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Prevalence and transition of blood pressure and body mass index in South Africa

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Prevalence and Transition of Blood pressure and Body Mass Index in South Africa

by

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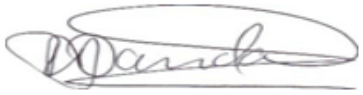
Thesis

Original published work submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy

Johannesburg, South Africa, 2021

DECLARATION

I Muchiri Wandai declare that this thesis is my original work. I submit it for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg, South Africa. I have not submitted it before for any other degree or examination at this or any other University or institution.

Signed  on 8th day of November 2021 at the University of the Witwatersrand, Johannesburg

DEDICATION

For the betterment of good health for all always

ACKNOWLEDGEMENT

I thank the Lord God for his goodness for he did not forsake or cast me off when doing studies in time of old age *(Psalm 71: 9,18 - **9** Cast me not off in the time of old age; forsake me not when my strength faileth. **18** Now also when I am old and grey-headed, O God, forsake me not; until I have shewed thy strength unto this generation, and thy power to everyone that is to come.)*

I am grateful to my three supervisors Professor Shane Norris, Professor Jens Aagaard-Hansen and Professor Samuel Manda for their support and guidance for the PhD.

Finally, I thank my family, my wife Wanjikū, my son Wandaī and daughter Wairimū for prayers, encouragement, and support as always.

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LIST OF SYMBOLS AND ABBREVIATIONS

BMI	Body Mass Index
BP	Blood pressure
BT20	Birth to Twenty
Cert	Certificate
CI	Confidence Interval
cm	Centimetre
CVD	Cardiovascular Disease
DBP	Diastolic Blood Pressure
Dip	Diploma
DPME	Department of Planning, Monitoring and Evaluation
EA	Enumeration Area
ec	Eastern Cape
ECD	Early Child Development
fs	Free State
GCM	Growth Curve Model
gp	Gauteng
HICs	High-Income Countries
HREC	Human Research and Ethics Committee
ICC	intraclass correlation coefficient
kg	Kilogram
Kg/M^2	Kilogram per square metre
kz	KwaZulu-Natal
LAS	Large Arterial Stiffness
LMICs	Low- and Middle-Income Countries
lp	Limpopo
melogit	Mixed Effect Logit
ML	Multilevel
mmHg	Millimetre of Mercury
mp	Mpumalanga
nc	Northern Cape
NCDs	Non-communicable Diseases

NDoH	National Department of Health
NiDS	National Income Dynamics Study
NSNP	National School Nutrition Programme
NSRP	National Sport and Recreation Plan
nw	North West
OECD	Organisation for Economic Co-operation and Development
OR	Odds Ratio
p/p-	Probability
PA	Physical Activity
PC101	Primary Care 101
PEPFAR	President's Emergency Fund for AIDS Relief
Pry	Primary
PSU	Primary Sampling Unit
PVR	Peripheral Vascular Resistance
SA	South Africa
SADHS	South African Demographic Health Survey
SANHANES	South African National Health and Nutrition Examination Survey
SBP	Systolic Blood Pressure
SD	Standard Deviation
SDGs	Sustainable Development Goals
SE	Standard Error
SES	Socio-Economic Status
SRD	Subclinical Renal Damage
SSA	sub-Saharan Africa
svy	Survey
uACR	urinary Albumin-to-Creatinine Ratio
UN	United Nations
VPC	Variance Partition Coefficient
vs.	Versus
wc	Western Cape
WHO	World Health Organisation

CONTRIBUTIONS AND THESIS MATERIALS

The data requisite for this thesis were from two sources, the National Income Dynamics Study (NiDS) and the Birth to Twenty (BT20) Plus Longitudinal Study. The candidate made the application for accessing the publicly available NiDS dataset by providing a description of the research agenda as per the study protocol and agreeing to the terms and conditions of data use. For the BT20 data, Professor Shane connected the candidate with the Data Manager, who provided access to the required data elements for the study. As data especially from the NiDS involved many files, the candidate was solely responsible for merging, cleaning, and coding of the data.

The candidate conceptualised each of the three journal articles, and in conjunction with the supervisors agreed on the aims and objectives for each of the papers. The candidate also did the literature searches, analysed the data, reported the results, and discussed the implication of the results as required in scholarly writing. Statistical analyses were certified by Professor Manda and the relevance of the study findings in the public health domain improved with inputs, suggestions and critique from both Professor Norris and Professor Aagaard-Hansen.

Finally, the candidate was involved in the submissions of the manuscripts to the relevant journals, and with guidance from the supervisors attended to corrections, changes, and questions raised by the reviewers and journal editors.

The following is a list of the three journal articles.

1. **Wandai ME**, Norris SA, Aagaard-Hansen J, Manda SO. Geographical influence on the distribution of the prevalence of hypertension in South Africa: a multilevel analysis. *Cardiovascular Journal of Africa. 2020 Jan;31(1):47-54*.
2. **Muchiri E Wandai**, Jens Aagaard-Hansen, Samuel OM Manda & Shane A Norris. Transitions between body mass index categories, South Africa. *Bull World Health Organ 2020; 98:878 ‑885I, doi: http://dx.doi.org/10.2471/BLT.20.255703*
3. **Wandai ME**, Manda SO, Aagaard-Hansen J, Norris SA. Blood pressure trajectories and association with body mass index using longitudinal data from a cohort of urban women in South Africa. *Cardiovasc J Afr*. 2021; 32(4): 208-214. DOI: 10.5830/CVJA-2021-014

ABSTRACT

Background: Hypertension and obesity are major risk factors for cardiovascular diseases and other chronic diseases, and their prevalence rates have been increasing in South Africa. Previous studies that have investigated prevalence of noncommunicable diseases and associated risk factors at the district level have used cross-sectional data that could not allow studying changes at both individual and ecological level. This PhD study's main aim was to address this gap by using two sets of longitudinal/panel data to profile and monitor the spatial and temporal distribution of hypertension and body mass index (BMI) by categories in South Africa. The PhD study's specific objectives were: (1) To estimate and compare the prevalence of hypertension over time and by districts for individuals aged 15 years and above; (2) to estimate the transition rates between BMI categories and to assess the factors associated with the transitions across all ages, and (3) to profile systolic (SBP) and diastolic blood pressure (DBP) changes by age and the effect of body mass index on the changes for women aged 22 to 89 years from an urban township. This integrated analysis provides policy makers with an improved and more accurate evidence in the variation of the burden of these two risk factors thereby enabling planning and resource allocation.

Methods: Data from the National income Dynamics Study (NiDS) panel survey were used for the first two specific objectives of the study, that is, estimation of the prevalence of hypertension at district level, and estimation of transition rates between BMI categories. Design-based and multilevel analyses were used for the estimation of hypertension prevalence, and multinomial regression model used for the analysis of the factors associated with BMI transitions. For the third specific objective, data from the Birth to twenty Plus Longitudinal Study (BT20) were used to fit growth curve models to describe intra- and inter-individual blood pressure (BP) trajectories, and the intra-class correlation coefficient (ICC) used to measure dependency of observations from the same individual.

Results: After accounting for demographic, behavioural, socioeconomic, and environmental factors, significant variation remained in the prevalence of hypertension at the district level. Districts with higher-than-average prevalence were found mostly in the South Western part of the country while those with prevalence below average were found in the Northern area. Between 2008 and 2017, the highest BMI increase was by the 7-13 years (4.7kg/m^2), 14-18

years (3.3kg/m^2), 19-24 years (3.2kg/m^2) age groups, and women (3.1kg/m^2). Overall, prevalence of obesity increased from 19.4% to 23.5%, with the 19-24 years age group (10.9% to 28.4%) and those with at least high school education (25.2% to 40.1%) having the highest increases. The transition rates to upward BMI level were higher than those to the downward BMI level. In the BT20 Plus data, four BP patterns were identified: a slow decrease with age before 30 years; a period of rapid increase in midlife up to 60 years; a flattening and slightly declining trend; and another increase in advanced ages. These phases persisted but at slightly low levels after BMI adjustment. Of the 1969 individuals, three groups were evident based on the severity of BP. In SBP, 1386 (70.4%), 482 (24.5%), and 101 (5.1%) were in low, medium, and highly elevated BP levels. For DBP, 1167 (59.3%), 709 (36.0%), and 93 (4.7%) were in low, medium, and highly elevated BP levels. The ICC was strong at 0.71 and 0.79 for SBP and DBP, respectively.

Conclusions: The aim of this PhD was to monitor spatial and temporal distribution of hypertension and BMI using two longitudinal data sets in South Africa. Although it has been known that hypertension prevalence differed substantially by district, the use of model-based estimation in this study using combined data over several time points provided precise estimates that correctly classified the districts' prevalence as below average, above average, or just average. BMI increased substantially between 2008 and 2017, and upward transition rate exceeded downward rate. Due to high retention in the overweight/obesity states, life course approach interventions that prevent transition into these states may need improvement. Based on the BT20 data, preventive and control measures for blood pressure early in life would be beneficial for control later in life. The evidence generated in this thesis enables public health decision makers to focus their resources on geographical areas (mostly South West districts of the country) and population segments (mostly women, ages 19-24 years, and individuals with higher level of education) where they are most needed. Furthermore, the comprehensive longitudinal methodology of this study could be useful in assessing future achievements of the South African strategies for prevention and control of these two risk factors of noncommunicable diseases.

PREFACE

Although my career started as a general Statistician, working and interacting with health professional inspired my interest in applying my statistical expertise with a bias towards public health domain. This journey started with previous research for MSc degree focussing on the epidemiology of HIV. In the preparations leading to this research, the ABC (Abstinence, Being faithful, Condom use) approach for prevention of the spread of HIV infection featured prominently, and this reminded me of the old adage attributed to the Dutchman Desiderius Erasmus that "prevention is better than cure". The present PhD research is therefore inspired by this awakening of the importance of disease prevention, and a deep conviction of the importance of data for decision making in preventive medicine.

My drive to do a PhD began as a result of working as a Statistician, Data Analyst and Monitoring & Evaluation Manager for organisations offering technical support to the SA Department of Health. This exposed me to various data sources that collect data, some periodically and others once-off on health, social and economic issues in South Africa. Interrogation of the data from these different sources beyond the work requirement made me have a sense of the richness of unexplored public health relevant information in the databases. This was a starting point in my journey for a PhD based research.

Disease surveillance paradigm dictates the importance of continuous and systematic collection and analysis of data to provide information on the burden of diseases. This would enable the tracking of health indicators' trends over time. Therefore, research relevant to indicators and targets set in relevant policy and strategic plans related to non-communicable diseases (NCDs) and their risk factors is needed on continuous basis. This thesis therefore utilises readily available longitudinal data for profiling the prevalence of hypertension, and overweight and obesity two main risk factors for NCDs. The importance of prevention and control of the risk factors for NCDs cannot be underrated in sub-Sahara African countries given the threat they pose, and the high cost associated with treatment.

This thesis is constructed through a publication model consisting of three peer reviewed journal articles. The thesis is made up of three sections:

Section 1: Introduction

The first section has two chapters. Chapter one consists of the background, literature review, the problem statement, the aim, and specific objectives. Chapter 2 provides details for a generalised methodology of the study.

Section 2: Empirical Chapters

This section is made up of chapters 3-5 and consists of the three published/under review journal articles.

1. Geographical influence on the distribution of the prevalence of hypertension in South Africa: a multilevel analysis.
2. Transitions between body mass index categories, South Africa
3. Long-term blood pressure trajectories and associations with age and body mass index among urban women in South Africa.

Section 3: Integrated discussion and conclusion

This section is made of chapter 6 and consists of a general discussion on the synthesis of the findings from the previous three chapters. The chapter concludes with an evaluation of the extent to which the study addressed the study's aim and objectives. It also discusses the study limitations, relevance and implications of these findings and related future work.

SECTION 1: INTRODUCTION

"A journey of a thousand miles begins with a single step" (Chinese saying)

CHAPTER 1: Background and literature synthesis

This chapter presents the background and literature review on the epidemiology of hypertension and body mass index (BMI) and associated risk factors.

1.1 Background

In 2016, it was reported that NCDs contributed the highest number of global mortalities accounting for an estimated 41 million deaths or 71% of all annual deaths.[1] More than three-quarters (~32 million) of the reported NCDs related deaths fall in the low- and middle-income countries (LMICs).[2] The main contributing factors for NCDs include behavioural or lifestyle risk factors (smoking, physical inactivity, fatty and sugary diets and binge alcohol consumption) and metabolic risk factors (raised blood pressure, overweight/obesity, high blood glucose (hyperglycaemia) and high fat levels (hyperlipidaemia) in the blood).[3] Socioeconomic factors (poverty/unemployment/low income and low education) are also indirectly linked to NCDs.

It is anticipated that since most countries especially the LMICs have low medical insurance coverage, they may be unable to provide universal care for reaching the globally set target of a "25% relative reduction in the risk of premature mortality from NCDs by 2025",[4] and the "SDG target of a one-third reduction in premature deaths from NCDs by 2030".[5] Prevention and reduction of the effect of the NCDs risk factors could therefore contribute immensely in reducing related deaths, thereby providing a huge boost for the economic development of these countries.

Primordial (preventing development of risk factors) and primary (reversing existing risk factors) prevention strategies on leading modifiable behavioural risk factors are vital in addition to strategies for identifying and managing people with NCDs.[1] The WHO global monitoring framework developed in 2013 a set of 9 discretionary targets with 25 specific indicators for member states to achieve by 2025.[6] These targets and indicators are categorised into three groups that relate to (1) reduction of NCD morbidity and mortality, (2) reduction of prevalence of risk factors for NCDs, and (3) health systems preparedness.[6] Excerpts for the targets and indicators for the risk factors are shown in Figure 1.1. Since

these targets and indicators are voluntary, countries can modify them according to their capacities, needs and priorities through country specific policies and strategies.

Framework Element	Target	Indicator
BEHAVIOURAL RISK FACTORS		
Harmful use of alcohol[1]	 2. At least 10% relative reduction in the harmful use of alcohol[2], as appropriate, within the national context	3. Total (recorded and unrecorded) alcohol per capita (aged 15+ years old) consumption within a calendar year in litres of pure alcohol, as appropriate, within the national context 4. Age-standardized prevalence of heavy episodic drinking among adolescents and adults, as appropriate, within the national context 5. Alcohol-related morbidity and mortality among adolescents and adults, as appropriate, within the national context
Physical inactivity	 3. A 10% relative reduction in prevalence of insufficient physical activity	6. Prevalence of insufficiently physically active adolescents, defined as less than 60 minutes of moderate to vigorous intensity activity daily 7. Age-standardized prevalence of insufficiently physically active persons aged 18+ years (defined as less than 150 minutes of moderate-intensity activity per week, or equivalent)
Salt/sodium intake	 4. A 30% relative reduction in mean population intake of salt/sodium[3]	8. Age-standardized mean population intake of salt (sodium chloride) per day in grams in persons aged 18+ years
Tobacco use	 5. A 30% relative reduction in prevalence of current tobacco use in persons aged 15+ years	9. Prevalence of current tobacco use among adolescents 10. Age-standardized prevalence of current tobacco use among persons aged 18+ years
BIOLOGICAL RISK FACTORS		
Raised blood pressure	 6. A 25% relative reduction in the prevalence of raised blood pressure or contain the prevalence of raised blood pressure, according to national circumstances	11. Age-standardized prevalence of raised blood pressure among persons aged 18+ years (defined as systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg) and mean systolic blood pressure
Diabetes and obesity	 7. Halt the rise in diabetes & obesity	12. Age-standardized prevalence of raised blood glucose/ diabetes among persons aged 18+ years (defined as fasting plasma glucose concentration ≥ 7.0 mmol/l (126 mg/dl) or on medication for raised blood glucose) 13. Prevalence of overweight and obesity in adolescents (defined according to the WHO growth reference for school-aged children and adolescents, overweight – one standard deviation body mass index for age and sex, and obese – two standard deviations body mass index for age and sex)

Figure 1.1: Global targets and indicators for monitoring the risk factors for NCDs[4]

Timely, accurate and continuous provision of reliable NCD and their risk factors data are therefore needed to appropriately inform prevention, control and improvement strategies to deal with the growing burden of NCDs in LMICs. The aim of this thesis was therefore to monitor temporal and spatial prevalence and transitions of hypertension, and overweight and obesity in South Africa, and how they differed by socioeconomic and lifestyle factors.

1.2 Hypertension, and overweight and obesity

Elevated blood pressure (BP) or hypertension and overweight/obesity are considered major contributing factors associated with cardiovascular diseases,[7] including heart diseases, stroke, and transient ischemic attack.[8] These two metabolic risk factors are also associated with diabetes and certain cancers,[9, 10] though study results on the relationship between high blood pressure and many types of cancers seem inconsistent.[11]

1.2.1 Hypertension (elevated blood pressure)

Hypertension is an important public health challenge worldwide contributing immensely to premature deaths mostly from cardiovascular diseases. In 2019, 10·8 (95% uncertainty interval 9·51–12·1) million deaths representing 19·2% [16·9–21·3] of all deaths were attributable to high systolic blood pressure.[12] Continuous provision of information on the burden of hypertension is therefore essential in developing effective prevention and control strategies.[13]

High blood pressure progressively rises over several years and so the risk rises with age leading to a high proportion of the elderly subpopulation having hypertension.[14, 15] Systolic blood pressure progresses continuously in an upward trajectory beginning from around 30 years of age, while diastolic blood pressure, progresses upwardly to around 50 years and slowly starts to decrease from the age of 60 years.[16] The rising of blood pressure with age is mostly related to the narrowing and stiffening of the blood vessel due to atherosclerosis.[17]

Several studies have also reported a plateauing of the upward trajectory in the BPs followed by decreasing trend at advanced ages.[18-20] These decreases have been associated with antihypertensive treatments,[19] poor health,[21, 22] including incident dementia,[23-25] and heart-failure and,[26] decreasing cholesterol and triglycerides.[22] Hypertensive related mortalities also tend to leave healthy individuals with lower BPs.[22]

Primary prevention of hypertension includes healthy lifestyle changes through diet, physical activity (PA), quitting smoking and alcohol use, and stress management. If high blood pressure is present and persists after implementation of these changes, medical management is used as an appropriate option,[27] in order to prevent or slow end-organ damage (irreparable damage to a target organ). The Global Action Plan for the Prevention

and Control of Noncommunicable Diseases 2013-2020[4] recommended a target of 25% relative reduction in the prevalence of raised blood pressure through a total risk approach for cardiovascular diseases.[28] However, the South Africa National Department of Health in the NCD strategy 2013-17 set its own target of 20.0% to be achieved by year 2020.[29]

1.2.2 Overweight and obesity

Overweight and obesity are a result of excessive fat deposits or accumulation in the body with deleterious health effect. The excess body fat is due to more calories being consumed than is expended. Globally, there has been an increased intake of energy-rich foods that are high in fat; and an increase in physical inactivity coupled with increasingly sedentary lifestyle in many forms of daily work activities, changing modes of transportation, and progressive urbanization.[30, 31] In adults 20 years and above for both sexes, overweight is defined as BMI greater than or equal to 25 Kg/m^2 and obesity as BMI greater than or equal to 30 Kg/m^2.[32] In children and teenagers, BMI is defined specific to sex and age, with overweight defined as a BMI at least the 85th percentile and below the 95th percentile, and obesity as a BMI at least the 95th percentile for children and teens of the same age and sex.[33]

People with increased BMI leading to overweight and consequently obesity are at increased risk for many diseases and other health issues compared to those with a normal or healthy weight. These health conditions include all-causes of death,[34, 35] high blood pressure,[36] dyslipidaemia,[37] type 2 diabetes,[38, 39] coronary heart disease,[40] stroke,[41] gallbladder disease,[42] osteoarthritis,[43, 44] sleep apnoea and breathing disorders,[45] some cancers,[9, 10] low quality of life,[46] mental disorders,[47, 48] and challenges in physical functioning.[49, 50]

In 2016, approximately 11.0% of men and 15.0% of women or 13% of the world's adult (18+ years) population were obese.[51] Consumption of processed and affordable foods that are concertedly marketed is highly linked to rising prevalence of obesity.[52] It is now acknowledged that increasing overweight and obesity in low- and middle-income countries including South Africa is a major health burden that potentially affects negatively the economic wellbeing and quality of life, and also increases health-care budgets,[53] in an already stretched and fragile health system.[54] In south Africa, the 2016 SADHS found that in women, 27.0% were overweight and 41.0% obese, of which 20.0% were severely obese

(BMI≥35 Kg/m^2). In men, 20.0% were overweight, and 11.0% obese, of which 3.0% were severely obese.[55]

1.2.3 Overweight and obesity as risk factor for hypertension

As already noted in the foregoing literature, high BMI and high BP share many risk factors, even though BMI is itself strongly and independently associated with hypertension. There is therefore a beneficial effect on blood pressure with weight reduction,[56, 57] most importantly if interventions are adopted earlier in life because this reduces the possibility of cardiovascular diseases later in life.[58] Prevention and control strategies for higher BMI would therefore directly and indirectly lead to prevention and control of hypertension. Although there is a linear increase in hypertension risk with increased weight gain, the effect is stronger in the young women,[59] and generally for both genders.[60] BMI slope which reflects velocity of body weight change may be a better predictor of hypertension in young adulthood. A longitudinal cohort study on Chinese aged 20 to 40 years provided results showing that a rapid upward BMI trajectory for individuals between 20 to 30 years, considerably increased the possibility of developing hypertension in older age.[61] In another similar study, BMI change between 13 and 33 years for both genders was shown to be the best predictors of adult SBP over a 20-year period.[62] Nevertheless, high BMI levels in young adulthood have also been found to be a risk factor for hypertension.[61] In another study based on a cohort of males, overweight or obese men in early adulthood or middle age were found to be at a higher risk of hypertension in old age life.[63]

In South Africa, the strategy for obesity prevention and control recommends dietary and physical activity interventions that include, fiscal measures, lowered salt intake, physician/dietitian counselling, worksite interventions, and mass media campaigns.[64] The dietitian-physician intervention is shown to be the most effective but costly strategy. The aim of these interventions is that patients may transit from obesity, and or overweight to a healthier body normal weight.

1.3 Conceptual framework

The research is based on a hierarchical conceptual framework according to Victora et al. 1997,[65] due to assumed hierarchical relationships between risk factors of disease. The

framework (Figure 1.2) shows risk factors of overweight/obesity and hypertension in a hierarchical manner. Risk factors at level 1 (demographic and socioeconomic factors) though used in epidemiology as determinants of ill health do not cause diseases, and are referred as distals determinants as they act through other intermediary (mediating) factors. In the development of hypertension, demographic and socioeconomic factors may exert their effect directly or indirectly through lifestyle factors (level 2), overweight/obesity (level 3), and other proximal factors. Lifestyle factors in turn exert their effect on overweight and obesity directly, and on hypertension indirectly or directly. Finally the proximate risk factor of overweight/obesity is related directly with hypertension.

