,966,28,704)	20,111	36,529
Population without secondary education (%)	28.2 (25.0,31.2)	15.6	44.4
Population below low income cut-off (%)	9.85 (8.3,15.0)	6.4	21.1
Rurality Index	25.5 (20.0,43.5)	5	80
Physician to Population Ratio (per 100,000)	141.6 (98.7,204.3)	26.8	272.8

Female sex and living alone were found to be significantly associated with the probability of missing data in the logistic regression analysis used to investigate systematic trends associated with the patterns of missing data. Participants living alone were more likely to have missing data than those who did not live alone (8.4% versus 6.3%, $p=0.0002$). In addition, females were more likely than males (8.0% versus 7.0%, $p=0.014$) to have missing data. Thus, gender and living alone status were forced into the multivariate models irrespective of statistical significance.

5.4 Objective A: Quantifying the extent of variability among communities

5.4.1 Variability in individual- and community-level characteristics

The community-level variability in individual-level characteristics, expressed as the coefficient of variation, is summarized in Table 9. The greatest variability across communities was in smoking (36.5%), followed by adding salt to food (28.3%), high alcohol consumption (28.0%) and diagnosis with diabetes (19.9%). When compared to the other individual-level characteristics, variability in physical activity (10.5%) was moderate and variability in fruit and vegetable consumption (6.1%), high fat and fast food consumption (3.8%), and body mass index (1.2%) was quite low.

The community-level variability in community-level characteristics, expressed as the coefficient of variation, is summarized in Table 10. The greatest variability across communities was in population growth (118.4%), followed by the Ruralty Index (62.3%), community size (52.2%) and physician to population ratio (47.7%). There was less variability in the proportion of the population who were 65 years and over (28.0%)

Table 9. Between-community Variability in Individual-level Characteristics in Participants Not Using BP Medication ($n=4,025$) and Participants Using BP Medication ($n=4,706$), C-CHAP 2006.

Individual-level Characteristic	Coefficient of Variation (%)	
	Participants not using BP medication ($n=4,025$)	Participants using BP medication ($n=4,706$)
Diagnosed with Diabetes	19.9	24.1
Body mass index	1.2	1.4
Current smoker	36.5	21.9
≥ 2 Alcoholic drinks daily	28.0	21.6
≥ 5 servings fruit/veg daily	6.1	4.7
Frequently add salt	28.3	22.4
Frequently eat high fat or fast foods	3.8	4.0
Physically active	10.5	7.8

Among the community-level socioeconomic characteristics, the greatest variability was in the proportion of the population below the low income cut-off before taxes (36.7%) followed by the unemployment rate (32.1%), the proportion of people without secondary education (20.8%). Median income for the population over 15 years of age (15.3%) was the community-level socioeconomic characteristic with the least variability.

Table 10. Between-community Variability in Community-level Characteristics, (n=20 communities)

Community-level Characteristic	Coefficient of Variation (%)
Population	52.2
Population growth 2001-2006 (%)	118.4
Population $\geq$ 65 years old (%)	28.0
Unemployment rate (%)	32.1
Median income for population 15+ (\$)	15.3
Population without secondary education (%)	20.8
Population below low income cut-off (%)	36.7
Rurality Index	62.3
Physician to Population Ratio (per 100,000)	47.7

5.4.2 Variability in Systolic Blood Pressure

In order to quantify the extent of variability in mean systolic blood pressure among the communities, community means for each of the 20 communities were compared. In addition, the ‘random effects’ analysis in the multilevel linear regression quantified the proportion of total variance in systolic blood pressure associated with between-community effects and were used to calculate the intraclass correlation coefficient.

The mean systolic blood pressure of the 20 study communities varied between 128.1 and 134.7 mmHg among participants who report not using blood pressure medication, a range of 6.6

mmHg. Among participants who report using blood pressure medication, the mean systolic blood pressure varied between 131.9 and 139.0 mmHg, a range of 7.1 mmHg.

Among the 4,025 participants who did not report the use of blood pressure medication, the variance component was negative. In cases of negative variance components, SAS defaults the value to zero, thus the intraclass correlation coefficient is zero. It is possible to override this default in SAS by using the NOBOUND function; however this function was not used. The negative variance component estimate was most likely a result of chance alone due to the small size of the variance component. The decision to constrain the negative variance component to zero may have decreased the Type I error rate (and thus study power) however this consequence was acceptable to the author in order to facilitate interpretation of the intraclass correlation coefficient (78).

Among the 4,706 participants who reported the use of blood pressure medication, the intraclass correlation coefficient was 0.16% in the empty model, 0.21% in the individual model and 0.10% in the final model.

5.5 Objective B: Examining the extent to which geographic disparities in blood pressure are explained by community composition versus community context

Since the between-community variance component was negative among participants not using blood pressure medication (resulting in the ICC being estimated as 0), it was impossible to evaluate the extent to which composition of the individuals in the community contributed to geographic disparity if at all.

Among participants reporting the use of blood pressure medication, the between-community variance increased slightly (from 0.6426 to 0.7951) with the addition of the

individual-level characteristics, suggesting that composition masked the between-community variance slightly. When the community-level characteristics were included in the model, the between-community variance decreased by nearly half (from 0.7951 to 0.4019) suggesting that these contextual effects explained a greater proportion of the between-community variance than the compositional effects.

5.6 Objective C: Identifying individual- and community-level characteristics associated with systolic blood pressure

The results of the estimated multilevel models for the 4,025 participants who did not report the use of blood pressure medication are summarized in Table 11. Convergence criteria were met for all estimated multilevel models. In this group, there were eight individual-level characteristics and three community-level characteristics retained in the final step of the multivariable model, after stepwise backward elimination of non-significant terms at the 10% level. Mean systolic blood pressure was 0.34 mmHg higher with every additional year of age ($p<0.0001$), 2.86 mmHg higher in females ($p<0.0001$), 0.66 mmHg higher with every one-unit increase in body mass index ($p<0.0001$), 2.34 mmHg higher in current smokers ($p=0.047$), 3.73 mmHg higher in those consuming 2 or more alcoholic drinks daily ($p=0.0003$) and 1.75 mmHg higher in those reporting being physically active ($p<0.041$). Mean systolic blood pressure was 2.13 mmHg lower among those who report often being stressed ($p=0.049$). There was a trend toward significance with 1.14 mmHg lower mean systolic blood pressure associated with consuming 5 or more fruits and vegetables daily ($p=0.077$). There was minimal change in the magnitude of the individual-level characteristic parameter estimates between the “individual model” and the “final model” demonstrating that the associations with individual-level characteristics were independent of the community-level characteristics.