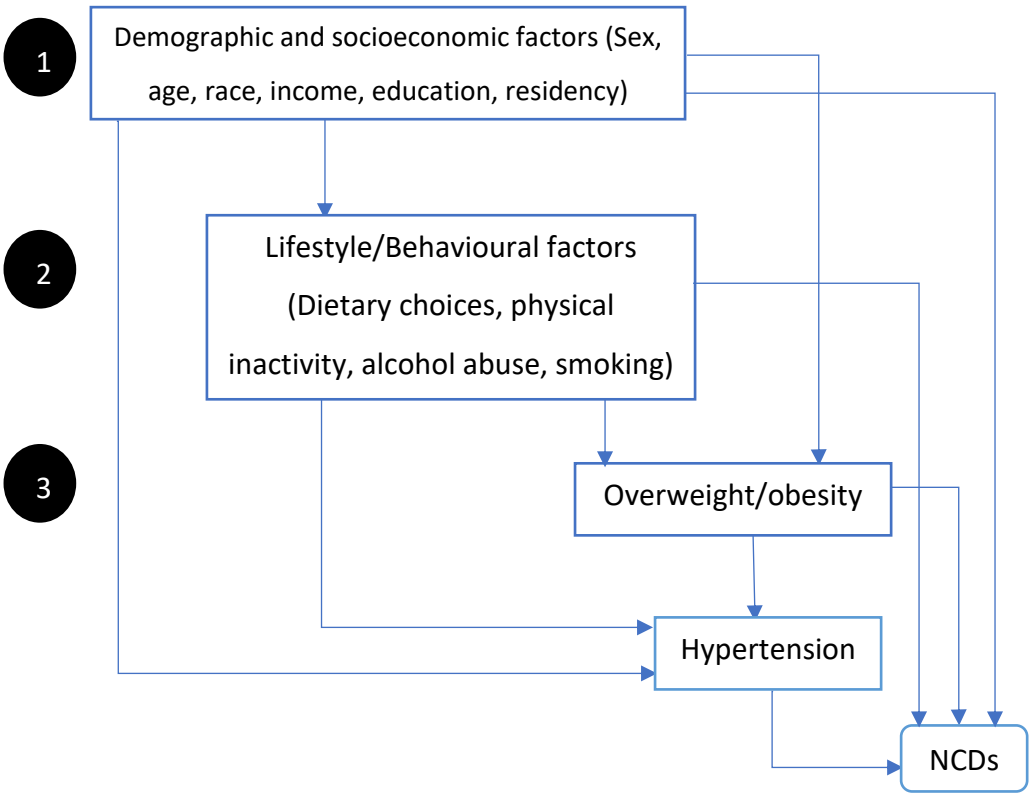


Figure 1.2: Conceptual framework

1.4 Interplay of risk factors for hypertension and, overweight and obesity, and historical prevalence in South Africa

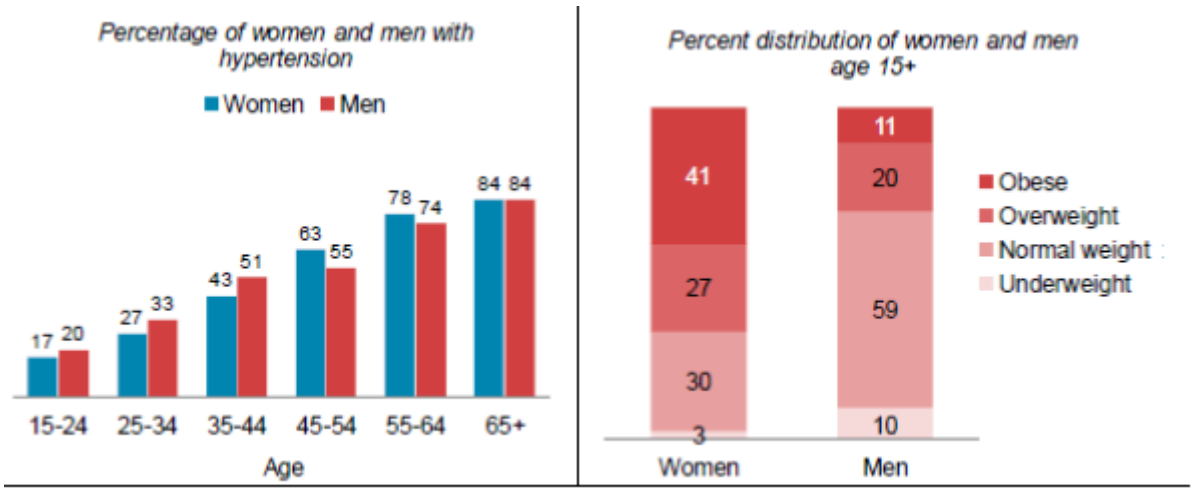
Overweight and obesity is known to contribute strongly in the development of hypertension, with proportionate increase in BMI associated with progressive incidence rate of hypertension in all ages.[66, 67] number of studies have shown a high proportion of hypertensive rate among overweight and obese individuals compared to normal weight individuals in both adolescents [68, 69] and adults.[70-72] Poor dietary choices, physical inactivity,

and sedentary lifestyle contribute strongly to a rise in the prevalence of overweight and obesity. Prevention and control measures for increased body mass include physical activities and diets rich in vegetables and fruits and low in carbohydrates and fat. These two metabolic risk factors for NCDs share, in addition to age, gender and race/ethnicity, several modifiable factors that include physical inactivity, excess alcohol, smoking, socioeconomic status, excessive salt, low dietary potassium and stressors.[73-75]

1.4.1 Age and gender

The likelihood of developing high blood pressure increases with age (

Figure *1.3*).[76] Up to early middle ages (about 45 years), raised blood pressure is higher in men, while prevalence is higher in women for those at least 55 years,[77] with the increase being more in LMICs than in the high income countries (HICs).[78] In South Africa, the percentage of women that are overweight and obesity is much higher than that of men.[76, 77] Aging is also associated with lifestyle and environmental factors changes that influence blood pressure.[79] Early life environmental influences are also known to affect blood pressure later in life.[80] Evidence shows that blood pressure in urban dwellers rises steeply with age, and this could be due to multiple and complex interaction between different environmental and lifestyle factors.[79] Urban lifestyle that lead to this change include too much salty diets, alcohol consumption,[81, 82] and psychological stresses. The vasoconstrictive effect of sodium loading on blood vessels is increases by age.[83] Physical inactivity levels, which mostly increases with age is accompanied by a sedentary lifestyle which further increases the risk for higher BMI and hypertension.[84]



Source: SADHS 2016

Figure 1.3: Prevalence of hypertension and BMI categories by age and gender 2016[15]

Evidence from much older studies showed that rise in systolic blood pressure was much lower in secluded dwellings[85] and in rural areas in the developing countries,[86] but when these rural residents migrated to urban environments, blood pressure rose in accordance with the adoption of the urban lifestyle.[87]

1.4.2 Race/ethnicity

A number of studies done in the USA show prevalence of hypertension to be higher among those from African origin compared with those from European origin.[88-91] However, in South Africa, national survey data indicate that the prevalence of both hypertension and overweight/obesity to be higher in those of European origin than in native Africans.[76, 77] However, these survey data report crude rates, that are not adjusted for age, and a higher proportion (almost 50.0%) of the Caucasian population is elderly (45+ years) in contrast to the African population in which ~60.0% are below 35 years of age (Figure 1.4). Similarly, the proportion of mixed-ancestry subpopulation that is below 35 years of age is also much higher (>50.0%) than that of the Caucasians.

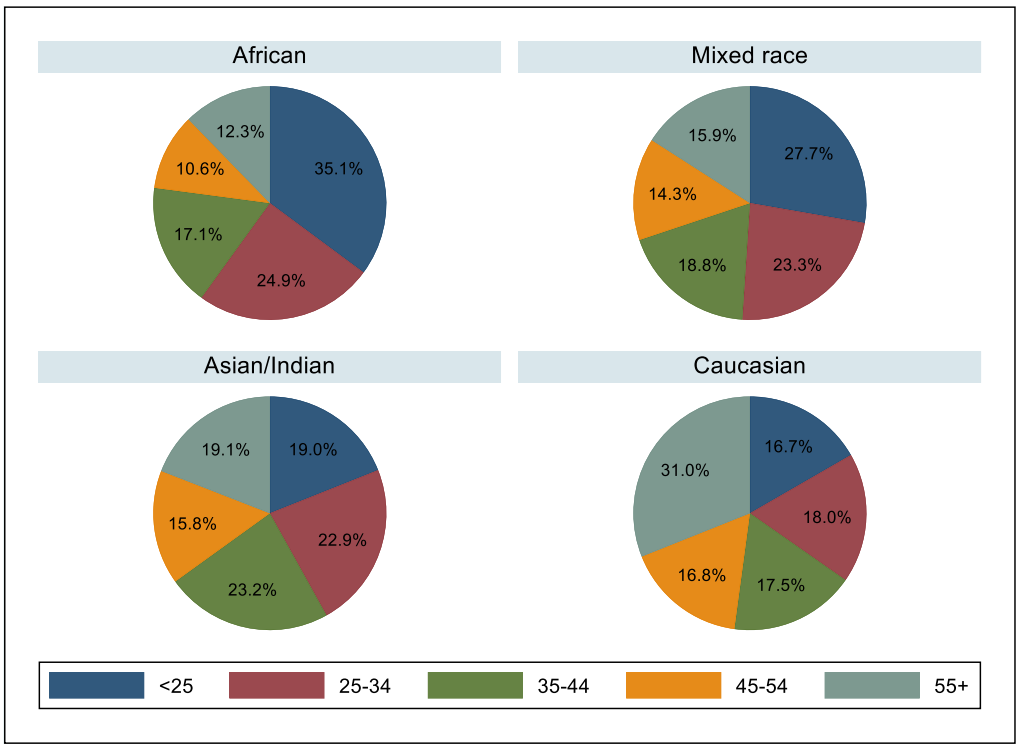


Figure 1.4: Age distribution by race/ethnicity in South Africa (NiDS)

Data collected from native Africans in Cape Town, South Africa have shown elevated blood pressures similar to those seen in US African Americans, and this has been attributed to racial discrimination traditional to these two multi-racial societies.[92] Socio-economic factors that affect health outcomes such as low education attainment, low income, and healthcare inaccessibility characterising these multi-racial societies have been found to contribute prevalence of hypertension.[93] Emerging knowledge on racial differences in genetic composition is also being shown to play a significant role in the development of high blood pressure and hypertension.[94]

1.4.3 Physical inactivity

Physical activity includes daily unplanned body fitness activities including household chores such as cleaning and gardening, commuting to work and other related occupational tasks; as well as planned, structured, repetitive and intentional movement for physical fitness such as brisk walking, cycling, and jogging.[95] Physical inactivity increases the chances of becoming overweight and obese and consequently increased risk of developing hypertension.[96-99] Characteristics that influence change in dietary intake and physical inactivity include perceived psychosocial stress and depression; and socio-demographic characteristics including education attainment, income, and race or ethnicity.[100, 101] In South Africa, data

show that women are less fit and engage in low physical exercise compared with men, but the prevalence of those not engaging in any form of physical exercise is high for both sexes (Figure 1.5).

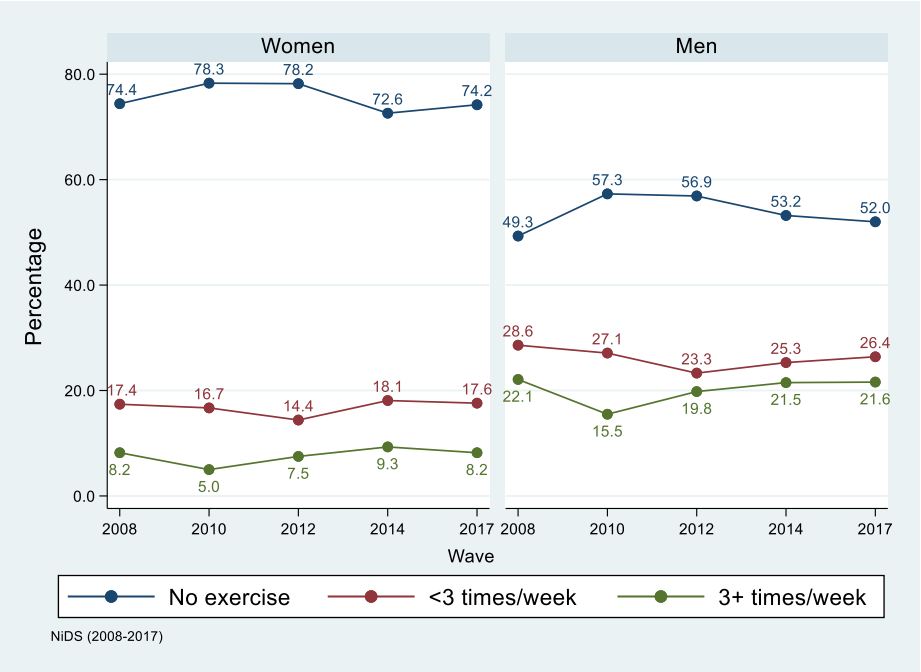


Figure 1.5: Prevalence (%) of levels of physical exercise by gender (2008-2017)

1.4.4 Alcohol abuse

Heavy drinking has been identified as a modifiable risk factor for hypertension in a number of studies,[102] especially in men.[103-105] Heavy and episodic alcohol consumption has also been found to increase risk of overweight and obesity.[97] According to the 2016 SADHS, South African men have a high prevalence of risky drinking (28.0%) than women (5.0%), and there are great variations between men and women across the provinces (Figure 1.6).

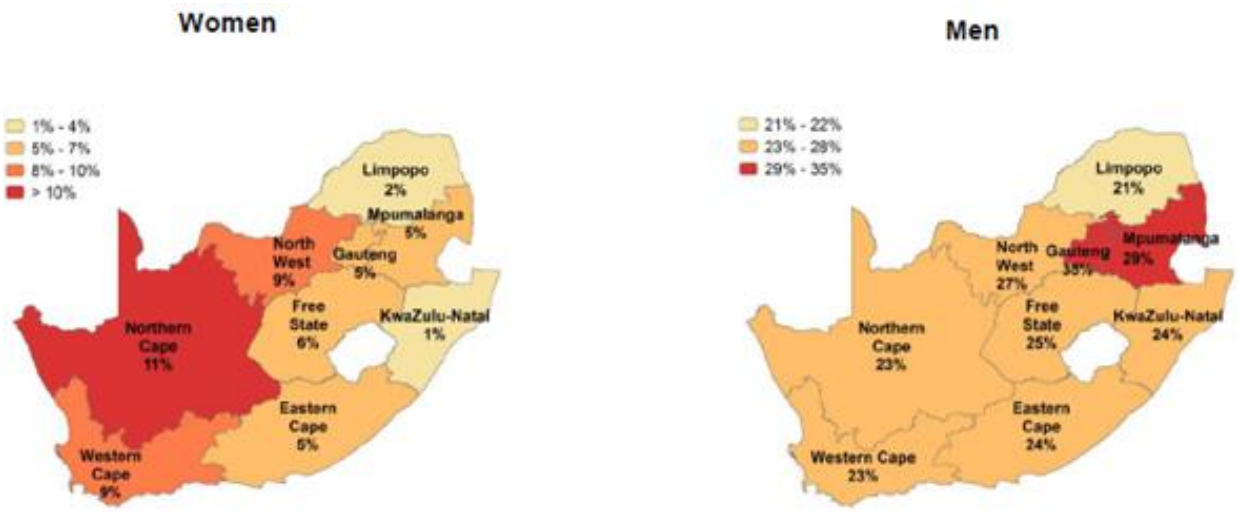


Figure 1.6: Prevalence of risky drinking for age 15+ years[55]

1.4.5 Tobacco use

Conflicting results have been obtained in various studies on effect of smoking on hypertension.[106] The prevalence of hypertension has been identified to be higher in smokers (current and past) in comparison to non-smokers,[107-111] while other studies have shown non-significant association between smokers and non-smokers.[112-115] Smoking has been shown to be a contributing factor for increased BMI. [97] However, current smokers have also been found to have lower BMIs compared with non-smokers.[116, 117] In South Africa prevalence of current smoking appears to be ~20.0% between 2008 and 2017 (Figure 1.7 - Figure 1.9).

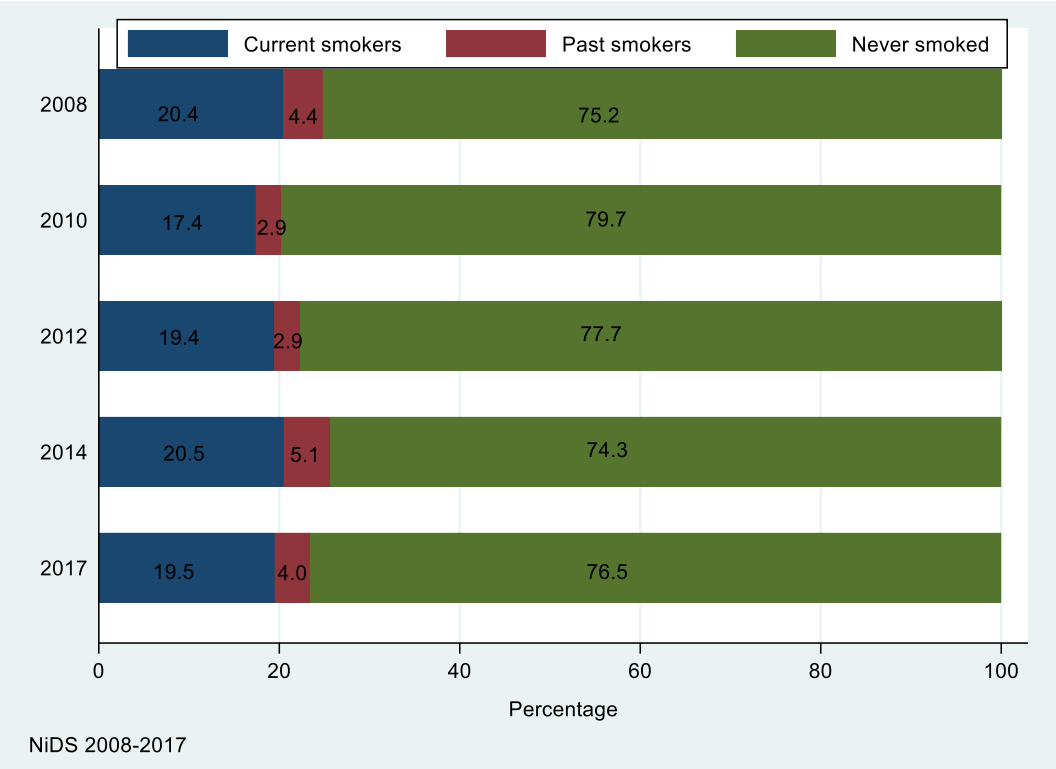


Figure 1.7: Prevalence of smoking, 2008-2017

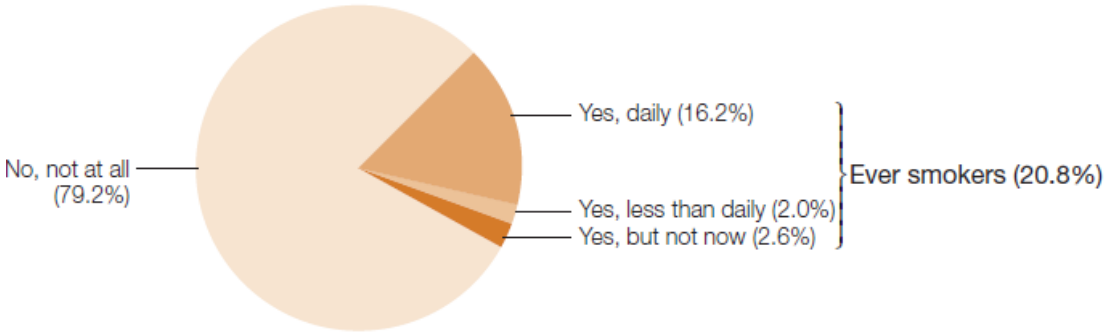


Figure 1.8: Prevalence of smoking, 2012 (SANHANES, 2012)

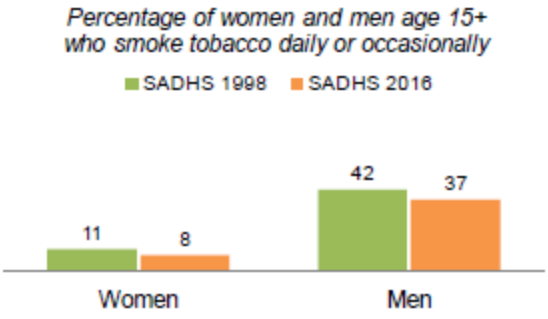


Figure 1.9: Prevalence of smoking in 2016 (SADHS[15])

1.4.6 Excess sodium in the diet

Increased dietary sodium ((sourced in table salt) can cause fluid retention in the body, which in turn can increase blood pressure.[118] Excess salt in foods has also been shown to increase risk of obesity.[75, 119] According to the 2016 SADHS, an estimated 13.0% of the population in South Africa consume salty snacks, and 14.0% processed meats.[55]

1.4.7 Low dietary potassium

Higher and greater long-term consumption of fruits and vegetables (natural sources for potassium) is a healthy dietary lifestyle that can contribute positively to hypertension prevention.[120-122] Potassium helps in balancing excess sodium in body cells, thereby reducing its (sodium) accumulation in the blood. Adequate intake of potassium can also reduce the risk of obesity.[73, 119] According to the 2016 SADHS, only 59.0% of adults reported consuming vegetables and 49.0% reported consuming fruits.[55]

1.4.8 Socioeconomic status (education and income)

Low socio-economic status characterised mostly by low education levels and low incomes has been associated with rising trends in blood pressure, primarily due to increased prevalence of obesity and high uncontrolled alcohol intake among these deprived socioeconomic group.[123, 124] Systematic review of studies for the association between socioeconomic status and obesity have shown an increasing positive associations and decreasing negative associations for countries as income levels decrease.[125]

1.4.9 Stress and insufficient sleep

Life stressors[126, 127] and short sleep durations[128, 129] are also independently associated with weight changes. In stressful moments, some individuals increase their caloric intake by consuming fatty foods, dense in carbohydrates,[130-132] but others have decreased appetite for food.[133, 134]

1.5 Geographically differences in prevalence

Globally the distribution of raised blood pressure is known to be disparate across regions while at the same time showing some similarities within divisions of a region. For instance in

2016, a study on blood pressure trends between 1975 and 2015 for 200 countries found that raised blood pressure decreased in HICs, remained high in central and eastern Europe, and increased in the LMICs mostly in South Asia and sub-Saharan Africa.[135] Even within a given country, subnational geographies can show disparities in prevalence of elevated blood pressure, not necessarily explained by existing behavioural or socio-demographic characteristics.[136] In the United States of America (USA), states in the south eastern ('stroke belt') part of the country, are known to experience a higher burden of hypertension in comparison with other states.[137] Additionally within a state, counties may also exhibit differences in prevalence, awareness, treatment and control.[138] These regional differences in hypertension prevalence have also been found to be associated with differential dietary patterns across the regions, with regions that consume high fatty acids and sodium, with low potassium, calcium and magnesium associated with higher hypertension prevalences.[139] Spatial analysis of essential soil elements in USA found that states with high declining rate of potassium in the soil also had higher prevalence of hypertension and hypertension-related mortality rates.[140] Existing distinct spatial clusters of disease prevalence within a country may require interventions programs that align to, and mirror the prevalence of the risk factors in specific subnational units.[141]

1.5.1 Geographically differentiated studies in Africa and South Africa

Studies in the African continent are mostly characterised by choice of a single administrative unit such as a state within a country and comparing prevalence by rural and urban divisions.[142-144] In Uganda, compass differentiated regions (East, West, North, South and West Nile) have been used to study disparities in hypertension.[145] In West Africa, spatial differences in hypertension and obesity prevalence have also been studied for an urban setting disaggregated by residential type (parcelled-out or non-parcelled-out areas),[146] or by hierarchical segregation of an urban area by level of infrastructure development.[147]

Studies on the distribution of hypertension and related predisposing factors in South Africa just like other African countries have mostly been by either rural or urban disaggregation, and for specific geographical areas. Ntuli et al 2015,[148] studied prevalence in a rural community not necessarily described by an administrative domain. Bärnighausen et al 2007,[149] and Malaza et al 2012,[150] studied hypertension and obesity prevalence using data from a large rural administrative unit (district) with high prevalence of HIV. Older studies

concentrated on geographical areas inhabited by a certain tribe, comparing prevalence between rural and urban dwellers. Sever et al 1980,[151] compared blood pressure and its risk factors for Xhosas living in rural and urban areas, while Seedat et al 1982, similarly compared hypertension prevalence in tribal Zulu.[152]

There have also been diverse studies differentiated by administrative geographical units. Otang-Mbeng et al 2017,[153] studied factors associated with obesity in a single administrative area of Nkonkobe local municipality of the Eastern Cape Province. Okop, Levitt and Puoane 2015,[154] looked at prevalence of excessive body fat for rural and urban dwellings in two different administrative (provincial) areas, while Rousseau et al 2017, studied distribution of adiposity of rural and urban settings within the same province (North West). Nationally representative surveys have reported prevalence by large (provincial) subnational units in addition to differing rural and urban settings.[155] The H3Africa AWI-Gen Study with 6 sites in Sub-Saharan Africa, including South Africa, has compared hypertension prevalence by rural and urban geographies administratively diverse within country and between countries.[156]

Surveys in South Africa with national focus include "Study of Global Ageing and Adults' Health (SAGE)" for those age 50 years and above.[157] Demographic Health Surveys (DHS) that have national representation however only report statistics at provincial level and they are not usually done regularly. Similarly, the "South Africa National Health and Nutrition Examination Survey (SANHANES)" which has been done once also reported statistics to the provincial level. Other studies at the national level have used self-reported data on hypertension to study the prevalence.[158] Recent and concurrent studies on CVDs and certain risk factors at district level using cross-sectional data such as SANHANES,[159] and the 2016 DHS data,[160] have been reported.