Table 11. Associations Between Individual- and Community-level Characteristics and SBP Among Participants Not Using BP Medication ($n=4,025$) C-CHAP 2006

	“Empty model”	“Individual model “ (Including all individual-level characteristics significant at $p<0.10$)			“Final model” (Including all individual- and community-level characteristics significant at $p<0.10$)		
Between-community variance	0	0			0		
Between-individual variance	359.38	349.27			348.79		
Intraclass correlation coefficient (%)	0	0			0		
Individual-level characteristic	β^*	95% Confidence Interval	p	β	95% Confidence Interval	p	
Age	0.34	0.24,0.44	<.0001	0.34	0.24,0.44	<.0001	
Sex (female vs. male)	2.85	1.56,4.15	<.0001	2.86	1.57,4.16	<.0001	
Live alone [†]	-0.37	-1.67,0.93	0.31	-0.36	-1.66,0.94	0.33	
Diabetes							
Body mass index	0.65	0.50,0.81	<.0001	0.66	0.50,0.81	<.0001	
Current Smoker	2.32	0.015,4.62	0.049	2.34	0.035,4.64	0.047	
Alcohol (≥ 2 drinks/day)	3.60	1.60,5.60	0.0004	3.73	1.73,5.73	0.0003	
Physically active	1.75	0.070,3.43	0.041	1.75	0.075,3.43	0.041	
≥ 5 Fruit/vegetables/day	-1.11	-2.38,0.15	0.085	-1.14	-2.41,0.12	0.077	
Frequent fast food							
Often add salt							
Often Stressed	-2.17	-4.30,0.040	0.046	-2.13	-4.26,-0.0081	0.049	
Community-level characteristic							
Low income							
Unemployment							
Low education							
Median Income							
Population (per 10,000)				-0.71	-1.38,-0.031	0.041	
Population growth				-0.11	-0.24,0.0090	0.069	
Population >65 years							
Rurality Index				-0.055	-0.096,0.013	0.01	
Physician:population ratio							

* Beta represents the change in SBP (mmHG) associated with a unit change in the independent variable

† Forced into model due to association with missing data

There were two community-level characteristics statistically significantly associated with systolic blood pressure among participants who did not report the use of blood pressure medication and one community-level trending toward significance. Based on the results of the final step in the backwards elimination procedure, mean systolic blood pressure was 0.71 mmHg lower with each 10,000 resident increase in the community size ($p=0.041$) and 0.06 mmHg lower with each one unit increase in the Rurality Index ($p=0.01$). There was a trend toward lower mean systolic blood pressure associated with higher community growth ($p=0.069$). No statistically significant associations were found between systolic blood pressure and the community-level socioeconomic characteristics, the proportion of community population 65 years and over or the physician to population ratio.

The results of all estimated multilevel models for the 4,706 participants reporting the use of blood pressure medication are summarized in Table 12. Convergence criteria were met for all estimated multilevel models. Among participants who reported the use of blood pressure medication, there were six individual-level characteristics and one community-level characteristic retained in the final step of the multivariable model, after stepwise backward elimination of non-significant terms at the 10% level. Mean systolic blood pressure was 0.42 mmHg higher with every additional year of age ($p<0.0001$), 1.62 mmHg higher in females ($p<0.011$), 0.30 mmHg higher with every one-unit increase in body mass index ($p<0.0001$) and 3.35 mmHg higher in those consuming 2 or more alcoholic drinks daily ($p=0.0009$). Mean systolic blood pressure was 1.46 mmHg lower among those who report consuming 5 or more fruit or vegetables daily ($p=0.018$). There was a trend to significance in the association between those reporting diagnosis with diabetes and 1.44 mmHg higher systolic blood pressure ($p=0.051$). There was minimal change in the magnitude of the individual-level characteristic

Table 12. Associations Between Individual- and Community-level Characteristics and SBP Among Participants Using BP Medication ($n=4,706$), C-CHAP 2006

	“Empty model”	“Individual model” (Including all individual-level characteristics significant at $p<0.10$)			“Final model” (Including all individual- and community-level characteristics significant at $p<0.10$)		
Between-community variance	0.6426	0.7951			0.4019		
Between-individual variance	395.39	386.76			386.75		
Intraclass correlation coefficient	0.16%	0.21%			0.10%		
Individual-level characteristic		β^*	95% Confidence Interval	p	β	95% Confidence Interval	p
Age		0.42	0.32,0.52	<.0001	0.42	0.32,0.52	<.0001
Sex (female vs. male)		1.63	0.38,2.88	0.011	1.62	0.37,2.87	0.011
Live alone		-0.37	-1.67,0.93	0.58	-0.36	-1.66,0.94	0.59
Diabetes		1.44	0.0089,2.88	0.049	1.42	-0.0031,2.85	.051
Body mass index		0.30	0.18,0.43	<.0001	0.30	0.17,0.43	<.0001
Current Smoker							
Alcohol (<2drinks/day)		3.37	1.39,5.35	0.0009	3.35	1.37,5.33	0.0009
Physically active							
≥ 5 Fruit/vegetables/day		-1.45	-2.66,-0.24	0.018	-1.46	-2.66,-0.25	0.018
Frequent fast food							
Salt often added to food							
Often Stressed							
Community-level characteristic							
% low income							
Unemployment							
Low education							
Median Income							
Population (per 10,000)					-0.62	-1.25,0.0053	0.052
Population growth							
% Population >65 years							
Rurality Index							
Physician:population ratio							

* Beta represents the change in SBP (mmHG) associated with a unit change in the independent variable

† Forced into model due to association with missing data

parameter estimates between the ‘individual model’ and the “final model” demonstrating that the associations with individual-level characteristics were independent of the community-level characteristics.

There was one community-level characteristic trending toward statistical significance among participants who reported the use of blood pressure medication. After adjusting for the statistically significant individual-level characteristics and living alone status, mean systolic blood pressure was 0.62 mmHg lower with each 10,000 resident increase in community population ($p=0.052$).

Table 13 is a comparison of the fixed effects between the two groups of participants, those using and not using blood pressure medication.

Table 13. Comparison of Associations Between Individual- and Community-level Characteristics and SBP Among Participants Using ($n=4,706$) and Not Using ($n=4,025$) BP Medication, C-CHAP 2006.

	Participants not using BP medication ($n=4,025$) β^* (95% Confidence interval)	Participants using BP medication ($n=4,706$) β (95% Confidence interval)
Individual-level characteristic		
Age	0.34(0.24,0.42)	0.42(0.32,0.52)
Female	2.86(1.57,4.16)	1.62(0.37,2.87)
Body mass index	0.66(0.50,0.81)	0.30(0.17,0.43)
Alcohol (≥ 2 drinks/day)	3.73(1.73,5.73)	3.35(1.37,5.33)
Diabetes	Ns	1.42(-0.0031,2.85)
Fruit/vegetable intake (≥ 5 /day)	Ns	-1.46(-2.66,-0.25)
Often stressed	-2.13(-4.26,-0.080)	Ns
Current smoking	2.34(0.035,4.64)	Ns
Physically active	1.75 (0.0070,3.43)	
Community-level characteristic		
Population (per 10,000)	-0.71(-1.38,-0.031)	-0.62(-0.13,0.00053)
Population change	-0.11(-0.24,-0.0090)	Ns
Rurality Index	-0.055(-0.096,-0.013)	Ns