1.5.2 Social contexts in geographical distribution of health outcomes

The social and physical settings in which people live based on spatial disparities by socioeconomic status, race and or ethnicity for populations within countries are recognized as potential contributing risks of health disparities, in addition to the effects of individual and household risk factors.[161] This as a result of neighbourhood cohesion that incorporates key social features of the neighbourhood environment. Neighbourhood social cohesion is defined by "perceived connectedness, solidarity, and shared resources that allow people to

act together".[162, 163] A consequence of this connectedness in health issues is that lack or availability of health services will be shared, health seeking behaviour may be patterned, and cultural choices, perceptions and health outcomes could be similar.[164] Separating disparities into within and between areal subdivisions may help in the understanding of the possible contribution of the socially disparate geographical entities in the prevalence and transitions of hypertension, and overweight and obesity.[161] Geographical level analysis is also important as it has been shown that prevalence of hypertension and BMI differ by place with evidence that areas with higher levels of deprivation are more likely to have poor health services and outcomes, with differentials also between men and women.[165]

Geographical differences have great implications in the surveillance and monitoring of the burden of diseases and planning for remedial actions. Approaches to understand how areal disparities affect health has been argued to be of importance in order to deliver 'effective, contextually sensitive policy interventions'.[166] In sub-Saharan Africa, HIV spatial data have been used to provide evidence on how to improve HIV planning,[167] prioritise key populations and administrative division at more risk of infection, and to tailor interventions to mirror the local health needs.[168] National trends can also mask substantial differences by place in understanding of local level changes and monitoring of epidemics.[169] Spatial data can also help in equitable allocation of scarce resources,[170] in understanding differences between area surveillance data,[171] and in tailoring localised services and targeted interventions.[172] Subnational estimates characterise disease patterns in the local population, thereby supporting the planning and delivery of prevention and management services that meet local needs.[173]

1.6 Research gaps and need

With several global and national policies and strategies being developed for dealing with the pandemic due to NCDs and their risk factors, research is indispensable partly to guide public health planning and partly to monitor and evaluate the extent the set targets and indicators are achieved. Given that the South African "Strategy for prevention and control of NCDs, 2013-2017, and the Strategy for prevention and control of obesity, 2015-2020" have both matured, the following research gaps and needs have been identified as specified in sub-strategy 3, that is, "Monitor NCDs and their main risk factors and conduct innovative research" of the NCD strategy.

- Surveillance to monitor trends and measure progress in addressing inequalities: This required identification of data sets on "behavioural and metabolic risk factors (harmful use of alcohol, physical inactivity, tobacco use, unhealthy diet, overweight and obesity, raised blood pressure, raised blood glucose, and hyperlipidaemia)", and how they differ by key dimensions such as gender, age (children, adolescents, adults), socioeconomic status and place.
- Dissemination of results from innovative research: As cross-sectional data does not allow studying of the changes and transitions between the different hypertension and BMI states at the individual level, the literature in the South African context is short of information that show how individuals move between these states and what factors characterises the transitions. Understanding the factors associated with BMI transitions from an adverse category (overweight/obese) to a normal status, and vice versa, would help policymakers to come up with programs that mediate the effects of the factors to the populace.
- Group-based BP trajectory analysis has shown that a high (>140 mmHg SBP) in midlife increases risk of stroke and death.[174] Population-based cohort studies "support the view that high BP in later life originates in childhood."[175-177] Since the degree to which BP tracks from childhood to adulthood varies by sex and age,[178] there is need to study and identify the ages with the highest likelihood for transitioning from hypertensive to non-hypertensive state, information which may be helpful in policy formulation.

Another gap in the literature discussed above relates to the methods used to obtain subnational estimates of diseases incidence and prevalence. Breaking down data into subdomains ultimately reduces the sample sizes for each subdomain, thereby reducing the statistical precision of the estimates for these smaller domains. In such scenarios, an averaging or pooling of data across the subnational domains can be used to obtain more reliable estimates by using hierarchical or multilevel models. These models are also useful in improving estimates by combining information over time such as is available in longitudinal or panel studies.

1.7 Justification and relevance of the study

The South African "Strategy for Prevention and Control of Noncommunicable Diseases (NCDs) 2013-17 and the Strategy for the Prevention and Control of Obesity in South Africa 2015–2020", pointed out the importance of research "to understand the context-specific factors and social determinants" of NCD risk factors in order to implement "interventions effectively, especially in resource-constrained settings where there are multiple competing health problems".[29, 64] The NCD strategy also mentions sources of surveillance data, both routine, for example, the District Health Information System and specific surveys such as those carried out by Statistics South Africa (Stats SA) and other bodies. This study therefore, also demonstrates the usefulness of the readily available data in South Africa,[179] in addressing the public health challenge posed by NCDs.

It is anticipated that this research will contribute to the monitoring of hypertension and obesity prevalence, and as an indicator to the extent the targets set out in the strategies are being met. The study may also be beneficial as a guide for inter-sectoral action at district level, in accordance with the "sustainable development goals (SDGs)" that were adopted in 2015 that called for "countries to increase the availability of disaggregated data as part of the aim for strengthening data monitoring and accountability (SDG target 17.18)".[180]

1.8 Aim, specific objectives, and hypotheses of the thesis

The main aim of this thesis was to profile and monitor the spatial and temporal changes in hypertension and body mass index in South Africa.

Specific objective 1: To estimate and compare the prevalence of hypertension over time and by districts for individuals aged 15 years and above.

Specific objective 2: To estimate the transition rates between BMI categories and to assess the factors associated with the transitions across all ages.

Specific objective 3: To profile "systolic and diastolic blood pressure" changes by age and the effect of body mass index on the changes for women aged 22 to 89 years from an urban township.

Hypothesis 1: The “prevalence of hypertension in South Africa” has remained constant between 2008 and 2017 across the 52 districts.

Hypothesis 2: There is no difference between the proportion of individuals transiting to an upward or downward BMI level by categories of any of the risk factors.

Hypothesis 3: Systolic and diastolic BPs increase throughout life for women caregivers in the BT20 Plus study

In the following chapter, a brief methodology of the data sources, collection and setting is discussed. A combined discussion of the statistical strategies employed for the three journal articles is also briefly included.

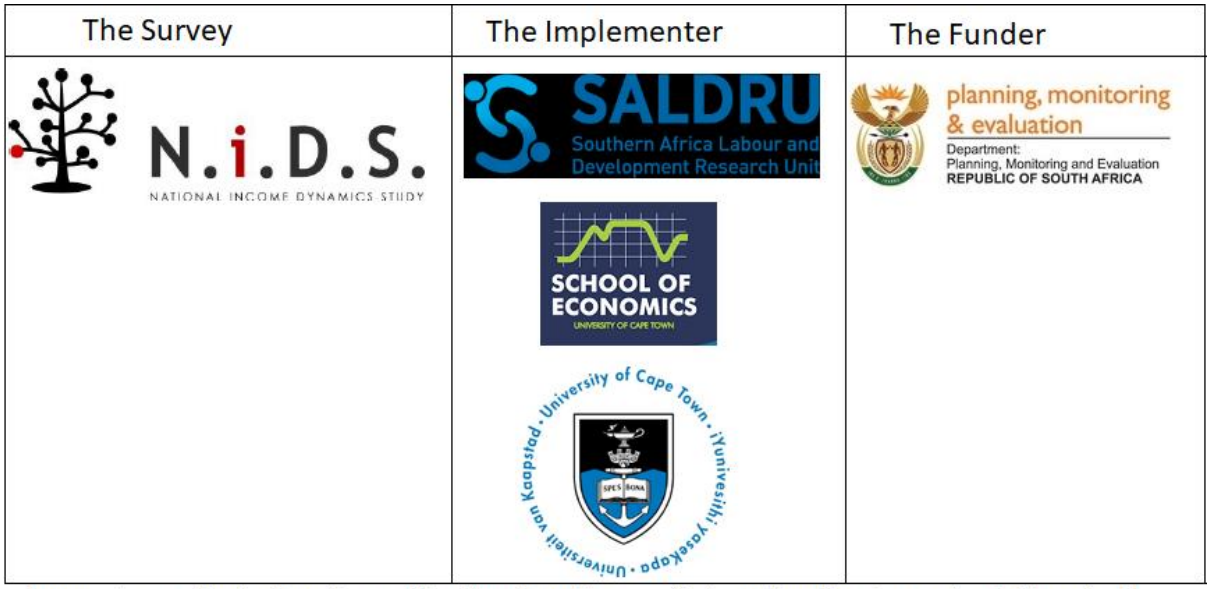
CHAPTER 2: METHODOLOGY

2.1 Data sources

The data for this study were acquired from two longitudinal/panel data sets; the National Income Dynamic Study (NiDS) with national representation, and the Birth to Twenty Plus Longitudinal study based on mothers and caregivers of a cohort of children born in Soweto, Johannesburg in 1990.

2.2 Study setting and design: NiDS

The National Income Dynamics Study (NiDS) is national panel survey, which started in 2008 with a sample of 28,000 individuals. The survey is taken approximately every 2-3 years. This far, 5 waves of the study have been completed.[181-185] The survey is funded by the Department of Planning, Monitoring and Evaluation (DPME) and implemented by the Southern Africa Labour and Development Research Unit (SALDRU) based at the University of Cape Town's School of Economics (Figure 2.1.) The main purpose of NiDS is tracking and understanding poverty transitions in the population.



Reconstructed as sourced from: http://www.nids.uct.ac.za/ (Surevy); https://www.saldru.uct.ac.za/ (Implementer); https://www.dpme.gov.za/Pages/default.aspx (Funder)

Figure 2.1: Description of the survey, implementer and funder (NiDS)

South Africa is administratively made of 9 provinces and 52 districts (Figure 2.2). Of the 52 districts units, 44 are district municipalities and 8 metropolitan municipalities. According to

the 2016 Community Survey,[186] the population was estimated at 55,653,654. The 2020 mid-year population estimate was at 59,622,350, with Gauteng (smallest geographically) accounting for more than a quarter of the population at 15,488,137. More than 60.0% of the population lives in urban areas. It is reported that urbanization is one of the major factors that contribute to increased consumption of fast food products in South Africa, as slightly more than 50% of the urban dwellers depend on fast food outlets on a daily basis.[187]



Figure 2.2: Districts and Metropolitan Municipalities of South Africa

In the NiDS, data are collected from individuals of all ages dwelling within sampled households stratified by districts. Person data from children (<15 years) are captured separately from those aged 15 years and above. The target population is "individuals in private households and residents in workers' hostels, convents, and monasteries, but excludes other living quarters such as students' hostels, old age homes, hospitals, prisons,

and military barracks." The stratified sampling method, with two-stage clustering[188] is used to sample study household and individuals. The 52 districts are used as the strata.[188] The first stage involved selecting a sample of 400 Primary Sampling Units (PSUs) within strata, from a Master Sample of 3000 PSUs developed by Statistics South Africa in 2003.[188] In this case, a PSU is a geographical area made up of at one or more Enumeration Areas (EAs), with each EA consisting of at least 74 dwelling units. The second stage involved systematically selecting clusters from each PSU, where a cluster consists of 8 non-overlapping dwelling units. In this thesis, data on those aged 15 years and above was used for estimating hypertension prevalence, while the combined under 15 years data and the 15+ years data were used in estimating BMI transitions. All individual respondents in the NiDS sample who had at least two BP measurements taken at the time of the survey were included in the study.

2.2.1 Data collection

Data are collected by trained fieldworkers using household and individual questionnaires. The individual questionnaires are designed separately for those aged below 15 years and those 15 years and above. Anthropometric measurements are taken twice for all individuals in a household, with a third measurement only if the difference between the first two is above 0.5 kg for weight and 0.5 cm for height. Waist circumference and blood pressure measurements are taken for those aged 15 years and above in the household. Blood pressure measurements are usually taken twice using an Omron Automatic BP monitor. Date, month, and years when the interviews and measurements were taken are also recorded.

Individuals self-reported on population group (race), gender, alcohol use (Ever used, regularity, and amount), smoking status (Ever smoked, current and amount) and physical exercise (days per week) highest education level, employment status, marital status, household income and household size.[189] The electronic version of the publicly available data is hosted by DataFirst (https://www.datafirst.uct.ac.za/dataportal/index.php/catalog/central) and disseminated to users through their online web catalogue. The public release data set excludes the names and addresses of the respondents as well as the names of towns and suburbs in which they live.

2.2.2 Data management and preparation for analysis

The data analysis procedures for the journal articles in Chapters 3 and 4 are described in the respective methods sections. A brief description of the data structures and files for each wave of the NiDS is provided here. The following files were used to source the required data items for this PhD study and merged accordingly using procedures described in the NiDS documentation.[189]

Link File lists the individual and household identifiers for each wave in the household in which that person is resident. It has one record per individual, and the uniquely identified by a personal ID.

Household Roster File has one record per person and provides data for each household family member, even for those not residing in the household at the date of the survey. Those non-residents are deemed to be residing in another household, have died or in an institution (boarding school or university residence, hospital, or prison).

Household File data are unique by household ID, and holds data collected using a household questionnaire, but excludes data in the household roster.

Adult Data File with one record per entry contains questionnaire data from those aged 15 years and above on the day of the interview.

Child Data File has a single data record obtained using children-specific (<15 years) questionnaire. It has unique identifiers for household and individual.

Derived Variable Data File keeps data such as aggregated income and expenditure variables. These are not directly taken using the questionnaires but are calculated or estimated from other data points collected using the questionnaires. In the NiDS dataset, there are two derived data files, one on household level and the other at individual level.

Derived Household Data File with one record per household is uniquely identified by a household ID.

Individual Derived File with single record for each person residing in a household. The data has unique household and individual identifiers.

2.3 Study setting and design: Birth to Twenty (BT20) Plus Study

The Birth to Twenty (BT20) Plus Study is a continuing longitudinal study done in Soweto (Figure 2.3), Johannesburg, South Africa.[190] The study population is made up of children and their families in this urban setting.[191] The original sample was made up of births recorded in a seven-week long duration between April-June 1990, when 5,460 single births occurred to women who provided concrete addresses within the study area.[192] Based on the 2011 national census, Soweto which has a geographical area of approximately 200 km² had a population of 1,271,628 of which 640,588 were women and 1,253,037 (98.5%) were Africans. It is a densely populated suburb with density of 6,357/km² as per the 2011 census.

Data for this thesis however came from women, who were mothers, grandmothers, sisters, aunties or other female caregivers of the Birth to Twenty Plus participants. There were four waves of data collection period with the first wave done in 2003, the second in 2005/6, the third 2007/9 and the fourth between 2011 and 2014.

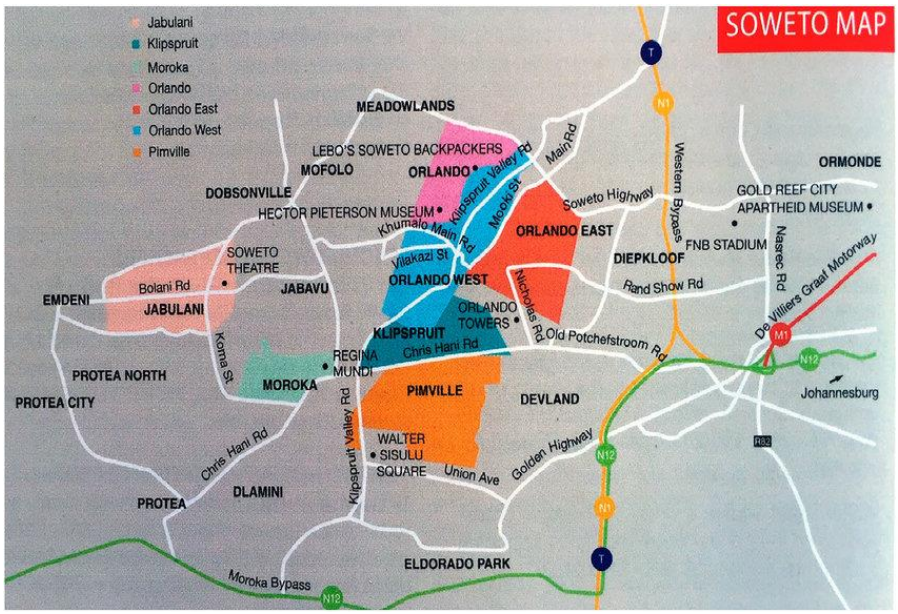


Figure 2.3: Map of Soweto

2.3.1 Data collection and management

During baseline recruitment, questionnaires were used to collect self-report sociodemographic and behavioural data including age/date of birth, socio-economic status (SES), smoking, physical activity, alcohol use, and individual and family histories of

hypertension. Blood pressure was measured twice by an appropriate sphygmomanometer and cuff using standard guidelines (seated position after reasonable rest). Anthropometric data used in the calculation of BMI were measured to one decimal point using calibrated equipment and standard procedures. Participants with missing data on blood pressures, height, and weight at any of the timepoints were excluded from the study. This total sample size was made up of 1969 women aged between 22 and 89 years.

2.4 Statistical analysis strategy for the whole study

Detailed data analyses specific to each objective are included in the relevant chapters. Here I include a general analytical strategy relating to the type of data (longitudinal/panel) characterising the thesis. The main benefit of collecting longitudinal data is because it allows analysis of change or stability of an outcome of interest at the individual (unit) level.

In this thesis, statistical approaches developed specifically for longitudinal data were considered appropriate as they enable measurement of the time effects on different cohorts since we had repeated measurements over time from the same individual. The approach also enabled limited control for unavailable/unknown explanatory variables that are constant over time and that possibly determine the outcome (dependent) variables. Multilevel model[193] with 3 levels (repeated measurements, individual and districts) was applied for the first specific objective, the event history model for transition probabilities with multiple states (competing risks)[194] was used for the second specific objective, and the growth curve model[193] was used for the third specific objective of the thesis.

2.4.1 Multilevel model

Logistic regression is a statistical strategy used either to predict a single dependent binary variable using one or more other independent variables, or to determine the numerical relationship between such a set of variables.[195] Multilevel logistic regression is an extension of normal logistic regression ideally suited if sample data contain repeated (longitudinal) measurements from the same unit or have a clustered or hierarchical structure.[196]

A three-level logistic regression model with repeated measurement data was used for the first objective of this PhD study. The general form for the model is as follows:[197-199]

$$logit[\Pr(y_{tij}=1)] = \underbrace{\sum_t \beta_{0,t} + \sum_t \sum_k \beta_{k,t} x_{k,tij}}_{} + \underbrace{\sum_t v_{tj} period_{tij} + u_{0ij} + u_{1ij} + e_{tij}}_{}$$

For a dataset with n subjects or units, i indexes the subjects, j indexes the clusters/groups (districts), and t the observation time. y_{tij} = 1 denotes presence of the event (hypertension), while y_{tij} = 0 denotes absence of the event (normotensive state) at time t. The first two terms in the logit equation are the fixed effects, which show the expected value of the log odds of y over time given values of the k covariates. $x_{k,tij}$ denotes the k[th] explanatory variables from the i^{th} subject in district j at time t. The rest of the terms in the equation represent the random effects (or residuals). v_{tj} denotes the residuals representing group (district) effect and accounts for the differences in y across the districts. $period_t$ is an indicator variable for observation t. The random intercepts u_{0ij} capture subjects' differences in the level of y for the null model (without covariates) at the baseline (i.e. around $\beta_0 + v_j$), [the log odds for presence of hypertension in subject i from district j compared to the mean], and u_{1ij} captures individual differences in the rate of change of *y* (around β_1). Last, we have the residual, e_{tij}, which captures time-specific variation in *y* around individuals' growth trajectories (i.e., scatter around the individual trajectories due to noise, measurement error, or omitted time-varying covariates).

The Stata's general notation for fitting a three-level random-intercept model for repeated measures of hypertension given the covariates at the individual-level (level 2) nested within districts (level 3) is as follows:

$$melogit\ hypertension\ x_1,\ x_2, \cdots, x_k\ ||\ district:\ ||\ individual_id:$$

In the notation, $hypertension$ is a variable with 0/1 entries indicating absence or presence of hypertension, and $x_1,\ x_2, \cdots, x_k$ are the covariates (independent variables). Specific details of the model's covariates are given in methods section of chapter 3.

2.4.2 Event history model

Panel data such as obtained in the NiDS give rise to sequence of discrete observable events in an individual's lifetime.[194] These events represents an individual's transition from one discrete state to another in a space of one or several other discrete states.[200] Event-history modelling is a statistical technique used to analyse time-to-event data for research designs where the state of subject i over time is only known at discrete time points $(t_1,\ t_2, \cdots,$

t_T).[200] In the NiDS panel data, anthropometric measurements on study participants helps to trace an individual's BMI (underweight, normal, overweight, obese) transition states. These data produce a set of events with multiple states or competing risks[201] as shown in Figure 2.4.

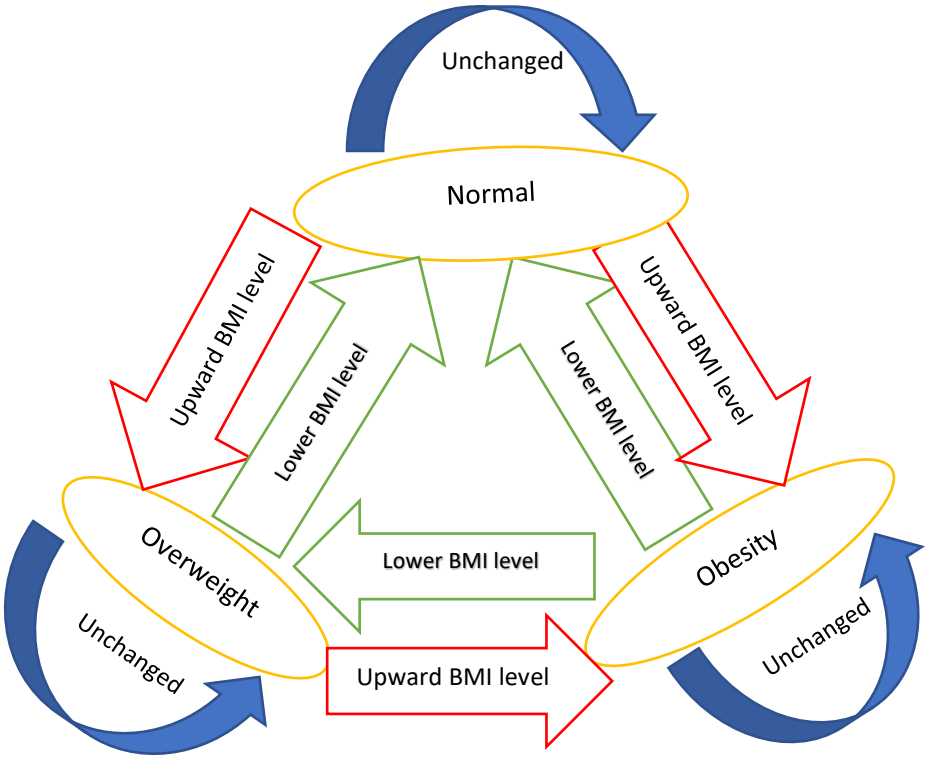


Figure 2.4: Body weight transitions amongst normal, overweight and obese categories

For a dataset giving rise to E types of transitions/events, in an interval of time t (of episode j of individual i), a categorical response variable for competing risk events can be defined as

$$y_{ijt} = \begin{cases} 0 \text{ if no event in t} \\ \text{e if event of type e in t (e } = 1, \cdots, \text{E)} \end{cases}$$

y_{ijt} can be analysed in one of two approaches for understanding the transition probability of a given event of type e. 1) by using a multinomial model for y_{tij} with correlated random effects that allow modelling of shared unobserved risk factors, or 2) by defining a binary response $y_{tij}^{(e)}$ for event type e, treating all other types of events as censored (no event observed), and analyse using a multilevel binary response model.[201] In this PhD research, the multinomial logit model for the probability ($p_{tij}^{(e)} = Pr(y_{tij} = e | y_{t-1,ij} = 0)\ for\ e = 1, \cdots, \text{E}$) of transition to an event of type e with the following notation[201] was used for the second objective.

$$log\left(\frac{p_{ijt}^{(e)}}{p_{ijt}^{(0)}}\right) = \alpha^{(e)}D_{ijt}^{(e)} + \beta^{(e)}x_{ijt}^{(e)} + u_i^{(e)}, \qquad e = 1, \cdots, E$$

Where:

- $D_{ijt}^{(e)}$ are dummy functions for time and α the effect of time duration
- $x_{ijt}^{(e)}$ are covariates at the individual level, and β is the effect of those covariates on the log odds of the transition
- $u_i^{(1)}, u_i^{(2)}, \cdots, u_i^{(E)}$ capture random effects of unobserved individual factors specific to each type of event.

The $mlogit$ command in Stata version 15.0[202] was used in finding out the relative risk for transiting upwardly, downwardly, remaining in overweight state, or obese state in comparison to remaining in the normal state.

2.4.3 Growth curve trajectory model

Repeated measures, panel or longitudinal data such as is produced in NiDS and BT20 samples can be used to study life course health outcomes in a population. A growth curve trajectory describes the evolution of an individua's characteristic over age or time.[203] Growth curve model (GCM) can be used for examining how individuals change on one (or more) observed outcome variable over time. In GCM repeated measurement of observed variables are used as indicators of latent variables that represent different aspects of individual's change.[204] A simple linear model in time takes the form:[205]

$$y_{ij} = \beta_{oi} + \beta_{1i}time_{ij} + r_{ij},$$

where i and j indexes person and measurement occasion, y_{ij} represents the outcome of interest (BPs). β_{oi} is the intercept for the BP trajectory for participant i, β_{1i} the slope of the trajectory for participant i per unit change in time, $time_{ij}$ the time corresponding to each measurement, and r_{ij}represents the random error or unexplained deviations from the trajectory for person i. The intercept (β_{oi}) and slope (β_{1i}) carry the person-level subscript i as they are assumed random and allowed to vary across participants.[206] In this PhD thesis, the results for Chapter 5 (Paper 3) were based on this model that defined a curvilinear growth form of the fourth degree (i.e. by including the quadratic, cubic and 4th degree

polynomial terms for $time_{ij}$.) This model was fit on the BP data using $'mixed'$ command in Stata SE Version 15.0.[202]

The developing of raised blood pressure and body mass index in a population may produce clustering of persons by groups that show decreasing, increasing or stable trajectories. A special case of the growth curve modelling tries to identify clusters of distinct developmental trajectories in a health or social outcome for a given population.[207] Interest lies in finding the distribution of an outcome conditional on age, or more specifically, the conditional probability distribution of an individual's BP trajectories denoted by $P(Y_i|Age_i)$ where Y_i and Age_i are the vectors of the repeated measurements of BP and age for individual i. Mathematically this is written as, $P(Y_i|Age_i, j;\ \beta^j) = \sum_{j=1}^{J} \pi^j P(Y_i|Age_i, j;\ \beta^j)$, where π^j is the probability of membership in group j and the unknown parameter β^j determines the shape of the group-specific trajectory. In this study, the censored normal distribution (Tobit model) was considered ideals since the repeated BP measurements were on a continuous scale which may be censored by either a scale minimum or maximum or both.[208]

Identifying distinct trajectories at different phases of life as well as examining the factors related to the trajectories is important for planning tailored and well-targeted health promotion strategies and interventions.[207] An extended analysis for objective 3 of the PhD study focussed on identifying groups of BP trajectories and how these trajectories were influenced by the time varying effect of BMI. The Stata's plugin module ($traj$)[209] was used in the identification of the groups. In the process for finding out the ideal number of groups of trajectories and the shapes of the trajectories, a null model with two groups was chosen as the starting point. This process was sequentially followed by improving model complexity using combinations of null, linear and polynomial terms and also by varying the number of groups. The command provides output for Walds test for the significance of model parameters, and Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC) for comparing the model differences.

2.5 Motivation for using NiDS and BT20 secondary data

The focus of the study was estimation of hypertension prevalence, blood pressure changes, and the transition rates between BMI categories. Unlike many studies in South Africa which concentrate in a single geographical setting at a single time point, this study looks at all the districts in the country simultaneously and at multiple times thus making it unique, also

given the use of advanced statistical methods of multilevel and panel data estimation methods. In addition, each added panel/wave of both the NiDS and BT20 data used in this study potentially introduces new information, which needs to be understood, and this is in line with the data mining paradigm for knowledge discovery that builds up as databases grows.[210] The analyses used in the study have not specifically been applied to the two datasets in answering the research questions stated in this study.

The NiDS data at various waves has been used in hypertension and BMI related research. BMI work includes estimation of the average rate of change using the first 3 waves of data,[211] and assessment of how food choices and measured BMI relates to people's self-perceived health status using the 2014/15 wave data.[212] Other studies have looked at how BP varied seasonally and how it differs by socioeconomic standards.[213, 214]

Some of the studies done using the BT20 data for mothers and caregivers include assessment of self-reported physical activity patterns and association with anthropometric measures and metabolic outcomes,[215] and comparison of how "risk factors for cardiovascular diseases and type 2 diabetes differed by levels of physically activity."[216] Other studies have aimed to propose an acceptable cut-off point for determining metabolic disorders,[217] and how a combination of "body composition measures relate with blood pressure (BP) and incident hypertension."[218]

2.6 Ethical considerations

Ethical approval (M170866) was granted by The Human Research and Ethics Committee (HREC) of the University of the Witwatersrand, Johannesburg. The research involves no direct health risk to either the NiDS or BTT20 survey respondents or any risk of regarding diffusion of personal details since no personal identifiers are provided to the publicly availed data.

SECTION 2: EMPIRICAL CHAPTERS

"The doctor of the future will give no medicine, but will instruct his patients in care of the human frame, in diet, and in the cause and prevention of disease." Thomas Edison

CHAPTER 3: PAPER 1

Wandai ME, Norris SA, Aagaard-Hansen J, Manda SO. Geographical influence on the distribution of the prevalence of hypertension in South Africa: a multilevel analysis. *Cardiovasc J Afr. 2020;31(1):47-54*.

Abstract

Background: As a response to the growing burden of non-communicable diseases, the South African government has set targets to reduce the prevalence of people with raised blood pressure, through lifestyle changes and medication, by 20% by the year 2020. It has also recognised that the prevalence varies at local administrative level. The study aim was to determine the geographical variation by district of the prevalence of hypertension among South African adults aged 15 years and above.

Methods: Data from all five waves of the National income Dynamics Study, a panel survey, were used for estimation by both design-based and multilevel analysis methods. In the multilevel analysis, a three-level hierarchy was used with repeated measurements in the first level, on participants in the second level, and districts in the third level.

Results: After accounting for demographic, behavioural, socio-economic and environmental factors, significant variation remained in the prevalence of hypertension at the district level. Districts with higher-than-average prevalence were found mostly in the south-western part of the country, while those with a prevalence below average were found in the northern area. Age, body mass index and race/population group were the individual factors found to have a strong effect on hypertension prevalence for this sample.

Conclusions: There were significant differences in hypertension prevalence between districts and therefore the method of analysis and the results could be useful for more targeted preventative and control programmes.

Keywords: district variability; hypertension prevalence; multilevel analysis; random effects.

3.1 Background

Hypertension is a major risk factor and consistent predictor for cardiovascular diseases such as coronary heart disease, stroke, transient ischemic attack, and congestive heart failure.[7, 8] A study based on data from the 36-year follow-up Framingham Study pointed out the urgent need for primary prevention of hypertension by addressing associated risk factors through weight control, exercise, and reduced salt and alcohol intake.[219] In 2015, global age-standardised prevalence of raised blood pressure was estimated to be 24·1% (21·4-27·1) of men and 20·1% (17·8-22·5) of women. The number of adults with raised blood pressure having increased from 594 million in 1975 to 1·13 billion in 2015, with the increase largely in low-income and middle-income countries (LMIC).[135] According to the 2012 South African National Health and Nutritional Examination Survey (SANHANES), prevalence of hypertension was approximately 26.0%,[76] and the 2016 Demographic Health Survey estimated the prevalence to be 46.0% and 44.0% for women and men respectively.[15] A number of studies have reported higher than global average prevalences in the LMIC,[220-222] and this has been attributed to non-compliance with treatment, urbanisation, population ageing and behavioural risk factors including tobacco and alcohol use, poor diet and physical inactivity.[220, 222, 223]

In 2013, the South African National Department of Health (NDoH) developed a Strategic Plan for the Prevention and Control of Non-Communicable Diseases, which targets to reduce the prevalence of people with raised blood pressure by 20% by the year 2020, through lifestyle and medication.[29] While prevalence has been estimated at both the provincial and national levels, little is known on the prevalence of hypertension at levels below the province due to limited data that can reliably be used for estimation.

In South Africa, existing surveillance and estimation of hypertension and other NCD related risk factors are overwhelmingly focused at the first (national) or second (provincial) level geographies,[76, 77, 224, 225] but gaining a better understanding of variations at the finer resolutions (district level in particular) could be important in decision making for improving the effectiveness and efficiency in the response to hypertension. While efforts have been made to estimate hypertension prevalence at the district level, the method used has fallen short as it does not account for factors that are known to be associated with the prevalence. In one study, district-based prevalence of cardiovascular comorbidities, including hypertension were estimated using an outdated dataset (1998 South African Demographic

Health Survey(SADHS)).[226] National prevalence of disease can conceal important differences in prevalence in subnational areas.[227] In most high-income countries (HICs) where data are available to finer geographies such as counties, NCD related studies have shown existing substantial heterogeneity in the prevalence of these diseases and associated risk factors between sub-regions within a country.[141, 228, 229]

The aim of this study was therefore to profile the variations in hypertension prevalence between districts in South Africa after controlling for the individual's demographic, social, economic, behavioural, and environmental variables.

3.2 Methods

3.2.1 Data source

The 2008, 2010/11, 2012, 2014/15 and 2017 samples for individuals aged 15 years and above from the National income Dynamics Study (NiDS) panel survey were used in the study. The survey provides a large nationally representative sample that is stratified by the country's 52 districts.

3.2.2 Population and sample

The target population is composed of individuals, 15 years and above, in private households and residents in workers' hostels, convents and monasteries, but excludes other living quarters such as students' hostels, old age homes, hospitals, prisons and military barracks. The sampling technique employed in panel study is exhaustively discussed elsewhere.[188] The sample retained for the study includes respondents who had at least two BP measurements taken at the time of the survey.

3.2.3 Outcome variable

The outcome of interest was hypertension prevalence for individuals with systolic/diastolic BP of more than 140/90 mmHg or on medication for hypertension. BP measurements for each panel were taken twice from each survey respondent. Valid BP measurements were determined according to previously applied criterion[225, 230] as follows: 1) if the second systolic or diastolic BP differed by more than 5 mmHg, the first BP reading was excluded; and 2) a set of BP readings (systolic and diastolic) was retained in the data set if the systolic BP was 80 mmHg or larger AND if the systolic BP was at least 15mmHg larger than the diastolic

BP level. A final systolic/diastolic blood pressure was calculated as the average of the valid blood pressure measurements.

Table 3.1: Sample by wave for participants 15 years and above (South Africa)

Wave	Valid hypertension data	Total sample	Percentage valid
2008	14 135	18 617	75.9
2010/11	15 128	21 943	68.9
2012	18 393	25 228	72.9
2014/15	22 526	28 460	79.1
2017	23 605	32 123	73.5
Total	**93 787**	**126 371**	**74.2**

3.2.4 Explanatory (risk factors) variables

Several factors known to be associated with hypertension and recorded in the NiDS data were adjusted for in estimating the prevalence of hypertension using the multilevel logistic regression. Important factors at the individual level were demographic factors age, gender and population group (self-identification as African, Coloured, White, Asian/Indian); biological factor (specifically BMI); behavioural factors alcohol use (Never used and past/current user), smoking status (Never and Past/current) and physical exercise (None or some exercises); social and economic factors education level (≤Primary school, High school, and post high school), employment status (Employed, Unemployed or economically inactive), medical cover status (membership subscription to a registered medical aid provider), residency type (urban and Traditional/Farms), and income tertile calculated from equivalised per capita household income (household income divided by square root of number of people in household); and one environmental factor, the season (Summer, Autumn, Winter and Spring) when the BP measurements were taken. Subjects self-identifying as Whites or Indians/Asians were combined in the analysis as they had relatively smaller sample sizes. The alcohol use variable was not available for wave 5 (2017), and so the last observed status (from previous waves) was used or indicated as unknown if subject was not in previous waves.

3.2.5 Statistical Analysis

The prevalence of hypertension was estimated using the following two statistical methods reporting results at the district level.

Design-based analysis

Design based estimates using the survey's post-stratification weights. This first step of the analysis was to estimate the prevalence of hypertension nationally and by the levels of each explanatory variable on univariate basis, followed by the estimation of the prevalence by districts.

Multilevel analysis model

A three-level multilevel analysis model where periodic (survey waves or the repeated measurements) hypertension statuses (first level) are nested in individual respondents (second level) nested within districts (third level). The risk factors listed above were adjusted for in the model. On the basis of population group, Caucasians and Asians were combined due to relatively small sample sizes especially for Asians and referred in this analysis as 'Other' population groups.

1. ***Level-specific distribution of hypertension variance***. This step aimed at estimating the distribution of the hypertension prevalence variance between the three levels, and the proportion of variance explained by the individual-level demographic, behavioural and socio-economic risk factors. This involved first fitting a multilevel model without the covariates (a null model), which allowed partitioning the variance between the hierarchical levels. This was followed by constructing a full model that adjusted for the risk factors (covariates) stated above. The variance structure was described by the variance partition coefficient (VPC) and the level-specific change in variance ($\Delta\sigma^2$). The VPC measures the proportion of variance explained by each level within the model and the level-specific change in variance measures the proportion of change in variance for each level between the null and the adjusted model. Taken together, these two measures describe how much of the variation is explained by the variables included in the model.
2. ***Association of hypertension prevalence with individual-level risk factors.*** Using the fully adjusted model, odds ratios and p-values were calculated for each risk factor in the model.
3. ***Estimation of adjusted hypertension prevalence at the district units***. This involved using the predicted individual probability for hypertension in estimating the

prevalence at district-level. The estimated prevalences and 95% CI for each district unit were graphically presented to profile districts. This procedure allowed a visualization of which units are significantly different from the national prevalence. Low or excess hypertension risk was also presented spatially to show the clustering of districts with either lower or higher than average hypertension prevalence. Further analysis was done allowing for hypertension prevalence to vary by age and BMI at the geographic (district) level. This analysis was used to graphically identify units with relatively steeper slopes by age and BMI.

All analyses were performed using Stata version 15.[202] For design-based prevalence estimates, the 'svy: tab' command for two-way tabulation was used, while the mixed effect logit (melogit) command was used for the multilevel analysis. The 'tmap' (Thematic maps) package[231] in the R Foundation for Statistical Computing platform was used to draw the map.

3.3 Results

3.3.1 Design-based (unadjusted) prevalence of hypertension

The univariate (weighted) analysis (Table 3.2) show a decreased trend in hypertension prevalence, except for a slight increase in 2012 period. On a period-by-period basis the prevalence of hypertension in females was higher than that of males. Age, BMI status and education level had the highest differentials with those relatively older (40+ years) having a prevalence that is about 4 times that of the younger adults (<40 years), and those whose BMI is 25 Kg/M^2 or above (overweight or obese) having a prevalence almost double that of those with a BMI less than 25 Kg/M^2 (normal weight). Subjects who had primary level education or no education had significantly higher prevalence compared to those with relatively higher education levels, and those who were unemployed had lower prevalence compared with the employed and economically inactive. Those of African background had lower prevalence compared with the other population groups. Urban dweller, and those who had a medical aid, or engaged in no physical exercise, or had ever smoked, or had ever used alcohol, or whose BP measurements were taken in winter had hypertension prevalences higher than their respective counterparts. Those who were higher in the income band had prevalences significantly higher than those in the lower income level.

Table 3.2: Percentage [95% confidence intervals] of hypertension by covariate and period (South Africa)

Characteristic	2008	2010/11	2012	2014/15	2017	Average (all)
Gender						
Female	33.7 [31.7,35.7]	31.9 [30.2,33.7]	33.5 [31.8,35.2]	29.4 [27.8,31.0]	28.5 [27.1,29.9]	31.2 [30.1,32.4]
Male	28.7 [26.5,30.9]	27.8 [25.5,30.2]	30.4 [28.0,32.9]	26.8 [24.7,28.9]	27.3 [25.6,29.1]	28.1 [26.5,29.8]
Age group						
≤40 years	16.4 [14.8,18.1]	16.0 [14.6,17.5]	17.3 [15.8,18.9]	13.8 [12.4,15.4]	13.9 [12.8,15.0]	15.3 [14.4,16.3]
>40 years	58.0 [55.5,60.4]	55.0 [52.6,57.3]	57.2 [54.8,59.5]	53.0 [51.0,55.0]	52.7 [50.6,54.7]	55.0 [53.5,56.4]
Race/population group						
African	29.2 [27.5,30.9]	28.2 [26.8,29.6]	30.0 [28.3,31.7]	25.6 [24.4,26.9]	25.4 [24.3,26.6]	27.5 [26.5,28.5]
Mixed ancestry	41.7 [37.4,46.1]	41.1 [35.1,47.3]	40.2 [34.7,45.9]	39.3 [35.8,42.8]	38.3 [34.3,42.5]	39.9 [36.2,43.7]
Asian/Caucasian	40.6 [35.8,45.7]	35.7 [29.0,43.1]	40.1 [35.1,45.4]	36.5 [29.5,44.2]	39.9 [35.7,44.3]	38.6 [34.7,42.6]
Residency						
Urban	33.4 [31.2,35.6]	32.6 [30.6,34.7]	33.0 [30.8,35.2]	29.5 [27.5,31.6]	29.3 [27.8,30.9]	31.3 [29.9,32.7]
Traditional/Farms	28.8 [26.8,30.9]	26.2 [24.6,27.9]	30.6 [28.6,32.7]	25.9 [24.5,27.3]	25.2 [23.8,26.7]	27.3 [26.2,28.5]
Education level						
≤Primary	46.1 [43.4,48.8]	45.3 [43.1,47.6]	48.9 [46.3,51.4]	48.1 [45.9,50.3]	47.9 [45.5,50.4]	47.2 [45.4,49.0]
High school	24.7 [22.6,26.8]	23.4 [21.6,25.3]	25.6 [23.6,27.8]	21.5 [19.7,23.4]	21.5 [20.1,23.0]	23.2 [21.8,24.7]
Cert/Dip/Bachelors+	28.1 [24.6,31.9]	28.3 [24.1,32.9]	31.0 [27.8,34.5]	26.8 [24.0,29.9]	29.4 [27.1,31.8]	28.7 [26.8,30.7]
Income tertile						
Low	29.1 [27.3,31.0]	27.3 [25.7,28.9]	28.7 [26.5,30.9]	24.4 [22.5,26.4]	23.5 [20.6,26.7]	27.3 [26.1,28.5]
Medium	33.3 [30.7,36.0]	31.8 [29.4,34.3]	32.4 [30.4,34.4]	27.7 [25.9,29.6]	26.1 [24.6,27.6]	29.9 [28.6,31.2]
High	34.3 [31.3,37.4]	32.0 [29.1,35.0]	34.4 [31.8,37.1]	29.8 [27.7,32.0]	29.8 [28.3,31.3]	31.4 [29.9,32.9]
Employment status						
Employed	32.8 [30.6,35.1]	31.4 [28.8,34.2]	32.9 [30.7,35.2]	28.6 [26.6,30.7]	27.8 [26.2,29.4]	30.3 [29.0,31.8]
Unemployed	24.4 [21.8,27.1]	23.1 [19.9,26.7]	23.4 [20.6,26.5]	19.8 [16.8,23.1]	19.9 [17.4,22.7]	22.2 [20.6,23.9]
Economically inactive	33.8 [31.3,36.3]	31.2 [29.5,33.0]	34.6 [32.5,36.7]	30.3 [28.5,32.1]	30.4 [28.8,32.1]	31.9 [30.5,33.3]
Medical aid						
Yes	35.7 [31.3,40.4]	31.7 [26.7,37.2]	36.8 [32.7,41.0]	33.2 [28.9,37.9]	33.3 [30.0,36.7]	29.0 [28.0,30.1]
No	30.8 [29.2,32.5]	29.7 [28.3,31.2]	31.3 [29.7,32.9]	27.2 [25.9,28.6]	26.9 [25.7,28.2]	34.1 [31.4,36.9]
BMI						
Below overweight	21.5 [19.7,23.3]	20.1 [18.5,21.7]	21.2 [19.4,23.1]	16.8 [15.4,18.2]	17.1 [15.8,18.5]	19.1 [18.1,20.2]
Overweight/Obese	40.7 [38.5,42.9]	38.7 [36.7,40.8]	41.9 [39.7,44.0]	38.6 [36.6,40.7]	38.2 [36.6,39.7]	39.5 [38.2,40.9]
Never exercise	34.2 [32.5,36.0]	32.2 [30.5,33.9]	34.0 [32.3,35.8]	31.1 [29.5,32.6]	30.7 [29.4,32.1]	32.3 [31.3,33.4]
Some exercise	26.7 [24.0,29.5]	25.4 [22.7,28.4]	27.8 [24.9,30.8]	23.1 [20.8,25.6]	22.8 [21.1,24.5]	24.9 [23.2,26.7]
Alcohol use						
Yes	34.1 [31.5,36.9]	30.5 [27.4,33.8]	33.3 [30.7,36.0]	29.8 [27.4,32.3]	30.3 [27.7,33.0]	29.5 [28.3,30.8]
No	30.6 [28.8,32.4]	29.9 [28.3,31.5]	31.6 [29.9,33.3]	27.3 [25.9,28.9]	28.4 [27.0,29.8]	31.4 [29.7,33.2]
Unknown	-	-	-	-	23.5 [21.2,26.0]	23.5 [21.2,26.0]
Smoking status						
Never smoked	30.6 [29.0,32.3]	29.2 [27.7,30.8]	31.0 [29.3,32.7]	26.7 [25.3,28.2]	26.9 [25.7,28.1]	28.7 [27.7,29.8]
Ever smoked	33.9 [31.2,36.7]	33.2 [29.8,36.9]	35.9 [32.2,39.8]	32.3 [29.2,35.6]	30.9 [28.6,33.4]	33.1 [31.0,35.3]

Characteristic	2008	2010/11	2012	2014/15	2017	Average (all)
Season of BP measurement						
Summer	29.3 [26.8,31.8]	24.4 [21.3,27.8]	25.3 [20.4,30.9]	25.4 [24.0,26.9]	24.7 [23.0,26.5]	26.1 [25.0,27.3]
Winter	35.8 [32.8,39.0]	31.9 [29.8,34.1]	32.9 [30.7,35.2]	32.2 [27.9,36.8]	31.3 [29.2,33.4]	32.5 [31.2,33.9]
Autumn/Spring	32.2 [29.7,34.9]	28.8 [26.6,31.2]	31.6 [29.4,33.9]	30.5 [27.9,33.3]	29.0 [27.1,30.9]	30.4 [29.0,31.8]
All	**31.5 [29.9,33.1]**	**30.0 [28.6,31.5]**	**32.1 [30.5,33.8]**	**28.2 [26.8,29.6]**	**27.9 [26.7,29.1]**	**29.8 [28.7,30.9]**

Figure 3.1 shows the unadjusted weighted hypertension prevalence and 95% confidence interval for SA districts. The average national prevalence was 29.8% (95% confidence interval 28.7%-30.9%: green band). Approximately 8 districts show a prevalence that is lower than that of the national, while about 16 districts show a prevalence that is significantly higher than that at the national level. These estimates though are imprecise as characterised by the large confidence intervals. Except for A Nzo and OR Tambo (both in the Eastern Cape Province), the districts with lower-than-average prevalence are found in the north-eastern provinces of Limpopo and Mpumalanga. By contrast, the districts with higher prevalence than average are from the Western Cape and Northern Cape provinces. In between these two extremes lies majority of the districts whose prevalence is approximately equal the average. The districts are mostly found in KwaZulu-Natal, Gauteng, parts of Free State and Eastern Cape, and North West provinces.