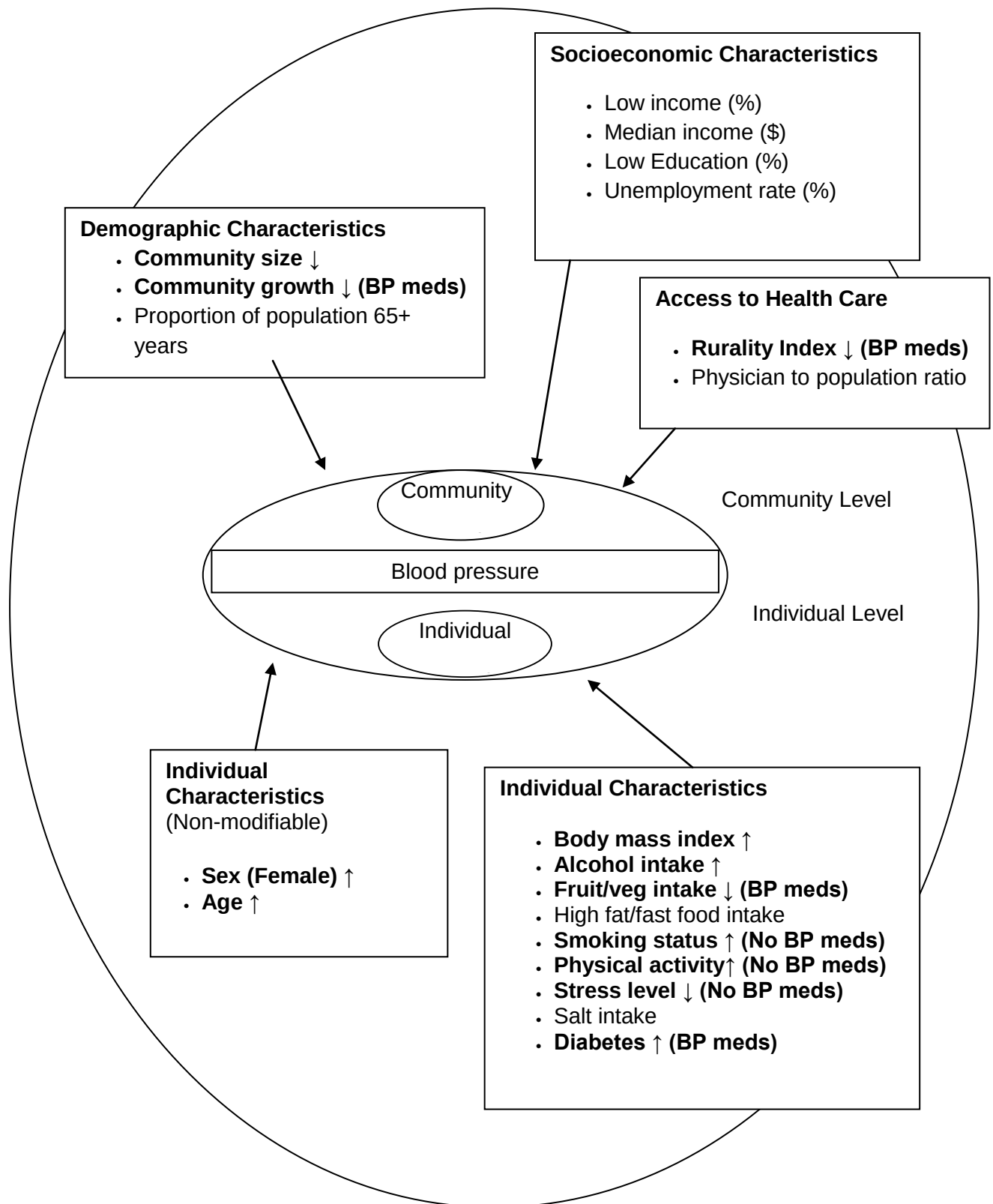
* Beta represents the change in SBP (mmHG) associated with a unit change in the independent variable

There were similarities and differences in the presence and magnitude of associations between systolic blood pressure and individual- and community-level characteristics between the two study groups. Mean systolic blood pressure was higher with advancing age, female sex, alcohol use and higher body mass index in both groups, but the magnitude of the association differed. Of particular note is the difference in the magnitude of the association between body mass index and systolic blood pressure between the two groups which is more than double in size in the no medication group. There were also four individual-level characteristics and two community-level characteristics that were significantly associated with systolic blood pressure in one group but not in the other. Figure 5 is a summary of the individual- and community-level characteristics that were significantly associated with systolic blood pressure.

5.7 Model Diagnostics

Collinearity among the variables was investigated using variance inflation factors for the individual-level characteristics and Spearman rank correlation coefficients for the community-level characteristics. The variance inflation factors were all below 1.2 thus confirming there were no issues of concern with collinearity among the individual-level characteristics. Spearman rank correlation coefficients between community-level characteristics were generally small (<0.5), except for socioeconomic characteristics where the correlation coefficients ranged from 0.58 to 0.76. To ensure collinearity was not responsible for the non-significant associations in the final model resulting in all of the socioeconomic variables being removed from the model, each of the variables were tested individually for an association with systolic blood pressure and the bivariable associations confirmed the results of the multivariable analyses.

Figure 5. Summary of the Significance (**bold**) at $p < 0.10$ and Direction ($\uparrow$ = positive, $\downarrow$ = negative) of the Associations Between Individual- and Community-level Characteristics and SBP



Histograms of the studentized residuals of the final multivariable multilevel models lend credibility to the assumption that the residuals are normally distributed among participants who do not report the use of blood pressure medication (Figure 6) and participants who do report the use of blood pressure medication (Figure 7). The normal quantile plots of residuals do not identify any large outliers (Figures 8 and 9). The plotting of the residuals against the covariates did not indicate any systematic trends thus transformation of the covariates was not required. A histogram of the random effects in the final multivariable model for the BP medication group confirmed the random effects were normally distributed. Due to the confinement of the negative variance components at zero, it was not possible to create the histogram of random effects for the group not using BP medication.

Figure 6. Histogram of Studentized Residuals from the Final Model Quantifying the Association Between Individual- and Community-level Characteristics and SBP Among Participants Not Using BP medication (n=4,025), C-CHAP 2006

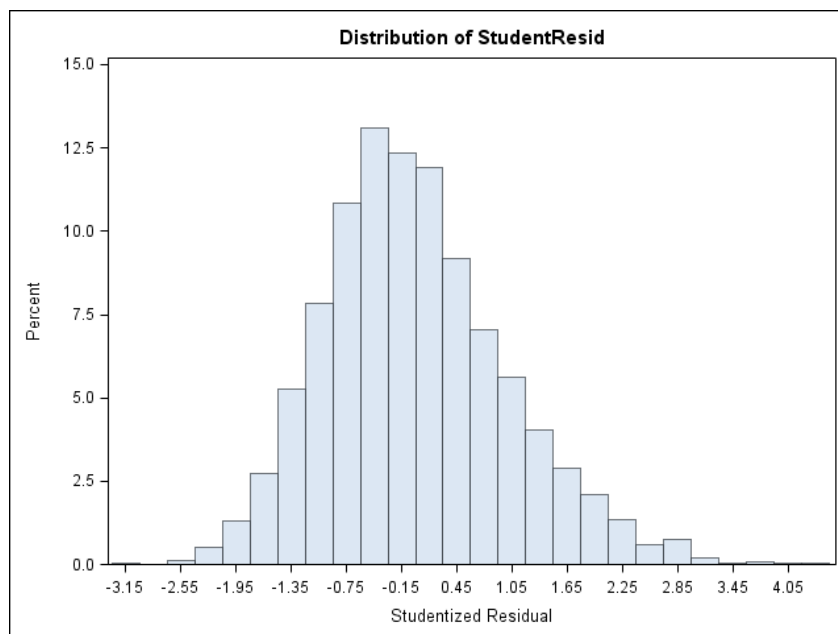


Figure 7. Histogram of Studentized Residuals for the Final Model Quantifying the Association Between Individual- and Community-level Characteristics and SBP among Participants Reporting the Use of BP medication ($n=4,706$), C-CHAP 2006