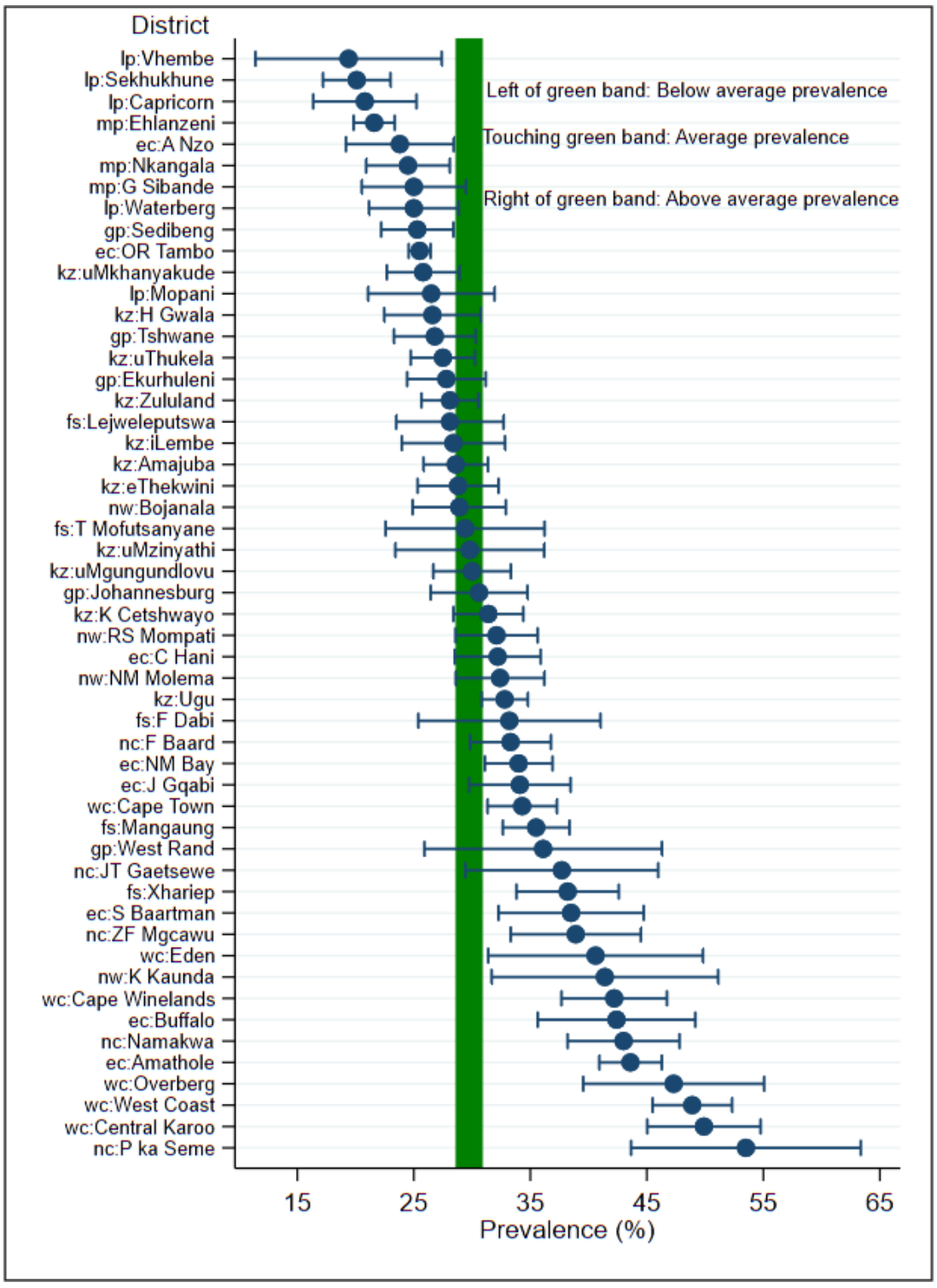


Figure 3.1: Design based hypertension prevalence rates by districts in South Africa

3.3.2 Factors associated with hypertension

After accounting for other factors, the greatest effect on hypertension was shown to be basically from the demographic factors of age and race/ethnicity, where the odds ratio is approximately 5.5 times more for every 5 years increase in age, while the Coloured and

Black African populations respectively are about 2.5 and 1.5 times more likely to be hypertensive compared with other population groups (Whites and Asians.) Other factors associated with hypertension prevalence were BMI (OR=2.29, p=0.001 for those with BMI at least 25.0 Kg/M^2), alcohol use (OR=1.25, p<0.001), season (OR=1.33, p<0.001 for winter vs. Autumn/Spring) and residency (urban vs. traditional/ farm, OR=1.12, p<=0.011). Adjusted prevalence was more likely to be lower for females compared with males and decreased with level of education. Medical aid and smoking status were not found significant predictor of hypertension prevalence for these samples.

Table 3.3: Fixed and random effects associated with hypertension prevalence (South Africa)

Factor	**Category**	**Odds ratio (95% CI)**	**p-value**
Period/year (vs. 2008)	2010/11	0.72 (0.66-0.78)	0.000
	2012	0.81 (0.75-0.88)	0.000
	2014/15	0.75 (0.70-0.81)	0.000
	2017	0.64 (0.59-0.70)	0.000
Gender (vs. Male)	Female	0.86 (0.80-0.92)	0.000
Age	Age	1.11 (1.10-1.11)	0.000
Race/ethnicity (vs. Asian/Caucasian)	African	1.52 (1.30-1.78)	0.000
	Mixed ancestry	2.56 (2.13-3.07)	0.000
Residency (vs. Traditional/Farms)	Urban	1.12 (1.03-1.22)	0.011
Education level (vs. Pry &below)	High school	0.86 (0.80-0.93)	0.000
	Cert/Dip/Bachelors+	0.76 (0.68-0.84)	0.000
Income tertile (vs. Low)	Medium	0.90 (0.85-0.96)	0.001
	High	0.96 (0.89-1.03)	0.231
Employment status (vs. Employed)	Unemployed	0.97 (0.90-1.04)	0.375
	Economically inactive	0.93 (0.87-0.99)	0.014
Has Medical aid	Yes	1.01 (0.91-1.11)	0.861
BMI (vs. ≤Normal weight))	Overweight/obesity (≥25)	2.29 (2.16-2.42)	0.000
Physical exercise (vs. No exercise)	Some exercise	0.98 (0.92-1.03)	0.438
Alcohol use (vs. Never used)	Yes	1.25 (1.17-1.33)	0.000
	Unknown	1.06 (0.93-1.20)	0.384
Smoking status (vs. Never smoked)	Ever smoked	1.00 (0.93-1.08)	0.920
Season (vs. Autumn/Spring)	Summer	0.80 (0.76-0.85)	0.000
	Winter	1.33 (1.26-1.40)	0.000
Random effects	District	0.11 (0.07-0.18)	
	Individual	3.32 (3.13-3.51)	

3.3.3 Hypertension variance

Table 3.4 presents the distribution of variance at the individual and district levels. Most of the variance for both the unadjusted and adjusted models is at the individual level. The variance partition coefficient (VPC) shows the proportion of hypertension prevalence variation at the district level to be 3.5%. When adjusting for the explanatory variables, about 1.9% (3.5-1.6%) of the variance in the higher level (district) is explained by the geographic distribution of demographic, behavioural, socio-economic and environmental factors.

Table 3.4: Variance partition and specific-level change in variance between the null and the adjusted model

Variance component	**Null model: Variance (SE)**	**Adjusted model: Variance (SE)**	**Change in variance ($\Delta\sigma^2$)**
Individual	8.47 (0 .224)	3.32 (0.0963)	-60.8%
District	0.430 (0.082)	0.110 (0.026)	-74.4%
Individual VPC	69.4%	49.4%	
Geographic VPC	3.5%	1.6%	

The level 1 variance (within individuals' observation) is the fixed value 3.29 ($\pi^2/3$), which is the value assigned for a multilevel logistic regression.

3.3.4 Adjusted prevalence at the district level

The risk factor adjusted prevalence estimates unlike the unadjusted (weighted) prevalences had narrower confidence intervals, and only about 10 districts had prevalences approximately equal the average prevalence. A common scenario under both estimation methods is that most of districts with lower-than-average prevalences were found in the northern and north-eastern part of the country (Figure 3.1, Figure 3.2 & Figure 3.3), while those with higher-than-average prevalence were mostly in the south and south western parts of the country (The 'Cape' provinces). All the districts in the Western Cape, except Cape Town, and all the provinces in Northern Cape except Frances Baard had prevalences above average. All districts in Limpopo, Mpumalanga and Gauteng had prevalence below average.

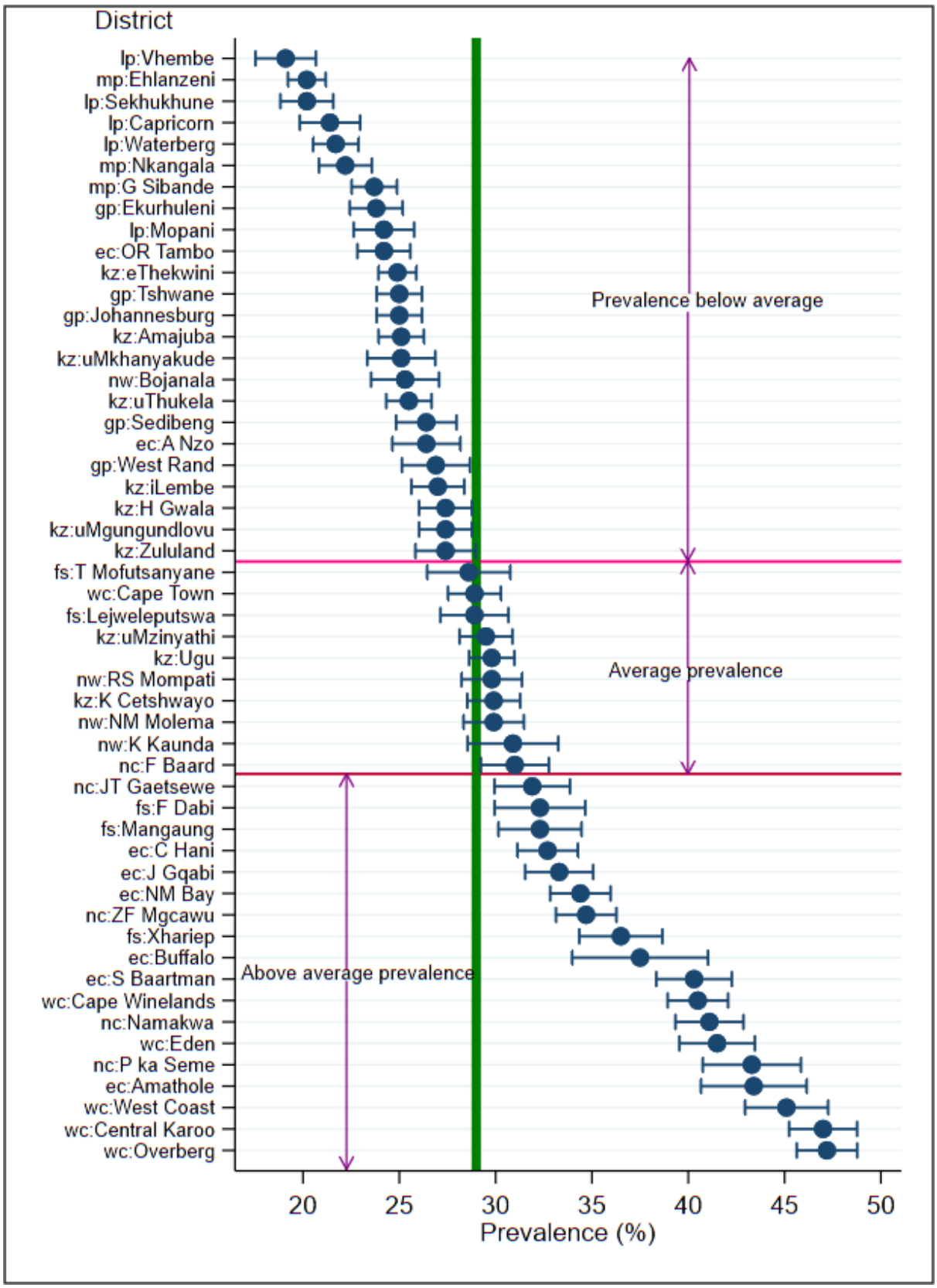


Figure 3.2: Mean difference in hypertension prevalence and 95% confidence interval for SA districts (Adjusted model)

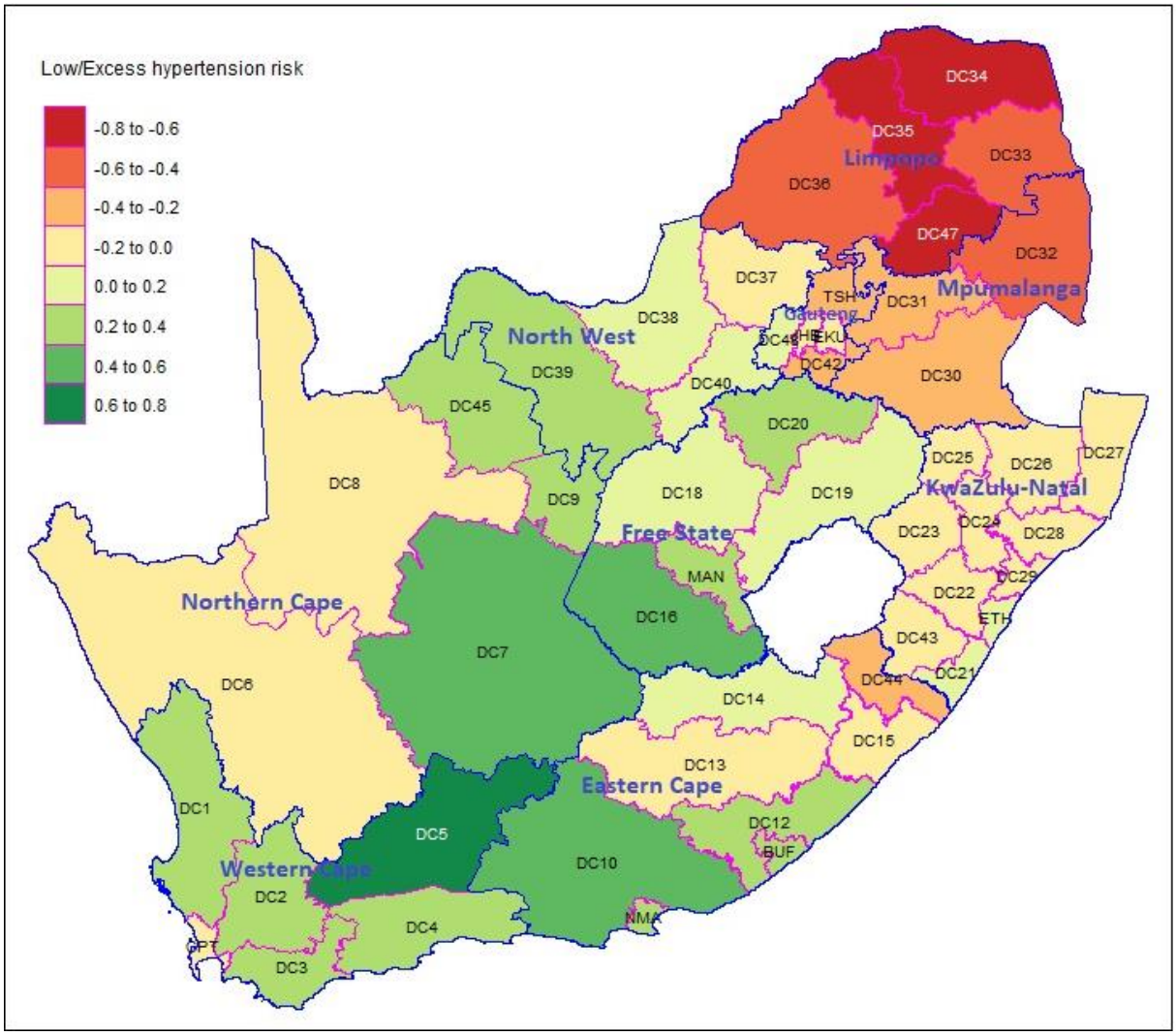


Figure 3.3: Spatial clustering of hypertension prevalence by districts

3.3.5 Random district slopes for age and BMI

The effect of age for some districts is lower (districts whose slopes below the red horizontal line in Figure 3.4) than its overall effect. These districts include all in Limpopo Province, and most of those in Kwa-Zulu Natal and Eastern Cape. The effect of BMI is relatively stronger in most of districts in Limpopo, Free State, Northern Cape and Kwa-Zulu Natal, and least for most districts in the Eastern Cape.

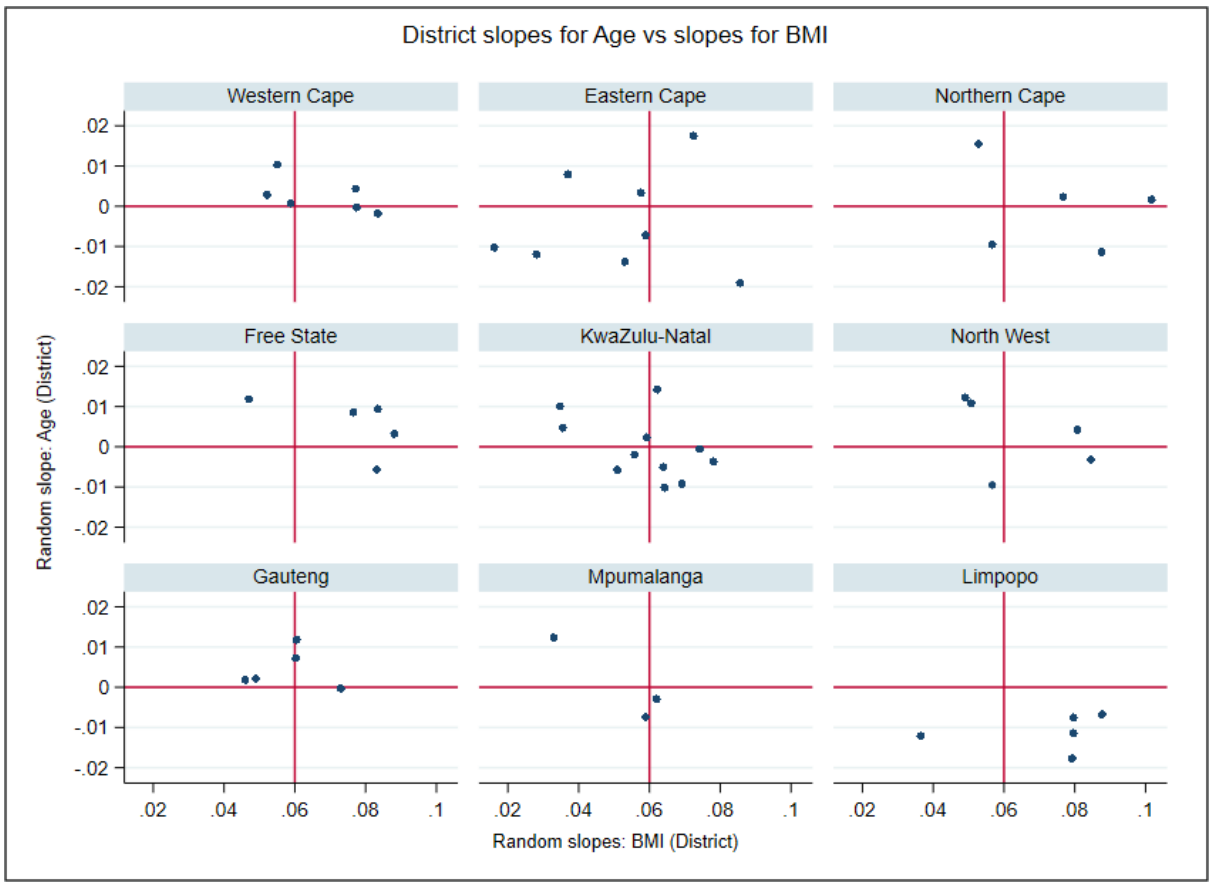


Figure 3.4: Scatter plot for districts' random slopes for age and BMI

3.4 Discussion

The purpose of this study was to analyse the degree of hypertension prevalence variation for adults aged 15 years and above, at the district level, before and after adjusting for risk factors associated with hypertension. According to the results of the multilevel model, factors that explained variation in hypertension status in this study were found consistent in certain aspects with previous research. For example, age and BMI the two strongest factors affecting hypertension prevalence in this study have been so found in other studies.[148, 232-235] The effect of gender on hypertension has been conflicting with some studies showing weak association with females have chances of lower prevalence than males,[234-236] while other have showed no association.[148, 233, 237] The results in the multivariate analysis in this study showed that women have lower hypertension prevalence compared with men.
Alcohol use (past or current) has also been found to increase risk of hypertension in some studies,[103, 233, 238] while in another study no relationship was found.[234] Smoking status, education, and employment status have also given conflicting results from various studies.[148, 234] The mixed ancestry and Africans were found in the multilevel logistic

regression to have increased prevalence of hypertension compared with Asians/Caucasians. This is consistent with a study done in the United States of America where there are such groups of mixed ancestry.[239] The univariate analysis showed that prevalence for those who had subscription to a medical aid provider was higher compared with those without medical aid, but the multivariate analysis showed no association. This is possibly because its confounding effect was reduced by income level and education. The percentage of those subscribed to a medical aid cover increased with higher income and education.

The study also found seasonal effects with the odds of increased hypertension prevalence being higher in the winter months compared with the summer. This is consistent with other studies that have shown cold ambient temperatures to be associated with elevated blood pressure, [240-243] and therefore the effect has also been found to be larger in winters than in summers.[213, 244, 245]

Analyses of variance at the individual and district levels showed differences in the hypertension prevalence variance distribution at the higher level (district), with a variance partition coefficient (VPC) of 3.8% and 2.1% for the null and the risk-factor adjusted models respectively. After adjusting for the effect of the risk-factors, the level-specific change in variance ($\Delta\sigma^2$) was equally important at both the individual and district levels. This implies that the risk factors were unequally distributed between the individuals and between districts. This could possibly be the reason for the difference in race/ethnicity-wise results between the unadjusted and the adjusted estimates. The unadjusted prevalence showed that prevalence was highest in Asian/Caucasians, followed by the mixed ancestry and lowest in Africans, while the adjusted estimates showed lower chances of hypertension in Asians/Caucasians. This most likely was due to reduced confounding effect of age whose average was highest in Asians/Caucasians, followed by the mixed ancestry and lowest for Africans. A previous study had found age-standardised self-reported hypertension to be highest in mixed ancestry women followed by African women.[158]

There are important geographic variations in hypertension prevalence between districts in South Africa even after controlling for socio-demographic and behavioural background factors. Districts with lower-than-average prevalence were mostly in the North-Eastern part of the country (Limpopo, Mpumalanga, and Gauteng provinces) while those with higher-than-average prevalence are mostly found in Western, Eastern and Northern Capes provinces. Most of these districts are coastal districts that neighbour the Atlantic Ocean or are in close vicinity to the Atlantic Ocean. A previous study that limited geographic variation

of hypertension to provincial level had found similar clustering of hypertension prevalence.[232]

Identifying districts (sub-units) with high and low hypertension prevalence could be useful in programming public health interventions. Districts with high hypertension burden could be considered for targeted prevention and control program rather than one for all national intervention program. As governments especially in the Low- and Middle-Income Countries (LMICs) are faced with multiple needs and limited resources, their role of ensuring that all people have equitable access to the preventive, curative and rehabilitative health services they need to prevent them developing hypertension and its complications is critical.[246-248]

Our study has shown that, although majority of South African districts have approximately the same burden of hypertension, some have a heavier burden than others, even after accounting for risk factors documented to have a strong influence on hypertension prevalence.

The effects of age and BMI on hypertension prevalence were found to vary from district to district, whereby their slopes were higher in some districts relative to others. Health services that address the risks of hypertension, for example, body mass should more target such areas.

3.5 Conclusions

The results from this study shows that there are significant differences in the prevalence of hypertension at the district level. The districts with higher-than-average prevalence appear to be clustered together as are those with lower-than-average prevalence. An implication of these results is that there could still be other risk factors, not captured in the data, that are associated with hypertension prevalence, and which are also distributed unequally between the districts. Still, it could be that there are differentials at the clusters of districts in the prevention, management and control of hypertension. Effective management, even without complete control could imply people living longer with the condition, thereby increasing prevalence. On the other hand, districts with low prevalence could indicate poor management which could result in hypertensive related deaths. Alternatively, low prevalence could also be a result of low incidence rates or effective prevention and control interventions. These could be issues for further and related research and in particular an examination of the impact of district level covariates (factors).

3.6 Strengths and limitations

To the best of our knowledge this is the only study to have estimated the prevalence of hypertension at the district level, taking into consideration the associated risk factors. The study, however, has a few limitations. First, while the study sample is big enough to allow credible estimates of hypertension at the national level, the samples at the district level were not large enough and this resulted in wide confidence intervals for the estimated prevalence rates. Secondly, although in the present study we adjusted for seasonal variation when the BP measurements were taken for each subject, it was not possible to fully adjust for ambient temperatures since the measurements were not available in our data set. Thirdly, although we adjusted for race/ethnicity in the analysis, it is good to understand that it is possible that there could be differences accountable by difference within the same race/ethnic group especially for the Africans who are also characterised by differences by tribes. The dataset did not have details on ethnicity or tribe. Few studies in sub-Saharan Africa (SSA) have shown variability of hypertension by ethnicity. In Nigeria, prevalence of hypertension was found to differ significantly by ethnicity after adjusting for age, gender, place of residence and socio-economic status.[249] Similarly, some evidence of ethnic variation has been reported in Kenya where statistically significant differences between ethnic groups were reported after adjusting for socio-demographic and other cardiovascular risk factors,[250] but a study from Nigeria and Cameroon did not find any association of hypertension with ethnicity.[251] It may be interesting to analyse other aspects of diet and cultural differences in food intake, such as salt and sugar consumption, both of which were not available in our dataset, and are known for their high influence on hypertension.

CHAPTER 4: PAPER 2

Muchiri E Wandai, Jens Aagaard-Hansen, Samuel OM Manda & Shane A Norris. Transitions between body mass index categories, South Africa. *Bulletin of the World Health Organization 2020; 98:878-885I. doi: http://dx.doi.org/10.2471/BLT.20.255703* (Submitted: 18 March 2020 – Revised version received: 31 August 2020 – Accepted: 31 August 2020 – Published online: 28 September 2020)

Abstract

Objective To profile the prevalence of the three-category body mass index (BMI) classification by sociodemographic characteristics, and to calculate the percentage transitioning (or not) from one BMI category to another, to inform South African health policy for the control of obesity and noncommunicable diseases.

Methods We used data from the National Income Dynamics Study, including sociodemographic characteristics and BMI measurements collected in 2008, 2010, 2012, 2014 and 2017. For each data collection wave and each population group, we calculated mean BMI and prevalence by category. We also calculated the percentage making an upwards transition (e.g. from overweight to obese), a downwards transition or remaining within a particular category. We used a multinomial logistic regression model to estimate transition likelihood.

Findings Between 2008 and 2017, mean BMI increased by 2.3 kg/m2. We calculated an increased prevalence of obesity from 19.7% (3686/18 679) to 23.6% (3412/14 463), with the largest increases in prevalence for those aged 19–24 years and those with at least high school education. The percentages of upwards transitions to overweight or obese categories increased sharply between the ages of 19 and 50 years. Once overweight or obese, the likelihood of transitioning to a normal BMI is low, particularly for women, those of higher age groups, and those with a higher income and a higher level of education.

Conclusion In the development of national strategies to control obesity and noncommunicable diseases, our results will allow limited public health resources to be focused on the relevant population groups.

4.1 Introduction

The mean body mass index (BMI) of the African population is increasing,[252] resulting in a steady rise of the prevalence of people being overweight or obese across Africa, with the southern part of Africa being most affected.[252, 253] In 2016, the prevalence of the population aged ≥ 15 years being overweight or obese in South Africa was 68% for women and 31% for men.[15]

Global efforts to combat obesity include the World Health Organization (WHO) Global Strategy on Diet, Physical Activity and Health,[254] the Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013–2020[4] and the United Nations (UN) High-level Meetings of the General Assembly on Prevention and Control of Non-communicable Diseases. [255, 256] The Global Action Plan proposes the promotion of healthy diets by Member States to halt the rise in the prevalence of school children, adolescents and adults being overweight or obese. Similarly, the 2011 Sixty-sixth session of the UN Political Declaration of the High-level Meeting of the General Assembly on the Prevention and Control of Non-communicable Diseases committed to strengthening national policies and health systems by promoting multisectoral and multi-stakeholder engagement to reverse, stop and decrease the rising trends of obesity in child, youth and adult populations.[255] In line with global strategies and policies, the South African Department of Health developed the Strategic Plan for the Prevention and Control of Non-communicable Diseases 2013–2017[29] and the Strategic Plan for the Prevention and Control of Obesity 2015–2020;[64] the targets of these strategic plans were to reduce obesity prevalence by 3% by 2017 and by 10% by 2020 in all age groups. These two strategic plans are aligned with the agenda of the country's 2030 National Development Plan for the promotion of healthy diets and physical activity at schools, workplaces and in the general community.[257]

Promotion and support through research is an essential component of global and national strategies for prevention and control of obesity and noncommunicable diseases.[4, 29, 64, 254] We anticipate that a better understanding of transitions between the BMI categories – normal, overweight and obese (Table 4.1)[258] – will allow the improvement of interventions to reduce the prevalence of obesity. Our objectives are: (i) to profile the prevalence of the three BMI categories within a study population according to various sociodemographic characteristics, and to estimate the percentage of these population groups that underwent

transitions (or not) between BMI categories; (ii) to identify the factors associated with transitions between BMI categories; and (iii) to discuss the key public health implications of our findings for national obesity control strategies.

4.2 Methods

4.2.1 Study population

The National Income Dynamics Study, first conducted in 2008, is a nationally representative panel study that collects information on a wide variety of social, demographic, economic and health characteristics of the civilian non-institutionalized population.[188] We used data from the five completed waves of the panel survey (the subsequent four waves were conducted in 2010, 2012, 2014 and 2017) from participants for which anthropometric measurements had also been recorded. In the first wave in 2008, the survey recorded weight and height measurements for the calculation of BMI for 21 002 individuals; 2323 (11.1%) were immediately lost to follow-up. Of the remaining 2008 sample of 18 679 individuals for which at least a second BMI calculation was recorded, 13 298 (71.2%), 15 331 (82.1%), 15 623 (83.6%) and 14 463 (77.4%) are represented in the 2010, 2012, 2014 and 2017 waves, respectively.

Table 4.1:Body mass index categories for children and adults, according to WHO[258]

BMI category	**z-BMI of children (≤ 18 years)**	**BMI of adults (> 18 years) (kg/m^2)**
Normal	> –2SD to ≤ 1SD	≥ 18.5 to < 25
Overweight	> 1SD to ≤ 2SD	≥ 25 to < 30
Obese	> 2SD	≥ 30

4.2.2 Study variables

Our main study variable of interest is whether transition occurred from one BMI category to another during a particular period in time. This derived variable has seven possible outcomes: two downwards transitions (either from obese to overweight or from overweight to normal); two upwards transitions (either from normal to overweight or from overweight to obese); and three no-transition outcomes, when a person's BMI category does not change from either normal, overweight or obese between two waves of the survey (Figure 2.4). If a population is experiencing a higher number of upwards than downwards transitions, the prevalence of adverse conditions will increase.

Our independent time-invariant variables were sex and race/ethnicity, and baseline time-variant variables were age, whether urban or rural residence, education level, equivalized income level and frequency of physical exercise. To account for the economies of scale in household consumption, we used the equivalization method of the Organisation for Economic Co-operation and Development of dividing household income by the square root of the number of people within the household.[259]

4.2.3 Statistical analysis

For each BMI category and for each of the five waves of data collection, we calculated both average BMI with 95% confidence intervals (CI) and prevalence. To visualize how prevalence varies with age, we calculated the prevalence of all three BMI categories for all ages and averaged over all five data collection waves (2008–2017). We also calculated the percentage within each population subgroup either transitioning to an upwards or downwards BMI category or remaining within the same category during the four periods between subsequent waves (i.e., ending in 2010, 2012, 2014 and 2017). We used a multinomial logistic regression to model the probability of transitioning (or not) from one BMI category to another, relative to the probability of remaining within the normal category. We performed all statistical analyses using Stata SE Version 15.0 (StataCorp, College Station, United States of America).

4.3 Results

4.3.1 Average BMI and prevalence

Between 2008 and 2017, mean BMI increased by 2.3 kg/m^2, from 23.1 to 25.4 kg/m^2. We observed that the age group 7–13 years experienced the highest increase (by 4.7 kg/m^2), followed by the age groups 14–18 years (3.3 kg/m^2) and 19–24 years (3.2 kg/m2; Table 4.2). We note that the groups that demonstrated at least an average increase in mean BMI (i.e. ≥ 2.3 kg/m^2) include women, Africans and Caucasians, rural dwellers, those with some education and those whose level of physical exercise was unknown. When examining the data by income, those with the lowest income demonstrated the largest increase in mean BMI (2.5 kg/m^2). We also observed that women, those aged ≥ 25 years, Caucasians, urban dwellers, those with no formal schooling, those with a high school education or more, those within the highest-income tertile and those exercising < 3 times per week had an average

BMI of > 25.0 kg/m^2 for most, if not all, of the study period, contributing to the high prevalence of people being overweight and obese (Figure 4.1).

Our data show an increase in the prevalence of obesity from 19.7% (3686/18 679) in 2008 to 23.6% (3412/14 463) in 2017. In terms of age group, we observed the highest increase in the prevalence of obesity over this period in those aged 19–24 years from 10.9% (227/2079) to 28.4% (449/1581). In terms of education level, those with the most education (high school and above) demonstrated the largest increase in the prevalence of obesity from 25.2% (708/2811) to 40.1% (840/2093). The prevalence of people being overweight and obese was lowest for those aged around 11–18 years (Figure 4.1). The prevalence of obesity increases steeply after this age up to around 50 years, when it reaches a plateau (Figure 4.1). Between the ages of 40 and 70 years, the prevalence of obesity is higher than that of normal BMI.

Table 4.2: Mean body mass index and percentage of study population within each body mass index category by sociodemographic characteristics and data collection wave, South Africa, 2008–2017

Sociodemographic property/data collection wave	N	Mean BMI (kg/m^2) (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
Sex					
Women					
2008	10 687	24.8 (24.5–25.1)	5444 (50.9)	2374 (22.2)	2869 (26.8)
2010	7 887	26.3 (25.9–26.6)	3504 (44.4)	1881 (23.8)	2502 (31.7)
2012	8 936	26.4 (26.1–26.7)	4033 (45.1)	2270 (25.4)	2633 (29.5)
2014	9 040	27.3 (27.0–27.7)	3853 (42.6)	2154 (23.8)	3033 (33.6)
2017	8 461	27.9 (27.5–28.2)	3473 (41.0)	2057 (24.3)	2931 (34.6)
Men					
2008	7 992	21.1 (20.8–21.3)	5885 (73.6)	1290 (16.1)	817 (10.2)
2010	5 411	22.2 (21.9–22.6)	3737 (69.1)	1054 (19.5)	620 (11.5)
2012	6 395	22.4 (22.0–22.7)	4539 (71.0)	1196 (18.7)	660 (10.3)
2014	6 583	22.4 (22.1–22.7)	4985 (75.7)	1036 (15.7)	562 (8.5)
2017	6 002	22.5 (22.2–22.7)	4552 (75.8)	969 (16.1)	481 (8.0)
Baseline age (years)					
0–6					
2008	2 770	16.8 (16.6–17.0)	1792 (64.7)	544 (19.6)	434 (15.7)
2010	1 627	16.7 (16.4–16.9)	1106 (68.0)	275 (16.9)	246 (15.1)

Sociodemographic property/data collection wave	N	Mean BMI (kg/m²) (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
2012	2 468	17.0 (16.8–17.3)	1780 (72.1)	387 (15.7)	301 (12.2)
2014	2 571	17.9 (17.6–18.1)	2090 (81.3)	321 (12.5)	160 (6.2)
2017	2 479	19.2 (18.9–19.4)	2029 (81.8)	314 (12.7)	136 (5.5)
7–13					
2008	3 458	17.8 (17.4–18.1)	2781 (80.4)	378 (10.9)	299 (8.6)
2010	2 327	19.8 (19.4–20.2)	1733 (74.5)	359 (15.4)	235 (10.1)
2012	2 973	20.7 (20.5–21.0)	2306 (77.6)	485 (16.3)	182 (6.1)
2014	3 026	21.8 (21.5–22.0)	2375 (78.5)	459 (15.2)	192 (6.3)
2017	2 807	22.5 (22.2–22.8)	2128 (75.8)	442 (15.7)	237 (8.4)
14–18					
2008	2 384	21.5 (21.2–21.8)	1899 (79.7)	329 (13.8)	156 (6.5)
2010	1 761	23.1 (22.7–23.4)	1230 (69.8)	358 (20.3)	173 (9.8)
2012	1 803	23.7 (23.3–24.0)	1254 (69.6)	368 (20.4)	181 (10.0)
2014	1 953	24.2 (23.9–24.5)	1253 (64.2)	387 (19.8)	313 (16.0)
2017	1 803	24.8 (24.4–25.3)	1070 (59.3)	392 (21.7)	341 (18.9)
19–24					
2008	2 079	23.5 (23.2–23.9)	1445 (69.5)	407 (19.6)	227 (10.9)
2010	1 455	24.6 (24.1–25.1)	871 (59.9)	334 (23.0)	250 (17.2)
2012	1 563	25.5 (24.9–26.1)	847 (54.2)	395 (25.3)	321 (20.5)
2014	1 703	26.2 (25.7–26.7)	838 (49.2)	431 (25.3)	434 (25.5)
2017	1 581	26.7 (26.1–27.2)	718 (45.4)	414 (26.2)	449 (28.4)
25–34					
2008	2 199	25.8 (25.5–26.2)	1184 (53.8)	536 (24.4)	479 (21.8)
2010	1 597	26.4 (25.9–26.9)	721 (45.1)	430 (26.9)	446 (27.9)
2012	1 721	26.9 (26.5–27.4)	741 (43.1)	493 (28.6)	487 (28.3)
2014	1 831	27.6 (27.1–28.0)	749 (40.9)	458 (25.0)	624 (34.1)
2017	1 705	27.4 (26.9–27.9)	689 (40.4)	425 (24.9)	591 (34.7)
35–44					
2008	1 966	27.7 (27.3–28.2)	790 (40.2)	495 (25.2)	681 (34.6)
2010	1 514	28.4 (27.8–29.0)	539 (35.6)	387 (25.6)	588 (38.8)
2012	1 634	28.6 (28.0–29.1)	562 (34.4)	425 (26.0)	647 (39.6)
2014	1 647	28.8 (28.2–29.4)	560 (34.0)	376 (22.8)	711 (43.2)
2017	1 556	28.7 (28.1–29.2)	507 (32.6)	379 (24.4)	670 (43.1)

Sociodemographic property/data collection wave	N	Mean BMI (kg/m²) (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
45–54					
2008	1 687	28.8 (28.2–29.3)	630 (37.3)	400 (23.7)	657 (38.9)
2010	1 305	29.3 (28.6–29.9)	424 (32.5)	330 (25.3)	551 (42.2)
2012	1 415	29.4 (28.8–30.0)	458 (32.4)	378 (26.7)	579 (40.9)
2014	1 370	29.6 (28.9–30.2)	425 (31.0)	343 (25.0)	602 (43.9)
2017	1 260	29.5 (28.9–30.2)	403 (32.0)	320 (25.4)	537 (42.6)
> 55					
2008	2 136	28.4 (27.9–28.9)	808 (37.8)	575 (26.9)	753 (35.3)
2010	1 712	28.4 (27.9–28.9)	617 (36.0)	462 (27.0)	633 (37.0)
2012	1 754	28.0 (27.6–28.4)	624 (35.6)	535 (30.5)	595 (33.9)
2014	1 522	28.1 (27.5–28.7)	548 (36.0)	415 (27.3)	559 (36.7)
2017	1 272	28.0 (27.4–28.6)	481 (37.8)	340 (26.7)	451 (35.5)
Race/ethnicity					
African					
2008	15 621	22.9 (22.6–23.1)	9592 (61.4)	3049 (19.5)	2980 (19.1)
2010	11 536	24.3 (24.0–24.6)	6262 (54.3)	2569 (22.3)	2705 (23.4)
2012	12 941	24.2 (24.0–24.5)	7312 (56.5)	2937 (22.7)	2692 (20.8)
2014	13 228	24.8 (24.5–25.0)	7581 (57.3)	2714 (20.5)	2933 (22.2)
2017	12 317	25.3 (25.0–25.5)	6945 (56.4)	2557 (20.8)	2815 (22.9)
Mixed ancestry					
2008	2 360	24.0 (23.3–24.6)	1441 (61.1)	405 (17.2)	514 (21.8)
2010	1 400	24.4 (23.6–25.2)	821 (58.6)	254 (18.1)	325 (23.2)
2012	1 887	24.9 (24.3–25.4)	1091 (57.8)	356 (18.9)	440 (23.3)
2014	1 923	25.4 (24.9–26.0)	1087 (56.5)	332 (17.3)	504 (26.2)
2017	1 770	25.8 (25.3–26.3)	949 (53.6)	348 (19.7)	473 (26.7)
Asian					
2008	199	23.4 (22.9–23.9)	116 (58.3)	46 (23.1)	37 (18.6)
2010	128	23.8 (22.9–24.7)	72 (56.3)	31 (24.2)	25 (19.5)
2012	141	25.5 (25.0–26.0)	66 (46.8)	45 (31.9)	30 (21.3)
2014	152	24.4 (23.5–25.2)	77 (50.7)	42 (27.6)	33 (21.7)
2017	145	24.0 (22.9–25.1)	63 (43.4)	49 (33.8)	33 (22.8)
Caucasian					
2008	499	25.7 (24.6–26.8)	180 (36.1)	164 (32.9)	155 (31.1)

Sociodemographic property/data collection wave	N	Mean BMI (kg/m²) (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
2010	234	26.9 (25.1–28.7)	86 (36.8)	81 (34.6)	67 (28.6)
2012	362	27.8 (26.8–28.8)	103 (28.5)	128 (35.4)	131 (36.2)
2014	320	28.2 (26.8–29.6)	93 (29.1)	102 (31.9)	125 (39.1)
2017	231	28.3 (26.8–29.7)	68 (29.4)	72 (31.2)	91 (39.4)
Residence					
Rural					
2008	10 849	22.2 (21.9–22.5)	6916 (63.7)	2060 (19.0)	1873 (17.3)
2010	7 937	23.8 (23.5–24.1)	4374 (55.1)	1791 (22.6)	1772 (22.3)
2012	8 420	23.6 (23.3–23.9)	4912 (58.3)	1916 (22.8)	1592 (18.9)
2014	8 152	24.2 (23.9–24.4)	4825 (59.2)	1646 (20.2)	1681 (20.6)
2017	7 501	24.7 (24.4–25.0)	4369 (58.2)	1546 (20.6)	1586 (21.1)
Urban					
2008	7 830	24.0 (23.7–24.3)	4413 (56.4)	1604 (20.5)	1813 (23.2)
2010	5 361	25.1 (24.6–25.5)	2867 (53.5)	1144 (21.3)	1350 (25.2)
2012	6 911	25.3 (24.9–25.7)	3660 (53.0)	1550 (22.4)	1701 (24.6)
2014	7 471	25.7 (25.4–26.1)	4013 (53.7)	1544 (20.7)	1914 (25.6)
2017	6 962	25.8 (25.5–26.2)	3656 (52.5)	1480 (21.3)	1826 (26.2)
Education					
None					
2008	1 761	25.2 (24.8–25.6)	921 (52.3)	382 (21.7)	458 (26.0)
2010	1 391	26.3 (25.8–26.7)	638 (45.9)	324 (23.3)	429 (30.8)
2012	1 437	25.8 (25.4–26.1)	687 (47.8)	384 (26.7)	366 (25.5)
2014	1 345	25.9 (25.5–26.2)	672 (50.0)	316 (23.5)	357 (26.5)
2017	1 168	26.1 (25.7–26.5)	583 (49.9)	274 (23.5)	311 (26.6)
Pre-school					
2008	2 603	16.8 (16.6–16.9)	1666 (64.0)	522 (20.1)	415 (15.9)
2010	1 508	16.7 (16.5–16.9)	1020 (67.6)	251 (16.6)	237 (15.7)
2012	2 324	16.9 (16.8–17.1)	1677 (72.2)	358 (15.4)	289 (12.4)
2014	2 418	17.5 (17.4–17.7)	1969 (81.4)	295 (12.2)	154 (6.4)
2017	2 338	18.9 (18.7–19.0)	1919 (82.1)	290 (12.4)	129 (5.5)
Primary school[a]					
2008	11 504	23.0 (22.9–23.2)	7356 (63.9)	2043 (17.8)	2105 (18.3)
2010	8 441	24.6 (24.5–24.7)	4760 (56.4)	1823 (21.6)	1858 (22.0)