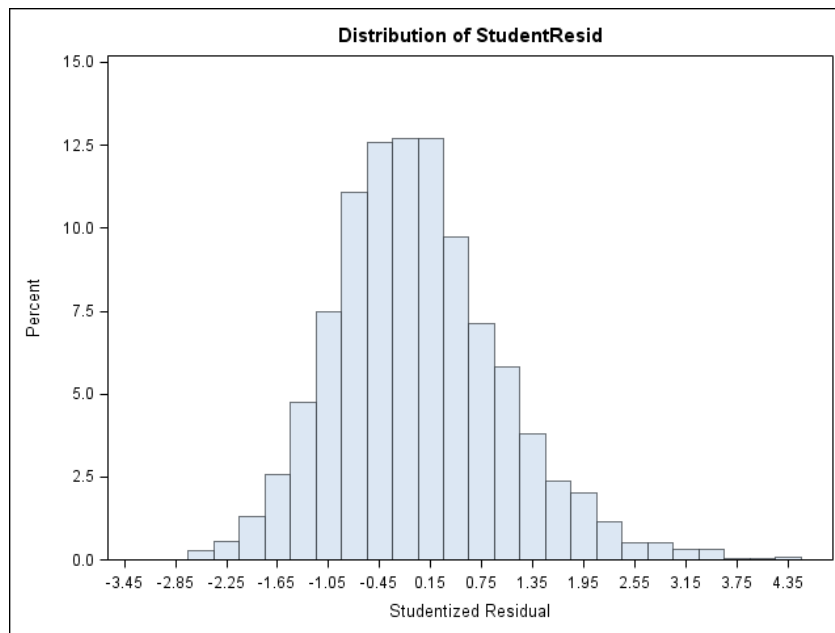
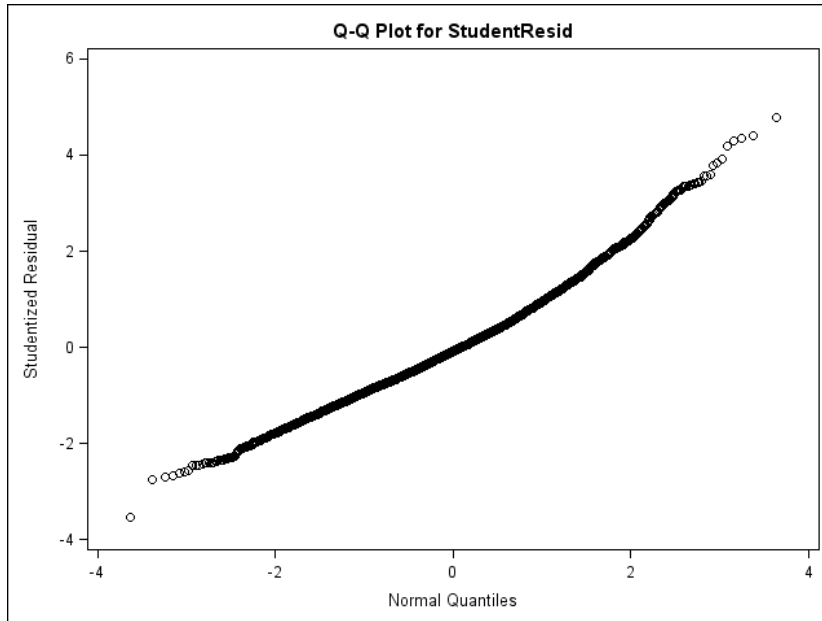


Figure 8. Normal Quantile Residual Plot for the Final Model Quantifying the Association Between Individual- and Community-level Characteristics and SBP Among Participants Not Using BP medication ($n=4,025$), C-CHAP 2006



Figure 9. Normal Quantile Residual Plot for the Final Model Quantifying the Association Between Individual- and Community-level Characteristics and SBP Among Participants Using BP medication ($n=4,706$), C-CHAP 2006



6.0 Discussion

This study found that most of the variability in blood pressure was attributable to ‘who you are and what you do’ rather than ‘where you live’. Associations between systolic blood pressure and individual- and community-level characteristics were found; for some characteristics, the magnitude and statistical significance of the associations were modified by the reported use of blood pressure medication. In all cases, the associations between individual-level characteristics and systolic blood pressure were independent of the associations with community-level characteristics.

The intraclass correlation coefficients indicated that less than 0.2% of the total variability in systolic blood pressure among participants occurred at the between-community level. This finding was consistent with the seven studies in the literature review reporting between-area effects (7, 40, 42, 43, 45, 48, 49). Despite this general consistency with other studies, the intraclass correlation coefficients observed in this study were the smallest of those reported in five other studies where the intraclass correlation coefficients ranged from 0.3% to 8%. The small sizes of the intraclass correlations found in this study may have been related to the relatively large size of the clusters themselves, defined as the community. Boyle and Wilms (1999) reported that the larger the area studied, the smaller the intraclass correlation or place effect (79). As a result, community-level studies of the effects of place on health may find smaller effects than neighbourhood-level studies. The rationale for this finding according to Boyle and Wilms (1999) was that when smaller geographic areas are grouped together, such as grouping numerous neighbourhoods into one community, the community can be expected to become more heterogeneous and as a result, the between-community differences are smaller (79). In addition, the power to show random effects is a function of the number of clusters included in

the study (74). Thus, the results of this study may have been different if more than 20 communities had been examined.

The analyses in this study conducted at the individual-level, revealed that age, female sex, increasing body mass index and alcohol consumption were associated with higher systolic blood pressure and a diet including recommended levels of fruit and vegetables was associated with lower systolic blood pressure. Age was associated with higher blood pressure or risk of hypertension in all fourteen studies included in the literature review. This association was also apparent in the increased prevalence of high blood pressure among older adults reported in the Canadian Health Measures Study and the Ontario Blood Pressure Survey (4, 9). The association between female sex and higher blood pressure is consistent with other studies of older adults. The Canadian Health Measures Study found that males had higher mean systolic blood pressure in early and middle adulthood but that beginning at approximately age 60 and through older adulthood, females had higher mean systolic blood pressure (9). A similar effect was evident in the National Health and Nutrition Examination Survey (NHANES 1999-2002) conducted in the United States where the prevalence of hypertension which is higher among males in early adulthood becomes higher among females after age 55 (80). This effect is consistent with the Menec et al. (2010) study where, among adults aged 65 years and over, the odds of hypertension for males was 27% lower than for females (49). In a study describing blood pressure through aging and menopause, Taddei (2009) suggests the abrupt fall in circulating estrogen levels associated with menopause may contribute to the rise in blood pressure noted in older women (80).

Also consistent with other studies was the positive association between blood pressure and body mass index (42, 43, 47, 48). The magnitude of this association found in this study was

twice as large (0.64 versus 0.30 mmHg) among participants not using blood pressure medication. Overweight and obese people appear to benefit from the use of blood pressure medication.

Alcohol consumption was associated with higher blood pressure and the effect was not modified by the reported use of blood pressure medication. This association is consistent with the literature review studies investigating this association (47, 48).

Cigarette smoking was associated with higher mean systolic blood pressure among participants who did not report the use of blood pressure medication in this study but not among participants reporting the use of blood pressure medication. Two other studies investigating this association found smoking to be associated with lower blood pressure (48) although in one study this association was only present in females (43). The prevalence of current smoking among participants not using blood pressure medication is approximately 30% higher than among those using blood pressure medication in this study. Although speculative, this difference suggests smoking cessation among individuals who are being treated with blood pressure medication. Since the CHAP Risk Profile Recording Form asks only whether a participant is a current smoker (yes/no) and does not ascertain the quantity of cigarettes smoked, one could also speculate that participants who are being treated with blood pressure medication may also smoke less frequently. This may explain the inconsistent association with smoking status between the two groups in this study.

Among participants not using blood pressure medication, physical activity was associated with higher systolic blood pressure, a finding that seems counterintuitive. Among the literature review studies, Matheson et al. (2010) found a decreased risk of self-reported hypertension associated with physical activity. Li et al. (2009) found that physical activity was associated with

lower systolic blood pressure among participants in high walkability neighbourhoods but higher systolic blood pressure among participants in low walkability neighbourhoods. Further investigation using measured rather than self-reported levels of physical activity among older adults would be helpful to clarify the relationship between physical activity and blood pressure.