Sociodemographic property/data collection wave	N	Mean BMI (kg/m^2) (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
2012	9 335	24.8 (24.7–24.9)	5374 (57.6)	2057 (22.0)	1904 (20.4)
2014	9 573	25.4 (25.3–25.6)	5416 (56.6)	1953 (20.4)	2204 (23.0)
2017	8 864	25.9 (25.7–26.0)	4848 (54.7)	1884 (21.3)	2132 (24.1)
High school and above					
2008	2 811	26.3 (26.1–26.6)	1386 (49.3)	717 (25.5)	708 (25.2)
2010	1 958	27.4 (27.1–27.6)	823 (42.0)	537 (27.4)	598 (30.5)
2012	2 235	27.9 (27.6–28.2)	834 (37.3)	667 (29.8)	734 (32.8)
2014	2 287	28.6 (28.3–28.9)	781 (34.1)	626 (27.4)	880 (38.5)
2017	2 093	29.0 (28.7–29.3)	675 (32.3)	578 (27.6)	840 (40.1)
Income level					
Low					
2008	11 220	22.1 (21.9–22.4)	7236 (64.5)	2055 (18.3)	1929 (17.2)
2010	8 162	23.7 (23.6–23.9)	4625 (56.7)	1771 (21.7)	1766 (21.6)
2012	9 264	23.4 (23.3–23.6)	5548 (59.9)	2019 (21.8)	1697 (18.3)
2014	9 582	24.0 (23.9–24.1)	5861 (61.2)	1858 (19.4)	1863 (19.4)
2017	8 974	24.6 (24.4–24.7)	5371 (59.9)	1770 (19.7)	1833 (20.4)
Middle					
2008	4 564	23.5 (23.1–23.9)	2738 (60.0)	868 (19.0)	958 (21.0)
2010	3 243	24.6 (24.4–24.9)	1777 (54.8)	683 (21.1)	783 (24.1)
2012	3 780	24.6 (24.3–24.8)	2094 (55.4)	809 (21.4)	877 (23.2)
2014	3 776	25.1 (24.9–25.4)	2060 (54.6)	757 (20.0)	959 (25.4)
2017	3 501	25.5 (25.3–25.8)	1866 (53.3)	745 (21.3)	890 (25.4)
High					
2008	2 895	25.0 (24.6–25.5)	1355 (46.8)	741 (25.6)	799 (27.6)
2010	1 893	26.1 (25.7–26.4)	839 (44.3)	481 (25.4)	573 (30.3)
2012	2 287	26.5 (26.2–26.7)	930 (40.7)	638 (27.9)	719 (31.4)
2014	2 265	27.0 (26.7–27.3)	917 (40.5)	575 (25.4)	773 (34.1)
2017	1 988	27.5 (27.2–27.8)	788 (39.6)	511 (25.7)	689 (34.7)
Physical exercise					
< 3 times per week					
2008	10 452	26.3 (26.0–26.5)	5342 (51.1)	2404 (23.0)	2706 (25.9)
2010	7 950	27.2 (27.0–27.3)	3521 (44.3)	2002 (25.2)	2427 (30.5)

Sociodemographic property/data collection wave	N	Mean BMI (kg/m^2) (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
2012	8 315	27.5 (27.3–27.6)	3503 (42.1)	2239 (26.9)	2573 (30.9)
2014	8 444	27.8 (27.7–28.0)	3440 (40.7)	2068 (24.5)	2936 (34.8)
2017	7 742	28.1 (27.9–28.3)	3056 (39.5)	1935 (25.0)	2751 (35.5)
≥ 3 times per week					
2008	1 460	24.0 (23.5–24.6)	981 (67.2)	274 (18.8)	205 (14.0)
2010	985	24.7 (24.3–25.0)	591 (60.0)	228 (23.1)	166 (16.9)
2012	1 135	25.2 (24.9–25.5)	646 (56.9)	288 (25.4)	201 (17.7)
2014	1 143	25.6 (25.2–25.9)	623 (54.5)	266 (23.3)	254 (22.2)
2017	1 040	25.8 (25.4–26.1)	550 (52.9)	255 (24.5)	235 (22.6)
Unknown					
2008	6 767	17.6 (17.4–17.8)	5006 (74.0)	986 (14.6)	775 (11.5)
2010	4 363	19.0 (18.8–19.1)	3129 (71.7)	705 (16.2)	529 (12.1)
2012	5 881	19.3 (19.1–19.4)	4423 (75.2)	939 (16.0)	519 (8.8)
2014	6 036	20.2 (20.0–20.3)	4775 (79.1)	856 (14.2)	405 (6.7)
2017	5 681	21.2 (21.0–21.3)	4419 (77.8)	836 (14.7)	426 (7.5)
Total					
2008	18 679	23.1 (22.9–23.4)	11329 (60.7)	3664 (19.6)	3686 (19.7)
2010	13 298	24.5 (24.2–24.7)	7241 (54.5)	2935 (22.1)	3122 (23.5)
2012	15 331	24.6 (24.3–24.8)	8572 (55.9)	3466 (22.6)	3293 (21.5)
2014	15 623	25.1 (24.8–25.3)	8838 (56.6)	3190 (20.4)	3595 (23.0)
2017	14 463	25.4 (25.1–25.6)	8025 (55.5)	3026 (20.9)	3412 (23.6)

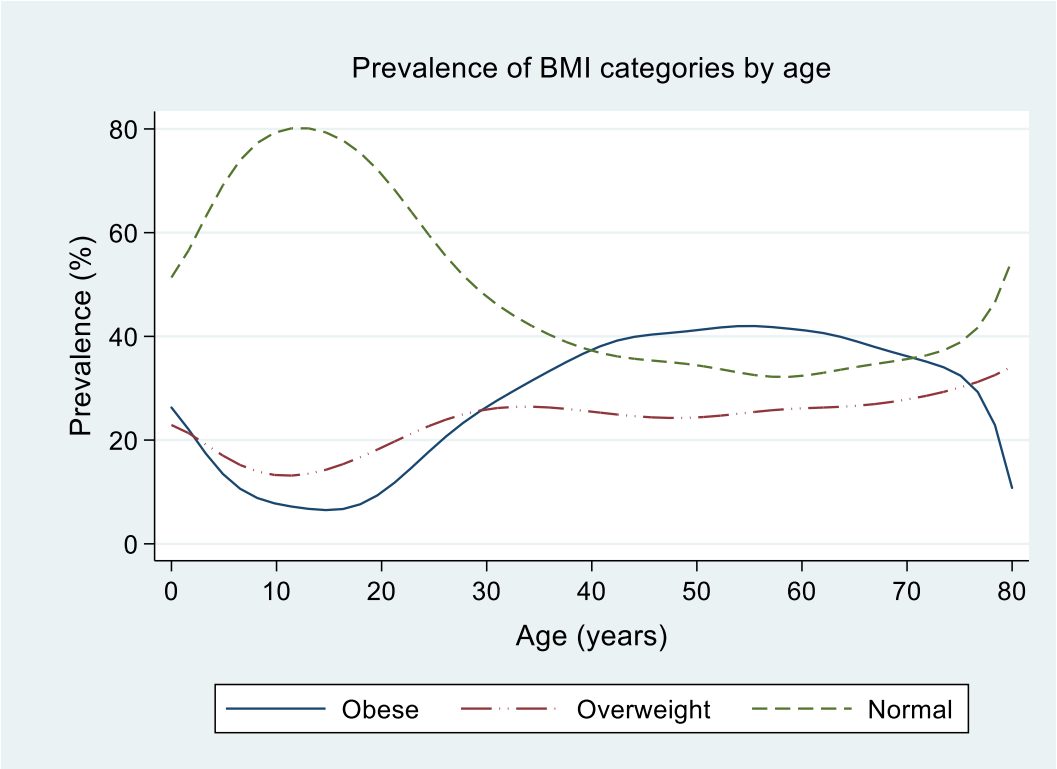


Figure 4.1: Prevalence of body mass index categories by age, South Africa

4.3.2 Transitions between categories

We provide percentages of the study population groups who transitioned (or not) from one BMI category to another during the four periods ending 2010, 2012, 2014 and 2017 in Table 4.3. As the cohort for each risk factor aged throughout the study period, the percentages transitioning generally decreased as the percentages remaining within a particular BMI category increased. The exceptions to this general observation, that is, the groups that demonstrated decreasing percentages of retaining a normal BMI, included those of age 14–18 years (from 61.7%; 1086/1761 to 54.6%; 984/1803) and 19–24 years (from 51.6%; 751/1455 to 41.0%; 648/1581), Asians (from 51.6%; 66/128 to 38.6%; 56/145), individuals with at least a high school education (from 34.3%; 671/1958 to 28.1%; 589/2093) and those who reported physical exercise ≥ 3 times per week (from 53.0%; 522/985 to 48.6%; 505/1040). Within all these groups, our data show that the decreasing percentages of those retaining a normal BMI was accompanied by upwards transition percentages that were much higher than downwards transition percentages. For example, for the age group 19–24 years, the percentage transitioning upwards by 2010 (22.4%; (187+139)/1455) was more than double that of those transitioning downwards (10.1%; (100+47)/1455). The percentage of those retaining a normal BMI remained relatively constant throughout the study period

for women (~35%) and for those aged > 35 years (~28%). At the end of every period, the percentage of those who retained a normal BMI was higher for those who exercised ≥ 3 times per week (e.g. for the period ending 2010, 53.0%; 522/985) compared with those who exercised < 3 times per week (e.g. for the period ending 2010, 36.1%; 2868/7950).

Table 4.3: Number and percentage of study population transitioning from one body mass index category to another (or not) by sociodemographic characteristics and year of end of transition period, South Africa, 2010–2017

Sociodemographic property		Transition year	n	No. transitioned upwards (%)		No. transitioned downwards (%)		No. unchanged (%)		
				Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
Sex	Women	2010	7887	750 (9.5)	845 (10.7)	526 (6.7)	575 (7.3)	2752 (34.9)	782 (9.9)	1657 (21.0)
		2012	8936	844 (9.4)	790 (8.8)	602 (6.7)	826 (9.2)	3097 (34.7)	934 (10.5)	1843 (20.6)
		2014	9040	775 (8.6)	876 (9.7)	546 (6.0)	470 (5.2)	3142 (34.8)	1074 (11.9)	2157 (23.9)
		2017	8461	521 (6.2)	481 (5.7)	382 (4.5)	364 (4.3)	3022 (35.7)	1241 (14.7)	2450 (29.0)
	Men	2010	5411	563 (10.4)	390 (7.2)	361 (6.7)	285 (5.3)	3201 (59.2)	381 (7.0)	230 (4.3)
		2012	6395	559 (8.7)	362 (5.7)	531 (8.3)	441 (6.9)	3725 (58.2)	479 (7.5)	298 (4.7)
		2014	6583	388 (5.9)	227 (3.4)	530 (8.1)	359 (5.5)	4224 (64.2)	520 (7.9)	335 (5.1)
		2017	6002	288 (4.8)	142 (2.4)	269 (4.5)	164 (2.7)	4232 (70.5)	568 (9.5)	339 (5.6)
Baseline age (years)	0–6	2010	1627	128 (7.9)	168 (10.3)	189 (11.6)	177 (10.9)	806 (49.5)	81 (5.0)	78 (4.8)
		2012	2468	165 (6.7)	223 (9.0)	254 (10.3)	309 (12.5)	1333 (54.0)	106 (4.3)	78 (3.2)
		2014	2571	142 (5.5)	92 (3.6)	243 (9.5)	247 (9.6)	1668 (64.9)	111 (4.3)	68 (2.6)
		2017	2479	130 (5.2)	62 (2.5)	116 (4.7)	80 (3.2)	1868 (75.4)	149 (6.0)	74 (3.0)
	7–13	2010	2327	244 (10.5)	178 (7.6)	137 (5.9)	130 (5.6)	1501 (64.5)	80 (3.4)	57 (2.4)
		2012	2973	278 (9.4)	117 (3.9)	224 (7.5)	227 (7.6)	1914 (64.4)	148 (5.0)	65 (2.2)
		2014	3026	237 (7.8)	114 (3.8)	220 (7.3)	125 (4.1)	2068 (68.3)	184 (6.1)	78 (2.6)
		2017	2807	181 (6.4)	109 (3.9)	128 (4.6)	50 (1.8)	1984 (70.7)	227 (8.1)	128 (4.6)
	14	2010	1761	237 (13.5)	128 (7.3)	105 (6.0)	68 (3.9)	1086 (61.7)	92 (5.2)	45 (2.6)

Sociodemographic property	Transition year	n	No. transitioned upwards (%)		No. transitioned downwards (%)		No. unchanged (%)		
			Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
	2012	1803	219 (12.1)	102 (5.7)	157 (8.7)	90 (5.0)	1043 (57.8)	113 (6.3)	79 (4.4)
	2014	1953	202 (10.3)	188 (9.6)	133 (6.8)	63 (3.2)	1095 (56.1)	147 (7.5)	125 (6.4)
	2017	1803	162 (9.0)	112 (6.2)	76 (4.2)	46 (2.6)	984 (54.6)	194 (10.8)	229 (12.7)
19–24	2010	1455	187 (12.9)	139 (9.6)	100 (6.9)	47 (3.2)	751 (51.6)	120 (8.2)	111 (7.6)
	2012	1563	209 (13.4)	144 (9.2)	102 (6.5)	78 (5.0)	713 (45.6)	140 (9.0)	177 (11.3)
	2014	1703	190 (11.2)	171 (10.0)	107 (6.3)	63 (3.7)	708 (41.6)	201 (11.8)	263 (15.4)
	2017	1581	118 (7.5)	97 (6.1)	62 (3.9)	50 (3.2)	648 (41.0)	254 (16.1)	352 (22.3)
25–34	2010	1597	186 (11.6)	175 (11.0)	97 (6.1)	90 (5.6)	590 (36.9)	188 (11.8)	271 (17.0)
	2012	1721	199 (11.6)	165 (9.6)	117 (6.8)	113 (6.6)	583 (33.9)	222 (12.9)	322 (18.7)
	2014	1831	148 (8.1)	167 (9.1)	116 (6.3)	75 (4.1)	612 (33.4)	256 (14.0)	457 (25.0)
	2017	1705	84 (4.9)	85 (5.0)	80 (4.7)	70 (4.1)	598 (35.1)	282 (16.5)	506 (29.7)
35–44	2010	1514	121 (8.0)	147 (9.7)	84 (5.5)	112 (7.4)	423 (27.9)	186 (12.3)	441 (29.1)
	2012	1634	110 (6.7)	156 (9.5)	89 (5.4)	123 (7.5)	439 (26.9)	226 (13.8)	491 (30.0)
	2014	1647	91 (5.5)	141 (8.6)	82 (5.0)	80 (4.9)	458 (27.8)	225 (13.7)	570 (34.6)
	2017	1556	65 (4.2)	64 (4.1)	60 (3.9)	77 (4.9)	438 (28.1)	246 (15.8)	606 (38.9)
45–54	2010	1305	92 (7.0)	130 (10.0)	64 (4.9)	96 (7.4)	334 (25.6)	168 (12.9)	421 (32.3)
	2012	1415	91 (6.4)	111 (7.8)	67 (4.7)	130 (9.2)	355 (25.1)	193 (13.6)	468 (33.1)
	2014	1370	68 (5.0)	113 (8.2)	66 (4.8)	78 (5.7)	343 (25.0)	213 (15.5)	489 (35.7)
	2017	1260	32 (2.5)	48 (3.8)	53 (4.2)	64 (5.1)	344 (27.3)	230 (18.3)	489 (38.8)
≥ 55	2010	1712	118 (6.9)	170 (9.9)	111 (6.5)	140 (8.2)	462 (27.0)	248 (14.5)	463 (27.0)
	2012	1754	132 (7.5)	134 (7.6)	123 (7.0)	197 (11.2)	442 (25.2)	265 (15.1)	461 (26.3)
	2014	1522	85 (5.6)	117 (7.7)	109 (7.2)	98 (6.4)	414 (27.2)	257 (16.9)	442 (29.0)
	2017	1272	37 (2.9)	46 (3.6)	76 (6.0)	91 (7.2)	390 (30.7)	227 (17.8)	405 (31.8)

Sociodemographic property		Transition year	n	No. transitioned upwards (%)		No. transitioned downwards (%)		No. unchanged (%)		
				Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
Race/ethnicity	African	2010	11536	1192 (10.3)	1134 (9.8)	777 (6.7)	764 (6.6)	5129 (44.5)	969 (8.4)	1571 (13.6)
		2012	12941	1225 (9.5)	981 (7.6)	1033 (8.0)	1130 (8.7)	5709 (44.1)	1152 (8.9)	1711 (13.2)
		2014	13228	1021 (7.7)	950 (7.2)	971 (7.3)	746 (5.6)	6234 (47.1)	1323 (10.0)	1983 (15.0)
		2017	12317	696 (5.7)	531 (4.3)	583 (4.7)	451 (3.7)	6251 (50.8)	1521 (12.3)	2284 (18.5)
	Mixed ancestry	2010	1400	86 (6.1)	78 (5.6)	88 (6.3)	71 (5.1)	696 (49.7)	134 (9.6)	247 (17.6)
		2012	1887	130 (6.9)	116 (6.1)	77 (4.1)	107 (5.7)	975 (51.7)	158 (8.4)	324 (17.2)
		2014	1923	109 (5.7)	122 (6.3)	70 (3.6)	56 (2.9)	1001 (52.1)	183 (9.5)	382 (19.9)
		2017	1770	91 (5.1)	76 (4.3)	48 (2.7)	63 (3.6)	892 (50.4)	203 (11.5)	397 (22.4)
	Asian	2010	128	10 (7.8)	5 (3.9)	5 (3.9)	4 (3.1)	66 (51.6)	18 (14.1)	20 (15.6)
		2012	141	13 (9.2)	8 (5.7)	7 (5.0)	5 (3.5)	58 (41.1)	28 (19.9)	22 (15.6)
		2014	152	13 (8.6)	9 (5.9)	11 (7.2)	7 (4.6)	65 (42.8)	23 (15.1)	24 (15.8)
		2017	145	11 (7.6)	7 (4.8)	7 (4.8)	6 (4.1)	56 (38.6)	32 (22.1)	26 (17.9)
	Caucasian	2010	234	25 (10.7)	18 (7.7)	17 (7.3)	21 (9.0)	62 (26.5)	42 (17.9)	49 (20.9)
		2012	362	35 (9.7)	47 (13.0)	16 (4.4)	25 (6.9)	80 (22.1)	75 (20.7)	84 (23.2)
		2014	320	20 (6.3)	22 (6.9)	24 (7.5)	20 (6.3)	66 (20.6)	65 (20.3)	103 (32.2)
		2017	231	11 (4.8)	9 (3.9)	13 (5.6)	8 (3.5)	55 (23.8)	53 (22.9)	82 (35.5)
Residence	Rural	2010	7937	882 (11.1)	826 (10.4)	536 (6.8)	508 (6.4)	3585 (45.2)	654 (8.2)	946 (11.9)
		2012	8420	801 (9.5)	625 (7.4)	711 (8.4)	793 (9.4)	3780 (44.9)	743 (8.8)	967 (11.5)
		2014	8152	609 (7.5)	572 (7.0)	639 (7.8)	515 (6.3)	3920 (48.1)	788 (9.7)	1109 (13.6)
		2017	7501	410 (5.5)	289 (3.9)	365 (4.9)	283 (3.8)	3929 (52.4)	928 (12.4)	1297 (17.3)
	Urban	2010	5361	431 (8.0)	409 (7.6)	351 (6.5)	352 (6.6)	2368 (44.2)	509 (9.5)	941 (17.6)
		2012	6911	602 (8.7)	527 (7.6)	422 (6.1)	474 (6.9)	3042 (44.0)	670 (9.7)	1174 (17.0)
		2014	7471	554 (7.4)	531 (7.1)	437 (5.8)	314 (4.2)	3446 (46.1)	806 (10.8)	1383 (18.5)

Sociodemographic property		Transition year	n	No. transitioned upwards (%)		No. transitioned downwards (%)		No. unchanged (%)		
				Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
		2017	6962	399 (5.7)	334 (4.8)	286 (4.1)	245 (3.5)	3325 (47.8)	881 (12.7)	1492 (21.4)
Education	None	2010	1391	115 (8.3)	145 (10.4)	84 (6.0)	104 (7.5)	506 (36.4)	153 (11.0)	284 (20.4)
		2012	1437	134 (9.3)	105 (7.3)	102 (7.1)	156 (10.9)	519 (36.1)	160 (11.1)	261 (18.2)
		2014	1345	90 (6.7)	85 (6.3)	107 (8.0)	76 (5.7)	543 (40.4)	172 (12.8)	272 (20.2)
		2017	1168	52 (4.5)	36 (3.1)	65 (5.6)	53 (4.5)	506 (43.3)	181 (15.5)	275 (23.5)
	Pre-school	2010	1508	116 (7.7)	160 (10.6)	181 (12.0)	165 (10.9)	735 (48.7)	74 (4.9)	77 (5.1)
		2012	2324	153 (6.6)	212 (9.1)	245 (10.5)	295 (12.7)	1247 (53.7)	95 (4.1)	77 (3.3)
		2014	2418	127 (5.3)	87 (3.6)	224 (9.3)	238 (9.8)	1571 (65.0)	104 (4.3)	67 (2.8)
		2017	2338	118 (5.0)	59 (2.5)	106 (4.5)	78 (3.3)	1768 (75.6)	139 (5.9)	70 (3.0)
	Primary school[a]	2010	8441	868 (10.3)	718 (8.5)	505 (6.0)	477 (5.7)	4041 (47.9)	692 (8.2)	1140 (13.5)
		2012	9335	865 (9.3)	617 (6.6)	657 (7.0)	671 (7.2)	4389 (47.0)	849 (9.1)	1287 (13.8)
		2014	9573	753 (7.9)	685 (7.2)	631 (6.6)	415 (4.3)	4608 (48.1)	962 (10.0)	1519 (15.9)
		2017	8864	518 (5.8)	402 (4.5)	405 (4.6)	317 (3.6)	4391 (49.5)	1101 (12.4)	1730 (19.5)
	High school and ·	2010	1958	214 (10.9)	212 (10.8)	117 (6.0)	114 (5.8)	671 (34.3)	244 (12.5)	386 (19.7)
		2012	2235	251 (11.2)	218 (9.8)	129 (5.8)	145 (6.5)	667 (29.8)	309 (13.8)	516 (23.1)
		2014	2287	193 (8.4)	246 (10.8)	114 (5.0)	100 (4.4)	644 (28.2)	356 (15.6)	634 (27.7)
		2017	2093	121 (5.8)	126 (6.0)	75 (3.6)	80 (3.8)	589 (28.1)	388 (18.5)	714 (34.1)
Income level	Low	2010	8162	897 (11.0)	803 (9.8)	555 (6.8)	529 (6.5)	3798 (46.5)	617 (7.6)	963 (11.8)
		2012	9264	894 (9.7)	647 (7.0)	779 (8.4)	811 (8.8)	4330 (46.7)	753 (8.1)	1050 (11.3)
		2014	9582	733 (7.6)	644 (6.7)	747 (7.8)	541 (5.6)	4827 (50.4)	871 (9.1)	1219 (12.7)
		2017	8974	525 (5.9)	373 (4.2)	418 (4.7)	298 (3.3)	4876 (54.3)	1024 (11.4)	1460 (16.3)
	Middle	2010	3243	276 (8.5)	254 (7.8)	216 (6.7)	187 (5.8)	1486 (45.8)	295 (9.1)	529 (16.3)
		2012	3780	294 (7.8)	297 (7.9)	238 (6.3)	289 (7.6)	1734 (45.9)	348 (9.2)	580 (15.3)

Sociodemographic property		Transition year	n	No. transitioned upwards (%)		No. transitioned downwards (%)		No. unchanged (%)		
				Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
		2014	3776	271 (7.2)	266 (7.0)	216 (5.7)	174 (4.6)	1769 (46.8)	387 (10.2)	693 (18.4)
		2017	3501	193 (5.5)	140 (4.0)	154 (4.4)	148 (4.2)	1673 (47.8)	443 (12.7)	750 (21.4)
	High	2010	1893	140 (7.4)	178 (9.4)	116 (6.1)	144 (7.6)	669 (35.3)	251 (13.3)	395 (20.9)
		2012	2287	215 (9.4)	208 (9.1)	116 (5.1)	167 (7.3)	758 (33.1)	312 (13.6)	511 (22.3)
		2014	2265	159 (7.0)	193 (8.5)	113 (5.0)	114 (5.0)	770 (34.0)	336 (14.8)	580 (25.6)
		2017	1988	91 (4.6)	110 (5.5)	79 (4.0)	82 (4.1)	705 (35.5)	342 (17.2)	579 (29.1)
Physical exercise	< 3 times per week	2010	7950	769 (9.7)	792 (10.0)	487 (6.1)	497 (6.3)	2868 (36.1)	902 (11.3)	1635 (20.6)
		2012	8315	799 (9.6)	724 (8.7)	530 (6.4)	648 (7.8)	2754 (33.1)	1011 (12.2)	1849 (22.2)
		2014	8444	636 (7.5)	784 (9.3)	502 (5.9)	412 (4.9)	2823 (33.4)	1135 (13.4)	2152 (25.5)
		2017	7742	399 (5.2)	387 (5.0)	354 (4.6)	349 (4.5)	2653 (34.3)	1236 (16.0)	2364 (30.5)
	≥ 3 times per week	2010	985	125 (12.7)	64 (6.5)	5 (5.2)	40 (4.1)	522 (53.0)	81 (8.2)	102 (10.4)
		2012	1135	119 (10.5)	73 (6.4)	85 (7.5)	57 (5.0)	546 (48.1)	127 (11.2)	128 (11.3)
		2014	1143	102 (8.9)	87 (7.6)	75 (6.6)	35 (3.1)	536 (46.9)	141 (12.3)	167 (14.6)
		2017	1040	64 (6.2)	47 (4.5)	38 (3.7)	38 (3.7)	505 (48.6)	160 (15.4)	188 (18.1)
	Unknown	2010	4363	419 (9.6)	379 (8.7)	349 (8.0)	323 (7.4)	2563 (58.7)	180 (4.1)	150 (3.4)
		2012	5881	485 (8.2)	355 (6.0)	518 (8.8)	562 (9.6)	3522 (59.9)	275 (4.7)	164 (2.8)
		2014	6036	425 (7.0)	232 (3.8)	499 (8.3)	382 (6.3)	4007 (66.4)	318 (5.3)	173 (2.9)
		2017	5681	346 (6.1)	189 (3.3)	259 (4.6)	141 (2.5)	4096 (72.1)	413 (7.3)	237 (4.2)
Total		2010	13298	1313 (9.9)	1235 (9.3)	887 (6.7)	860 (6.5)	5953 (44.8)	1163 (8.7)	1887 (14.2)
		2012	15331	1403 (9.2)	1152 (7.5)	1133 (7.4)	1267 (8.3)	6822 (44.5)	1413 (9.2)	2141 (14.0)
		2014	15623	1163 (7.4)	1103 (7.1)	1076 (6.9)	829 (5.3)	7366 (47.1)	1594 (10.2)	2492 (16.0)
		2017	14463	809 (5.6)	623 (4.3)	651 (4.5)	528 (3.7)	7254 (50.2)	1809 (12.5)	2789 (19.3)

4.3.3 Likelihood of transitions

The probability of transitioning upwards or downwards to another BMI category decreased with time, while the probability of remaining within the overweight or obese categories increased with time. The particular groups that demonstrated the largest probabilities of remaining within the overweight or obese categories, compared with other groups, also demonstrated the greatest likelihoods of transitioning either upwards or downwards. These groups included women, Caucasians, and those with at least a high school education and with a high income (Table 4.4).