Another somewhat counterintuitive finding was the association between stress and systolic blood pressure. The Risk Profile Recording Form assessed this variable by inquiring how frequently the participant felt overwhelmed or stressed in the last week. In the multivariable analyses of participants not using blood pressure medication, those who reported often feeling stressed or overwhelmed had lower blood pressure. Hildrum et al (2007) investigated the association between blood pressure and anxiety and depression; four of six previous studies of geriatric populations they reviewed found a significant association. The Hildrum et al (2007) study also found an association of low blood pressure with anxiety and depression. The CHAP question which used the terms ‘stressed or overwhelmed’ may have been measuring some features common to anxiety and/or depression which may explain the finding of an inverse association in the current study (81).

At the community-level, community size and community growth have been associated with other health outcomes among older adults , however this is the first study of the studies reviewed as part of this thesis to report this association with blood pressure. Lower mean systolic blood pressure was associated with larger community size irrespective of blood pressure medication use. In a study of social capital, community size and utilization of health services, Nauenberg, Laporte and Shen (2011) found that the effect of social capital varied by community size. Specifically, the effects of community social capital were predictive of health service utilization in larger communities but not in smaller ones (70). The authors speculate that

economies of scale in larger communities may facilitate the opening of community centers and the provision of other niche services including social clubs and other meeting venues which rely on having a certain size population to support them. This study specifically examined the effects of community characteristics on adults aged 65 and over. Like the Nauenberg et al. suggestion, the association between community size and blood pressure in the Ontario communities may be related to the availability of niche programs and services targeted to older adults such as social and recreational programs which may have health promoting effects.

Among participants who reported the use of blood pressure medication, two additional community-level characteristics were associated with lower systolic blood pressure: a higher rate of population growth and a higher Rurality index. A high rate of population change may be related to health outcomes for similar reasons as community size; a growing community may be a sign of increasing opportunity for employment and prosperity in a community as well as the extra resources both material and social that new residents may contribute to the community.

This is the first study of the studies reviewed as part of this thesis investigating the association between blood pressure levels and the Rurality Index. This association will need to be replicated in future studies to determine the consistency of the finding.

6.1 Study Strengths

6.1.1 Study design

The reasons behind geographical disparities in blood pressure may be contextual or compositional in nature. Contextual influences are those associated with the general living environment while compositional influences arise when particular types of people whose individual characteristics or behaviours affect their health tend to be found more commonly in

particular places. The use of multilevel analyses in this study allowed for the compositional and contextual influences on systolic blood pressure to be examined simultaneously.

The meticulous geographic coding of participants using the Postal Code Conversion File Plus rather than just assigning participants to the CHAP community they attended was a strength of this study. As a significant number of C-CHAP participants numbering over 4,000 attended a C-CHAP session from outside their own community; care was taken to exclude these participants from the analysis strengthening the study's internal validity.

6.1.2 Reliable and valid measurements of blood pressure

The use of automated blood pressure measurement with the BpTRU was shown in several studies to reduce the 'white coat effect' often seen with manual measurement of BP by a professional. Myers (2009) compared blood pressure measurements collected by BpTRU, manual sphygmomanometer measurements by a physician in the clinic, manual measurements by a technician in an ambulatory blood pressure monitoring unit (ABPM) and mean awake (ABP) measures (82). In this comparison of 309 hypertensive patients, Myers found that the Bp TRU value was similar to mean awake ABP, considered the gold standard in blood pressure measurement, supporting the claim of virtual elimination of the white coat response when compared to both manual measurements by the physician and the technician. In a separate study, Myers (2009) investigated the consistency between Bp TRU readings in two clinical settings (physician's office in a quiet room or ABPM unit) among a sample of 62 hypertensive adults and found that the Bp TRU value closely approximated the ABP value and was significantly lower than the manual measurements by either a physician and a technician (83). Myers also found that the Bp TRU values did not vary significantly between the two locations (physician's office

or ABPM unit). In a study designed to replicate and extend Myer's work, the CHAP working group designed a randomized trial to investigate whether BP values differed according to whether the BpTRU blood pressure measurement took place in a physician's office or in a pharmacy. Two hundred and seventy-five patients were randomized to one of two sequences for three blood pressure measurements: physician's office then pharmacy then physician's office or pharmacy then physician's office then pharmacy. The results of the study, which is in the manuscript preparation phase, indicated that there was no significant difference in the three blood pressure measurements, confirming that neither the sequence nor the location significantly changed the blood pressure measurement (84). Together these studies support the reliability and validity of the blood pressure values recorded in the 20 communities.

6.2. Study Limitations

6.2.1 Voluntary participation

Participation in C-CHAP was voluntary and therefore the sample may not be representative of all community residents 65 and over in Ontario. Since the recruitment strategies were standardized by the use of the *CHAP Implementation Guide* (58) across all 20 communities, it is likely any volunteer bias resulting was uniform across the communities thus minimizing the threat to internal validity of the thesis findings; however, a threat to the external validity of the study due to selection bias remains. Jones et al. (2008) compared CHAP participants in Airdrie, Alberta to the census data and found CHAP participants to be representative of the community population 65 and over. In addition, the prevalence of self-reported diabetes among CHAP participants was similar to the prevalence rates in Albertan and Canadian seniors (85).

A standardized recruitment campaign was used in each of the twenty communities including invitations and referrals from participating family physicians and pharmacies as well as community-wide advertising of CHAP sessions using posters, flyers and advertisements in the local media. These recruitment strategies resulted in between 6.3% and 18.8% of all adults 65 and over in the respective communities participating in C-CHAP.

In order to investigate the presence of volunteer bias in the C-CHAP sample, the characteristics of the study sample are compared to the randomly selected samples of Canadian adults in the Canadian Health Measures Survey and the Canadian Community Health Survey collected by Statistics Canada.

The comparisons of mean blood pressure, the frequency of hypertension and the frequency of hypertension treatment between the C-CHAP sample and the Canadian Health Measures Study is limited by the difference in the age ranges included in both samples. While the C-CHAP study included adults between the ages of 65 and 99, the Canadian Health Measures study included adults between the ages of 60-79 years. Due to the demonstrated association between age and systolic blood pressure, we would expect the mean systolic blood pressure and proportion of diagnosed hypertension to be higher in the C-CHAP sample for this reason.

There is also a marked difference in the prevalence of obesity reported however the differences may be largely due to the fact that self-reported height and weight was used in the C-CHAP study and measured height and weight in the 2004 Canadian Community Health Survey. Shields , Gorber and Tremblay (2008) compared self-reported height and weight in the Canadian Community Health Survey (2005) measured values by trained interviewers among the same survey participants (86). This study found that when self-reporting, subjects frequently

overestimate height and underestimate weight resulting in misclassification of subjects according to calculated body mass index categories. Shield, Gorber and Tremblay (2008) reported that body mass index derived from measured rather than self-reported height and weight increased the prevalence of obesity by 9 percentage points among males and 6 percentage points among females. This magnitude of differences was comparable to the difference between C-CHAP and the 2004 Canadian Community Health Survey. Table 14 summarizes the comparison of characteristics such as blood pressure, hypertensive status, body mass index, diabetes status, smoking status, diet, physical activity and alcohol intake between Canadian national survey data and C-CHAP participants.

Table 14. Comparison of Participant Characteristics in the C-CHAP Study to Canadian Survey Data

Characteristic	C-CHAP 2006	Population- based survey	Survey Source
Mean Systolic Blood Pressure (mmHg)			Canadian Health Measures Study
Male	132.5	122.4	Population aged 60-79 years(9)
Female	134.1	126.9	
Mean Diastolic Blood Pressure (mmHg)			Canadian Health Measures Study
Male	75.3	73.8	Population aged 60-79 years(9)
Female	72.6	71.7	
Hypertensive (%)	68	53	Canadian Health Measures Study Population aged 60-79 years(9)
Body Mass Index >30 (%)			
Male	18.2	28.0	2004 CCHS ¹ using measured
Female	20.2	31.0	height and weight(87)
Diabetic (%)	15.9	21.3	2006-2007 CCHS
Current Smoking (%)	6.6	9.0	Canadian Tobacco Use Survey(88)
Eat ≥ 5 Fruit/vegetable daily (%)	64.9	48.0	2004 CCHS(89)
Physically active (%)	80.2	43.0	2008 CCHS(88)
Alcohol ≥ 2 drinks/day (%)	9.9	6-10	Canadian Centre on Substance Abuse(88)

1.CCHS=Canadian Community Health Survey

As shown in Table 14, in general the C-CHAP sample appears reasonably comparable to the general Canadian adult population of older adults on measures of blood pressure, obesity and

alcohol consumption. The C-CHAP sample appears less likely to be diabetic and more likely to be physically active and to consume five or more fruits and vegetables daily.

6.2.2 Secondary analysis of data

This study was limited by the small number (20) of study communities taking part in the C-CHAP study. This small number of communities may have underpowered the study's ability to detect between community differences.

Also because this study was a secondary analysis of data, information on some individual-level characteristics that would have been desirable such as individual socioeconomic data or length of residence in the community was not available.

Blood pressure measures were taken during a single visit in C-CHAP which may entail potential measurement errors due to unmeasured confounders such as recent caffeine use. The use of self-report for individual-level characteristics may also have introduced some measurement bias. Participants may have overestimated their level of physical activity or been reluctant to report unhealthy behaviours such as smoking or frequent alcohol consumption.

6.4.1 Definition of the area-level under study

The lack of a significant intraclass correlation does not conclusively determine that context is not an important consideration in shaping blood pressure among older adults. An alternative explanation could be that the geographic boundaries used to define 'place', in this case community as defined by the community subdivision, may not have corresponded to the boundaries that shape the impacted blood pressure among older adults. Dragano et al. (2007) note that larger area-level units, such as communities, may be associated with a higher degree of

misclassification of individuals with respect to their actual social environment compared to smaller area-level units such as neighbourhoods (22). This effect could result in an underestimation of strength of associations between place and health. Thus communities may not be the geographic unit of analysis most relevant to blood pressure; unfortunately there is little consensus, theory or data on which to base hypotheses regarding the relevant spatial scale (40).

In addition, using geography to define ‘context’ may not have been the best approach. Geography is but one method to define context and it may not be the one that is most influential in shaping health, and in particular blood pressure. People belong to multiple contexts, such as a work context, a cultural context, a religious context that may also influence health.

6.3 Using the Bradford-Hill Guidelines to assess causality in the association of community-level characteristics and systolic blood pressure in this study

In 1965, Sir Austin Bradford-Hill suggested a set of nine guidelines which could be used to consider whether associations were causal. These guidelines include strength of association, consistency, specificity, temporality, biological gradient, plausibility, coherence, experiment and analogy (90). Each of the guidelines was used to consider whether the community-level associations with blood pressure reported in this study appear causal in nature. The results are summarized in Table 15.

6.3.1 Strength of association

As the strength of an association increases, so does the likelihood of a true effect. The association between community size and systolic blood pressure was the only community-level characteristic associated with systolic blood pressure irrespective of the reported use of blood pressure medication. According to the results of this study, mean systolic blood pressure is

Table 15. Summary of the Strength of the Community-level Associations with SBP Reported in this Thesis According to the Bradford-Hill Criteria

Bradford-Hill Criteria	Yes	No	Not Sure
Strength			X
Consistency			X
Specificity		X	
Temporality		X	
Biological Gradient	X		
Plausibility			X
Coherence			X
Experiment		X	
Analogy	X		

Yes=Guideline met by thesis, No=Guideline not met by thesis, Not sure= Inconclusive

approximately 0.7 mmHg lower for every 10,000-resident increase in community size. Based on Geoffrey Rose's estimation that a downward shift of 2-3 mmHg in average population blood pressure level would match the life-saving benefits achieved by antihypertensive treatment of individuals (15), a 30,000 resident increase in community size would be associated with an equivalent difference in the 2-3mmHg range. Although increasing a community's population is not a reasonable strategy to reduce blood pressure, further studies to identify modifiable community characteristics mediating the relationship between community size and blood pressure may be worthwhile.

6.3.2 Consistency

Consistent findings across studies and populations strengthen the likelihood of a true effect. In the fourteen studies included in the literature review, ten studies found significant area-level associations with blood pressure, two found associations in one sex only or with diastolic but not systolic blood pressure and two studies found no area-level association. In this study, community size was associated with systolic blood pressure among all participants, but

population growth and the Rurality Index were only associated with participants using blood pressure medication. The difference in community-level effects between the two groups has not been studied previously so the consistency across studies is not yet established.

As previously mentioned on page 41, the heterogeneity in the size of the area under study, such as neighbourhood versus community, and the heterogeneity in the methods of defining the outcome variable across the 15 studies, such as self-report, measured blood pressure or administrative data, makes comparing results among these studies difficult and may explain the lack of consistency of results.

6.3.3 Specificity

Specificity refers to evidence that a specific putative causal factor is associated a specific outcome. In this study, blood pressure is the specific outcome of interest. However, the literature review and the analyses of the data from the C-CHAP study identified a number of possible causal factors, some at the community-level and some at the individual-level.

6.3.4 Temporality

This guideline refers to the necessity of a cause to precede its effect. Cross-sectional designs, such as the C-CHAP study, investigating the effects of place on health are unable to ascertain whether exposures preceded the variation in blood pressure among C-CHAP participants. It is possible that sicker older adults might choose to live in larger and less ‘rural’ communities. In addition, there is no information available on the length of time participants were residents of the study community. The expected time lag between exposure to a contextual effect and development of the health outcome is uncertain. Longitudinal studies which follow

participants over time and track their movement between areas are necessary to respond to the question of temporality.

The C-CHAP data were cross-sectional; therefore we are unable to be confident that the exposures preceded the variation in blood pressure among C-CHAP participants. In addition, there is no information available on the length of time participants were residents of the study community. It is possible that sicker older adults might choose to live in larger and less ‘rural’ communities. The effects of place on health, if any exist, may have a temporal lag- meaning the outcome may not appear for years and perhaps decades after the exposure. In order to understand the effects of place on health over the life course, future studies will need to be longitudinal and to follow individuals, neighbourhoods and individual’s movements between neighbourhoods over time (91).

6.3.5 Biological gradient (or Gradient of effect)

This guideline suggests that when greater exposure is associated with higher incidence of disease, the likelihood of a true effect is strengthened. The linear associations modeled by the multivariable multilevel analysis in this study support a biological gradient with the community-level characteristics of community size for all participants (see Tables 11 and 12) and with population change and the Rurality Index for participants who report the use of blood pressure medication (see Table 12).

6.3.6 Plausibility or Biologic Sense

A plausible or biologically sensible mechanism between cause and effect helps to strengthen the likelihood of a true effect. Can our understanding of the human biologic mechanisms that are present in people with high blood pressure explain associations with

contextual factors? The causes of high blood pressure are a likely a complex combination of genetic, environmental, and other factors. The biological processes that lead to changes in blood pressure continue to be researched.

The negative association between systolic blood pressure and community size found in this study does not provide a plausible biological explanation of how community size could influence blood pressure. Community size may be a proxy for the availability of community resources to facilitate healthy living. A better understanding of the mechanism underpinning the association between community size and blood pressure would require data collection on specific community attributes, such as the number of community programs and services available for adults 65 years and over, to test specific hypotheses regarding possible biological processes mediating community-level effects on blood pressure such as diet or exercise.

6.3.7 Coherence

Coherence in connecting individual and community factors being associated is more likely when a specific disease or health condition occurs in a specific population, place or time with no other likely explanation. Coherence refers to the accumulation of all types of epidemiological evidence generated across studies. High blood pressure is a prevalent condition, particularly in older adults. There are many known risk factors associated with hypertension; no specific risk factor has been shown at the individual or community level to explain all the variation observed with blood pressure levels. Studies of place effects on health are complex with many contributing factors interacting at many levels of influence.

The aforementioned lack of consistency in the design and findings of studies of area-level effects on blood pressure is limiting when considering the epidemiological evidence. Two of the

three Canadian studies included in the literature review sampled participants from major Canadian cities (48, 49) whereas the third Canadian study sampled residents of small to medium-sized communities (44). The community-level characteristics found to be associated with blood pressure in this study, that is community population, community growth and the Rurality index, were not considered in the Canadian studies included in the literature review. As a result, it is not possible to consider these results coherent at this time.

6.3.8 Experiment

Experimental studies are considered strong evidence of a true effect. Controlled trials have shown that lifestyle changes and pharmacologic treatments can reduce blood pressure levels.

Experimental studies in which people would be assigned to a geographic or community to determine the future impact on their blood pressure are not feasible as random assignment of where people live or associate with each other would be neither ethical nor feasible.

Using experimental studies to improve the quality of the evidence of an effect of ‘place’ on blood pressure would require community cluster randomized trials. These trials would use area-level interventions such as building and making recreation centers more accessible to facilitate their use by older adults. If intervening on an area-level characteristic resulted in a change in blood pressure, this would be higher quality evidence of the presence of an effect.

6.3.9 Analogy

This guideline supposes that associations that can be likened to other associations are more credible. The association between area-level characteristics and blood pressure is similar

to many other studies investigating the effects of place on health, such as the association between state-wide smoking bans (92) and morbidity and mortality, benefits that are not isolated to the individual-level behaviour of smoking but offers protection for all citizens regardless of smoking status.

6.4 How these results can be used to improve population health

This study indicates that the majority of the variability in systolic blood pressure among the C-CHAP participants was associated with individual-level characteristics. While age and sex were significantly associated with systolic blood pressure, these are non-modifiable characteristics. Among the modifiable individual-level characteristics, a population health initiative would have a greater impact if it focused on the characteristics that were associated with systolic blood pressure in both groups of participants, irrespective of the use of blood pressure medication. The individual-level characteristics fitting these criteria are body mass index and high alcohol consumption. Since only a small minority of the population, approximately 10%, report consuming two or more alcoholic drinks daily, this is likely not the most effective focus of a public health campaign to lower the distribution of blood pressure in the community. This leaves body mass index as the remaining individual-level characteristic for consideration. In the C-CHAP sample, approximately 42% of participants were overweight, that is, a body mass index between 18.5 and 24.9, and 19% were obese, that is, a body mass index over 30. Since height and weight were self-reported, these data likely underestimate the prevalence of overweight and obesity. Due to the high prevalence of overweight and obesity and the linear association between body mass index and systolic blood pressure, this study suggests a community-wide initiative to reduce body mass index is the approach most likely to result in population benefits.

This suggested approach is consistent with the work of Leenan, McInnis and Fodor (2010) who investigated the association between body mass index and hypertension using data from the Ontario Survey on the Prevalence and Control of Hypertension (93). These authors reported an increase in the prevalence of obesity from 16% in adults 20–39 years of age to 33% in adults 60–79 years of age. Among adults 60–79 years, the prevalence of hypertension was 36% in lean, 51% in overweight, 59% in the obese stage I, and 68% in the obese stage II/III. Leenan, McInnis and Fodor (2010) established that body mass index was a mediator in the association between age and hypertension; the age-associated increase in hypertension prevalence was 30–50% less in those with a body mass index under 25 compared to those a body mass index over 25. Taking these findings into account, one of the best ways to prevent hypertension in the population and to moderate the non-modifiable association between age and hypertension, is to reduce the prevalence of overweight and obesity in the population, particularly among older adults.

The CHAP program provides a model for the effective delivery of a population-wide intervention. A testament to the feasibility of the CHAP model was the successful implementation of CHAP in each of the 20 communities assigned to the intervention (61). This model can provide a template the Ministry of Health and Long-Term Care in Ontario can replicate across the province to improve the health of Ontarians. CHAP builds community capacity by capitalizing on existing resources in the community including family physicians, pharmacies, health and social agencies and volunteer peer health educators. CHAP helps to close the loop between participants, physicians, and pharmacists. While offering educational materials and information about the availability of local community resources is an ongoing part of the activities at CHAP sessions, specific initiatives to target a reduction in body mass index

could become a priority focus. A review of the literature on community-based interventions to reduce overweight and obesity, focus groups in the community and environmental scans of community resources should be used to inform these population-based initiatives.

Adults aged 65 and over are the fastest growing population group in Canada. The proportion of seniors in the overall population has gone from one in twenty in 1921, to one in eight in 2001 and is forecast to increase to one in four by 2041(35). Average per capita health care costs are dramatically higher among adults 65 and over (\$10,318) compared to the population aged 1-64 (\$1,966) (94). As a result of the increased rate of aging anticipated over the next two decades, annual health care spending increases attributable to population aging in Ontario are projected to double (95, 93). This study demonstrates that population health initiatives to decrease body mass index would likely result in a downward shift of the mean systolic blood pressure among older adults. The health of the elderly in our community and the sustainability of our health care system will reap the benefits of the prevention and increased control of blood pressure.

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Appendix A.

Search Strategy used in EMBASE

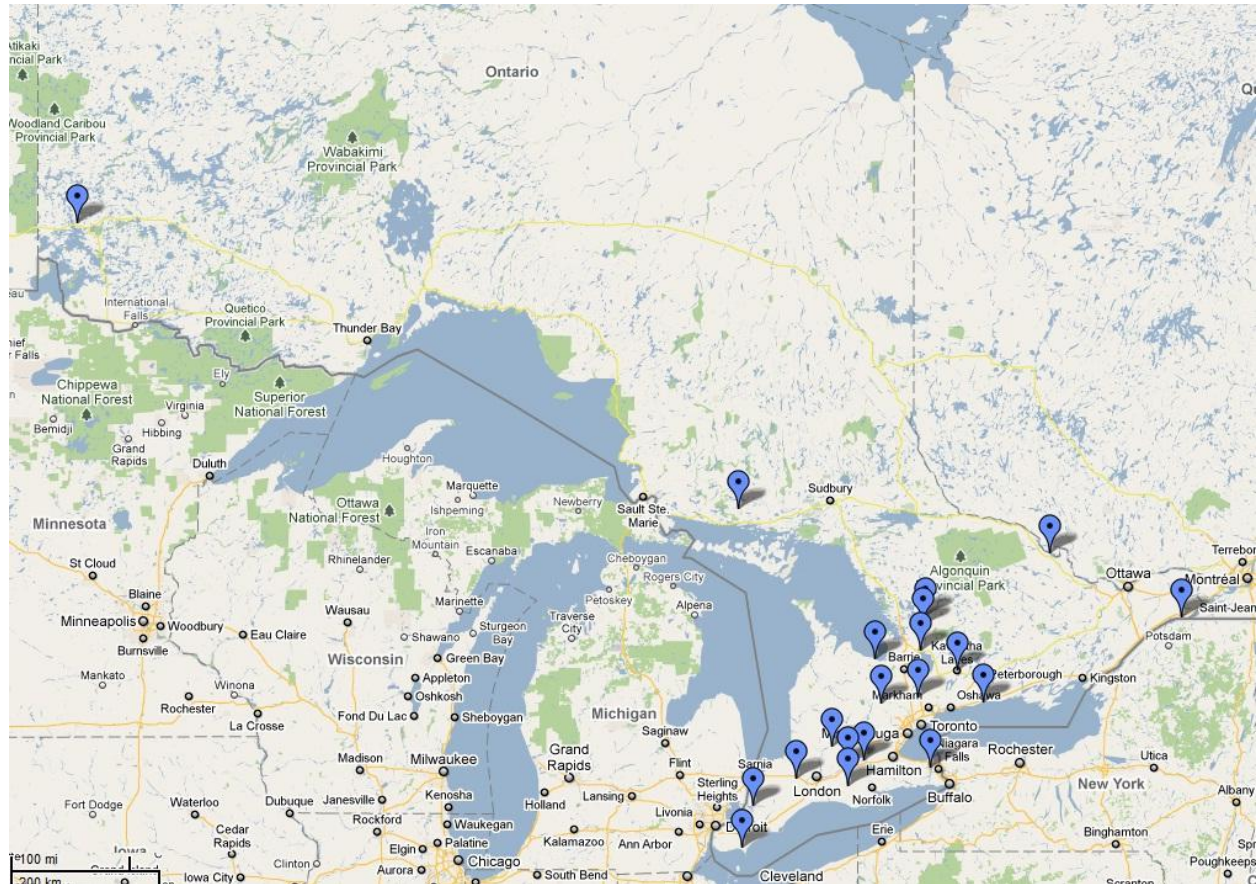
1. DEMOGRAPHY/
2. "residence characteristic\$.mp. or demography/
3. community/ or *social environment/
4. (Neighbourhood or neighborhood).mp. [mp=title, abstract, subject headings, heading word, drug trade name, original title, device manufacturer, drug manufacturer]
5. Multilevel model.mp.
6. "hierarchical linear model\$.mp.
7. "Mixed effect\$.mp.
8. "random effect\$.mp.
9. "area effect\$.mp.
10. "context\$ effects".mp.
11. "region\$ variation\$.mp.
12. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11
13. blood pressure/
14. blood pressure.ab.
15. hypertension.ab.
16. hypertension/dm, ep, et [Disease Management, Epidemiology, Etiology]
17. 13 or 14 or 15 or 16
18. adult/
19. 12 and 17 and 18
20. limit 19 to (human and english language)

Search Strategy used in MEDLINE

1. Demography/
2. Residence Characteristics/
3. Multilevel Analysis/
4. (neighborhood or neighbourhood).ab,ti.
5. communit\$.ab,ti.
6. "hierarchical linear models".ab,ti.
7. "geographic\$ disparit\$.ab,ti.
8. "area effect\$.ab,ti.
9. "context\$ effect\$.ab,ti.
10. "region\$ variation\$.ab,ti.
11. Blood Pressure/
12. hypertension/ or hypotension/
13. "blood pressure".ab,ti.
14. hypertension.ab,ti.
15. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10
16. 11 or 12 or 13 or 14

17. Adult/
18. limit 17 to (humans and yr="1995 -Current")
19. 15 and 16 and 17 and 18
20. "mixed effect\$".mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
21. "random effect\$".mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
22. 15 or 20 or 21
23. 16 and 17 and 18 and 22

Appendix B. Map of the 20 intervention communities in the C-CHAP study



Appendix C. CHAP Risk Profile Recording Form

 6478 FAX COMPLETED FORM TO: 1-800-858-6804	 CHAP Cardiovascular Health Awareness Program Programme de sensibilisation à la saine cardiovasculaire	Session Pharmacy ID 29 : (2-digit) (2-letter)
Risk Profile Recording Form Kenora		
Participant Information - Please PRINT CLEARLY in CAPITALS.		
Last Name	Sex ☐ Male ☐ Female	Postal Code (e.g. L5V7Q2)
First Name	Date of Birth 19 - - (year) (3-letter mo.) (day)	
Family MD's Last Name		
Consent to Release Participant Information Do you consent to having this information ☐ Yes ☐ No sent to your family physician? Do you consent to having this information ☐ Yes ☐ No sent to your regular pharmacist?		
Blood Pressure & Pulse Rate (average of 5 readings) Systolic mm Hg Pulse Rate bpm Diastolic mm Hg Cuff Size: ☐ S ☐ M ☐ L ☐ XL		
Cardiovascular Disease & Stroke Risk Profile For each question, solidly FILL one circle like this ● and not like this ⊗ or this ⊙. Thanks! 1. Is this a repeat visit? ☐ Yes ☐ No ***Please complete questions 2 to 20 below if you have not done so in the past year.*** 2. In general, would you say your health is: ☐ Poor ☐ Fair ☐ Good ☐ Very Good ☐ Excellent 3. What is your height? ft in OR cm → 4. What is your weight? lbs OR kg 5. Have you ever had a transient ischemic attack (TIA or mini-stroke)? ☐ Yes ☐ No ☐ Not sure 6. Have you ever had a stroke? ☐ Yes ☐ No ☐ Not sure 7. Have you ever had a heart attack? ☐ Yes ☐ No ☐ Not sure 8. Has your doctor told you that your cholesterol is high? ☐ Yes ☐ No ☐ Not sure 9. Has your doctor told you that you have diabetes? ☐ Yes ☐ No ☐ Not sure 10. Have you ever been diagnosed with high blood pressure by a doctor? ☐ Yes ☐ No ☐ Not sure 11. Are you currently taking prescription pills for high blood pressure? ☐ Yes ☐ No ☐ Not sure 12. If you currently use pills for high blood pressure, do you take them each day? ☐ Yes ☐ No ☐ Not applicable 13. Do you currently smoke? ☐ Yes ☐ No 14. In a typical week, how many times do you eat high fat or fast foods? ☐ Zero ☐ 1-2 ☐ 3 or more 15. Typically, do you drink 2 or more alcoholic drinks a day? ☐ Yes ☐ No 16. Do you eat 5 servings or more of fruits and vegetables a day? ☐ Yes ☐ No 17. How frequently do you add salt to foods during cooking or at the table? ☐ Rarely ☐ Sometimes ☐ Often 18. In a typical week, how frequently do you feel overwhelmed or stressed? ☐ Rarely ☐ Sometimes ☐ Often 19. Are you moderately physically active for 30 to 60 minutes, most days of the week? (e.g. brisk walking, active gardening, swimming, dancing or biking). ☐ Yes ☐ No 20. Do you live alone? ☐ Yes ☐ No		
Office Use Only (Print in CAPS) Today's Date 20 10 - - (year) (3-letter mo.) (day) Pt's Birthdate 19 - - (year) (3-letter mo.) (day) Family MD's ID : (3-letter) (3-digit) Regular Pharmacy's ID : (2-digit) (2-letter) First 4 letters of Pt's Last Name		
Office Use Only (Solidly FILL squares like this ■, not like this ⊠) Recommendations (Fill ALL that apply) ☐ Attend another CHAP+AP session for reassessment ☐ Make appointment with family physician ☐ See regular pharmacist OR ☐ None of the above Recommendations Actions (Fill ALL that apply) ☐ Nurse alerted for assessment and follow-up ☐ Session pharmacist alerted OR ☐ None of the above Actions Session Pharmacy ID? At top AND bottom pls.		
Session Pharmacy ID (2-digit) (2-letter) 29 : Version for 2010 only. Created 2009-11-12. Copyright © 2009 CHAP and Clinforma Data Systems & Management, Fig.P Software Incorporated 6478 		

Appendix D. Article describing C-CHAP