We note that the likelihood of either transitioning upwards or downwards, or of remaining within the overweight or obese categories, relative to that of retaining a normal BMI, increased with age. Our data show that women were 2.56 and 1.82 times more likely than men to transition upwards and downwards, respectively, and 4.81 times more likely than men to remain within the overweight or obese category. Men were therefore more likely to retain a normal BMI.

We note that Caucasians were 1.39 and 1.26 times more likely than Africans to transition upwards and downwards, respectively, and 1.21 times more likely than Africans to remain within the overweight or obesity category. Those of mixed ancestry and Asians demonstrated a higher probability of retaining a normal BMI than Africans and Caucasians. Urban dwellers were slightly more likely (1.08 times) than rural dwellers to remain within the overweight or obese categories, but less likely to transition upwards or downwards. We observed that individuals with a high school education and greater were more likely than the other education-level groups to either transition upwards or downwards or to remain within the overweight or obese categories. Compared with those with a low or middle income, high-income groups were more likely to transition upwards or downwards and remain within the overweight or obese categories; high-income groups were therefore less likely to retain a normal BMI than lower-income groups. Those who exercised ≥ 3 times per week and those whose frequency of physical exercise was unknown (data were unavailable for those of age < 15 years) were less likely to remain within the overweight or obese categories, and therefore more likely to retain a normal BMI, compared with those who exercised < 3 times per week.

Table 4.4: Probability of transitioning from one body mass index category to another (or not) by sociodemographic characteristics and year of end of transition period, South Africa, 2010–2017

Sociodemographic factor/year of end of transition period	Odds ratio (*P*-value) relative to that of retaining a normal BMI		
	Transition upwards (from normal to overweight, or overweight to obese)	Transition downwards (from obese to overweight, or overweight to normal)	Remain obese or overweight
End of transition period			
2010	1.00	1.00	1.00
2012	0.93 (0.032)	1.24 (0.000)	1.13 (0.000)
2014	0.77 (0.000)	0.93 (0.066)	1.28 (0.000)
2017	0.50 (0.000)	0.59 (0.000)	1.56 (0.000)
Sex			
Men	1.00	1.00	1.00
Women	2.56 (0.000)	1.82 (0.000)	4.81 (0.000)
Baseline age (years)			
0–6	1.00	1.00	1.00
7–13	0.93 (0.565)	0.72 (0.009)	1.14 (0.435)
14–18	1.21 (0.196)	0.71 (0.021)	1.50 (0.028)
19–24	1.40 (0.029)	0.81 (0.180)	2.75 (0.000)
25–34	1.59 (0.003)	1.19 (0.276)	4.92 (0.000)
35–44	1.65 (0.001)	1.54 (0.007)	8.33 (0.000)
45–54	1.67 (0.001)	1.75 (0.001)	10.44 (0.000)
≥ 55	1.65 (0.001)	2.17 (0.000)	9.68 (0.000)
Race/ethnicity			
African	1.00	1.00	1.00
Mixed ancestry	0.64 (0.000)	0.54 (0.000)	0.68 (0.000)
Asian	0.68 (0.005)	0.60 (0.001)	0.71 (0.003)
Caucasian	1.39 (0.002)	1.26 (0.043)	1.21 (0.037)
Residence			
Rural	1.00	1.00	1.00
Urban	0.85 (0.000)	0.92 (0.005)	1.08 (0.002)
Education level			
None	1.00	1.00	1.00
Pre-school	1.11 (0.448)	1.50 (0.003)	1.76 (0.001)
Primary school[c]	1.16 (0.005)	1.18 (0.002)	1.50 (0.000)

Sociodemographic factor/year of end of transition period	Odds ratio (*P*-value) relative to that of retaining a normal BMI		
	Transition upwards (from normal to overweight, or overweight to obese)	**Transition downwards (from obese to overweight, or overweight to normal)**	**Remain obese or overweight**
High school and above	1.69 (0.000)	1.43 (0.000)	2.27 (0.000)
Income level			
Low	1.00	1.00	1.00
Middle	0.98 (0.623)	0.94 (0.066)	1.18 (0.000)
High	1.46 (0.000)	1.28 (0.000)	2.06 (0.000)
Physical exercise			
< 3 times per week	1.00	1.00	1.00
≥ 3 times per week	0.93 (0.160)	0.86 (0.014)	0.83 (0.000)
Unknown	0.77 (0.001)	0.91 (0.322)	0.66 (0.000)

BMI: body mass index; OR: odds ratio.
[a] Transition from normal to overweight, or overweight to obese.
[b] Transition from obese to overweight, or overweight to normal.
[c] Includes those who may have started high school but dropped out before completing.

4.4 Discussion

Our data show a sharply rising prevalence of obesity coinciding with entry into adulthood in the community at large. We note that the prevalence of obesity increased by the greatest amount for the group aged 19–24 years between 2008 and 2017. This age group also reported the highest percentage of upwards transitions, as well as the largest difference between the percentage transitioning upwards and the percentage transitioning downwards. Although this age group had a normal category mean BMI during the first two study periods, the subsequent sharp increase in BMI resulted in an increased prevalence of being overweight and obese with time.

The South African Department of Health targeted a 3% reduction in the prevalence of obesity by 2017 for all age groups through diet and physical activity.[29, 64] To determine whether this target was achieved, we must compare data from different individuals of the same age at different times. However, by examining how BMI values change as a particular cohort ages, we were able to identify periods of increased obesity prevalence within a person's lifetime during which interventions may be critical. Our data show that there exists a decreasing trend in prevalence of being overweight or obese from birth to the age of 18 years, when most children usually leave high school. As our results are not capable of attributing this downwards trajectory from birth to age 18 years to the effectiveness of

national strategies for obesity prevention and control (our data were obtained from an observational study), further research is required.

Guidance for healthy eating for the population aged ≤ 18 years is provided in South Africa by the Guidelines for Early Childhood Development Services,[260, 261] and the National School Nutrition Programme Annual Report[262] and Guidelines for Tuck Shop Operators.[263] The teaching of life skills in primary and high schools, which includes nutrition education, is aimed at educating students to make nutritious food choices and develop healthy eating habits.[64] In averaging our data for all ages over the period 2008–2017, we found that the lowest combined prevalence of being overweight and obese was for those aged 7–18 years; the fact that prevalence rises steadily after this age highlights that, despite these strategies on controlling obesity, there remain substantial problems in communicating healthy food choices to children and adolescents. Other studies have also shown that these strategies are not functioning optimally.[264-266] A synthesis of studies conducted between 2006 and 2014 on the South African school food environment revealed that over half (from 51.1%; 1233/2412 to 69.3%; 330/476) of the students bought available and unhealthy foods from either tuck shops or vendors in their neighbourhood.[267] The population of age 15–24 years has also been identified as the largest consumers of sugar-sweetened beverages.[268]

Low levels of physical activity, especially in female adolescents (aged 10–19 years)[269] and in older teenagers (aged 16–18 years) of both sexes, could also be contributing to the existing prevalence of being overweight and obese.[270] Physical activity policies include the *Strategic plan 2009–2013: An active and winning nation*,[271] of which one of the aims was to facilitate the implementation of sports in schools. In the *National sport and recreation plan*, one of the objectives is to maximize access to sport, recreation and physical education in every school.[272] Consolidated findings on the level of physical activity in children aged 3–19 years (e.g. early childhood physical activity, organized sport participation, active play and active transportation) showed an average participation of around 50%, although the percentage of those in early childhood (age 3–6 years) participating in physical activity was generally found to be high (~80%).[270] Since pre-school children are naturally active, a physical activity intervention for this age group was only deemed necessary for promoting the engagement of teachers and parents or caregivers, and for outcomes such as cognitive development.[273]

The South African noncommunicable disease strategy[29] targeted an increase in the prevalence of physical activity (150 minutes of moderate-intensity physical activity per week, or equivalent) by 10% by 2020, and the WHO global action plan for noncommunicable

diseases[4] targeted a 10% relative reduction in the prevalence of insufficient physical activity by 2020. Although our data do not allow a detailed analysis of types of physical activity, we demonstrated the importance of physical exercise. About half of those who exercised ≥ 3 times per week maintained a normal BMI even as the cohort aged. However, the fact that the proportion of this group who maintained a normal BMI decreased slightly over time may reflect decreasing levels of energy expenditure with age. Interventions that increase physical activity may therefore be necessary to reduce the large percentages of groups who remain either overweight or obese. Studies on obesity, especially in women, have identified obese participants who meet the WHO guidelines on physical activity but have very poor cardiorespiratory fitness, possibly attributable to a lack of high-intensity physical activity.[215, 274] Suggested interventions include encouraging participation in high-intensity activities, such as sports and aerobics, and discouraging sedentary behaviour.[275] A dose-response relationship is known to exist between physical activity and cardiorespiratory fitness.[276]

The recent introduction of higher tax on products such as sugar-sweetened beverages[277] will probably reduce consumption and consequently reduce the percentages transitioning upwards. However, the life course approach, the basis of many WHO strategies and recommendations for disease prevention and control,[4, 278] may be a better strategy for maintaining normal BMI from this age. The life course approach stresses the importance of early intervention by considering which stages, transitions and settings of a person's life are critical for promoting or restoring health.[279] For example, the workplace has been found to be an important setting for health promotion during adulthood.[280] Effective interventions include the promotion of healthy food options in canteens, and the provision of nutrition education and counselling.[281] Similar interventions in settings such as community centres, churches and recreational facilities should also be promoted.[282]37 Barriers to leisure activity participation, including lack of time and facilities, safety issues and negative community perceptions regarding weight loss, may also need to be addressed,[283] along with the accessibility and affordability of healthy food options through subsidies.[282]

Population groups that demonstrated a higher probability of remaining within the obese category included women, higher age groups (> 35 years), and those with a higher income and higher level of education. These groups are usually the target of public interventions and of the weight management programmes of private health-care providers.[284] However, our data show a high resistance to a downwards transition from either overweight or obese categories, and this resistance increases with time. Other studies have shown that although

weight loss can be achieved through lifestyle changes,[285, 286] maintaining this weight loss over the longer term can be difficult; only approximately one-fifth (20.6%; 47/228)[287] of those who achieve weight loss maintain it for ≥ 1 year,[287, 288] and the majority of those who embark on a weight-loss programme give up before achieving success.[289-292] Our results indicate that, despite considerable percentages of the cohort transitioning downwards, any reductions in the prevalence of obesity were cancelled out by the larger percentages of these population groups transitioning upwards; we therefore believe that the South African target[64] of achieving a 10% reduction in the prevalence of obesity by 2020 will not be met.

The main strength of our study was our analysis of BMI transitions within a nationally representative sample of participants from a panel survey spanning birth to adulthood. However, our study had limitations. Some of the risk factors associated with higher BMI categories in this study, such as household income, education level and amount of physical exercise, were self-reported and therefore likely to produce biased results, especially due to self-reporting on physical exercise. A second limitation was loss to follow-up from one wave of data collection to another. Since we assume those lost to follow-up were randomly distributed throughout the study population, and the remaining numbers at each subsequent data collection wave were sufficiently high, we consider our results to be free of bias.

To conclude, we have demonstrated that the proportion of upwards transitions to overweight and obese categories in the South African population increases sharply between the ages of 19 and 50 years. Once overweight or obese, the likelihood of transitioning to a normal BMI is low, particularly for women, those of higher age groups, and those with a higher income and a higher level of education. With this evidence, we provide essential guidance for the South African Department of Health in the development of strategies to control obesity and noncommunicable diseases. Our study results will allow limited public health resources to be focused on the necessary population segments in which the largest reductions in the prevalence of obesity can be made.

CHAPTER 5: PAPER 3

Wandai ME, Manda SOM, Aagaard-Hansen J, and Norris SA. Long-term blood pressure trajectories and associations with age and body mass index among urban women in South Africa. *Cardiovasc J Afr.* 2021; **32**: online publication, www.cvja.co.za, DOI: 10.5830/CVJA-2021-014 . *(*Submitted 24/8/20, accepted 31/3/21)

Abstract

Background: Blood pressure (BP) is known to increase inevitably with age. Understanding the different ages at which great gains could be achieved for intervention to prevent and control BP would be of public health importance.

Methods: Data collected between 2003 and 2014 from 1,969 women aged 22 to 89 years were used in this study. Growth curve models were fitted to describe intra- and inter-individual trajectories. For BP tracking, the intra-class correlation coefficient (ICC) was used to measure dependency of observations from the same individual.

Results: Four patterns were identified: a slow decrease in BP with age before 30 years; a period of gradual increase in midlife up to 60 years; a flattening and slightly declining trend; and another increase in BP in advanced age. These phases persisted but at slightly lower levels after adjustment for body mass index. Three groups of increasing trajectories were identified. The respective number (%) in the low, medium and highly elevated BP groups were 1 386 (70.4%), 482 (24.5%) and 101 (5.1%) for systolic BP; and 1 167 (59.3%), 709 (36.0%) and 93 (4.7%) for diastolic BP. The ICC was strong at 0.71 and 0.79 for systolic and diastolic BP, respectively.

Conclusion: These results show that BP preventative and control measures early in life would be beneficial for control later in life, and since increase in body mass index may worsen hypertension, it should be prevented early and independently.

Keywords: blood pressure, hypertension, body mass index, trajectory, intra-class correlation coefficient

5.1 Background

Hypertension is a major risk factor for non-communicable diseases (NCDs) especially stroke and heart attacks,[293] and in South Africa, it was estimated to account for 19.0% of cardiovascular diseases deaths in 2016.[294] The prevalence of hypertension for women aged

15 years and above was also estimated at 28.5%,[295] and increased steeply with age, with 84.0% of women aged 65 years and above having hypertension.[55] Urban populations have been shown to have higher hypertension prevalence compared with their rural counterparts,[295] and women in such dwellings have also been reported to have higher percentages than men.[296, 297]

Accelerated global efforts for the Prevention and Control of NCDs began during the High Level Meeting of Heads of State and Governments at the 66th session of the United Nations General Assembly in September 2011.[298] Following this, the South African department of health developed a strategy in line with the declaration in 2013, of which one of the ten goals and targets was to 'Reduce the prevalence of people with raised blood pressure by 20.0% by 2020 (through lifestyle and medication)'.[29]

Changes in both systolic and diastolic blood pressure (BP) with age are known to show an increasing trajectory that mostly starts between 30 and 40 years.[299-301] However, from approximately 50 years, diastolic blood pressure may plateau, and thereafter start to decline.[300, 301] An individual's BP trajectory can be used as an indicator for age related vascular stiffening or for existence of an underlying disease.[302]

Growth curves (trajectories) plays an important role in life course epidemiology,[303] and can be used in identifying groups of individuals at risk of developing high blood pressure using known risk factors.[304] In addition, population subgroups with different BP trajectories can be useful in selecting people who might benefit most from intervention for prevention of CVD risk.[305]

Although age is highly correlated with an increasing BP trajectory, some studies have however reported a decrease in systolic and diastolic BPs at the population level especially for communities in the developed countries of Western Europe, Australasia and North America,[306-308] and this decrease is usually attributed to lifestyle and pharmacological interventions.[308] Understanding how individuals' BPs change and how fast these changes occur (Intra-individual change) through the life course and the patterns for people with different attributes (inter-individual differences in the intra-individual change) could be important in determining best methods for prevention at the appropriate timing. The aim of this study was therefore to find out the association of age with long-term BP observations. The study had three specific objectives: (1) to identify groups of women with similar systolic blood pressure (SBP) and diastolic blood pressure (DBP) between 22 and 89 years; (2) to find out how the trajectories are affected by body mass index (BMI); and (3) identify critical ages

when intervention measures would be more appropriate in slowing down a steep upward trajectory.

5.2 Methods

5.2.1 Study population and measurements

The study consisted of four measurement time points of data collection on African women dwelling in urban Soweto, Johannesburg, who were care givers of children in the Birth to Twenty Plus cohort study. Majority of the caregivers were the mothers, however a few of the participants included other close relatives such as sisters, aunts, and grandmothers. Data included four waves collected between 2003 and 2014. The four waves provided a sample of 1,969 individuals who had at least one wave of measurements for SBP, DBP, body weight and height resulting in 4,554 observations. Blood pressure measurements were taken in a seated position after 30 minutes of seated rest. The SBP and DBP were measured twice on the right arm using a standard mercury sphygmomanometer and appropriately sized cuff. A final systolic/diastolic blood pressure was calculated by taking the average of the blood pressures at each time point. Hypertension was defined as systolic/diastolic BP of more than 140/90 and body mass index (BMI) in Kg/m^2 was classified according to World Health Organisation (WHO) as underweight (<18.5), normal weight (≥18.5 - <25), overweight (≥25 - <30) and obesity (≥30).

5.2.2 Statistical analysis

Multilevel (ML) growth curve models (technique to describe and explain an individual's change over time) were used to describe the intra-individual BPs trajectories and the inter-individual differences in the intra-individual changes with age used as the time metric. Three models were used to describe the patterns of change. The first (Model 1) had time effect as the only covariate, Model 2 described the changes by adjusting for BMI and Model 3 built on Model 2 by allowing effect of BMI to also vary randomly between individuals. To estimate the mean SBP and DBP trajectories as a function of age, quadratic and cubic nonlinear models were used in the analysis as growth trajectories are known to take a variety of shapes other than linear,[309] mostly characterised by increases or decreases. Age was centred at the minimum age of 22 years to help in the interpretation of the models' intercepts. As BMI is generally known to increase with age, it was included as a time varying covariate in

the second stage of modelling to find out its effect on the BP trajectories. The intraclass correlation coefficient (ICC) was used to measure the degree of dependency among observations within an individual. A group-based trajectory model was used to identify distinct groups for the BPs.[208, 209]

5.3 Results

Summary measures for age, BPs and BMI at the four time points are shown in Table 5.1. The mean age at first occasion (2003) was 41.1 years and 49.6 years in the 4th occasion. Systolic and diastolic BPs increased from one time point to another, but the increases became smaller with time, and almost remained unchanged especially for SBP between the 3rd and 4th occasions. Mean BMI for the four occasions was high, at obesity state, and remained almost constant between first and third waves, but increased by at least 2.5 Kg/m^2 by the fourth occasion. There is indication of constant variation of the BPs and BMI across the measurement occasions.

Table 5.1: Mean and standard deviation for age, SBP, DBP and body mass index at the four data collection time points.

Time point	N	Age (years)	SBP	DBP	BMI
2003	1,358	41.1 (7.9)	116.0 (20.1)	76.0 (12.4)	29.9 (6.4)
2005/6	1,343	43.4 (8.0)	128.9 (21.6)	80.6 (13.5)	30.7 (7.0)
2007/9	854	45.6 (8.2)	133.5 (21.0)	86.8 (12.9)	30.5 (7.1)
2011/14	999	49.6 (5.7)	134.1 (21.9)	88.7 (12.6)	33.2 (7.2)

Table 5.2 shows the percentage of hypertension by BMI categories at each data collection time point. The percentage that had hypertension in 2003 was 16.7% and by 2014, this had increased to 47.1%, and at each time point it was highest for those with an obese BMI as expected. The greatest percentage increase was between the first and the second occasions (after ≅2.4 years), where it almost doubled. For those with normal or overweight BMI statuses, the percentage of hypertension almost tripled between the 1st and 4th occasions. Between the 3rd and the 4th time points (≅5.3 years), the percentage of those with hypertension among participants in the obesity category remained almost unchanged (50.7% in 3rd occasion and 51.4% in 4th occasion), even though the percentage of obesity increased by more than 15.6 (50.4% to 66.0%) points between the two occasions.

Table 5.2: Hypertension percentages by BMI categories at the four data collection time points.

Time point	BMI		Blood pressure category		
	Category	n (%)	Non-hypertensive	Hypertensive	Total
2003	Underweight	24 (1.8)	22 (91.7)	2 (8.3)	24 (100.0)
	Normal	300 (22.1)	263 (87.7)	37 (12.3)	300 (100.0)
	Overweight	405 (29.8)	349 (86.2)	56 (13.8)	405 (100.0)
	Obese	629 (46.3)	497 (79.0)	132 (21.0)	629 (100.0)
	Total	**1,358 (100.0)**	**1,131 (83.3)**	**227 (16.7)**	**1,358 (100.0)**
2005/6	Underweight	19 (1.4)	12 (63.2)	7 (36.8)	19 (100.0)
	Normal	269 (20.0)	202 (75.1)	67 (24.9)	269 (100.0)
	Overweight	343 (25.5)	252 (73.5)	91 (26.5)	343 (100.0)
	Obese	712 (53.0)	467 (65.6)	245 (34.4)	712 (100.0)
	Total	**1343 (100.0)**	**933 (69.5)**	**410 (30.5)**	**1343 (100.0)**
2007/9	Underweight	10 (1.2)	5 (50.0)	5 (50.0)	10 (100.0)
	Normal	188 (22.0)	125 (66.5)	63 (33.5)	188 (100.0)
	Overweight	226 (26.5)	146 (64.6)	80 (35.4)	226 (100.0)
	Obese	430 (50.4)	212 (49.3)	218 (50.7)	430 (100.0)
	Total	**854 (100.0)**	**488 (57.1)**	**366 (42.9)**	**854 (100.0)**
2011/14	Underweight	7 (0.7)	4 (57.1)	3 (42.9)	7 (100.0)
	Normal	116 (11.6)	77 (66.4)	39 (33.6)	116 (100.0)
	Overweight	217 (21.7)	127 (58.5)	90 (41.5)	217 (100.0)
	Obese	659 (66.0)	320 (48.6)	339 (51.4)	659 (100.0)
	Total	**999 (100.0)**	**528 (52.9)**	**471 (47.2)**	**999 (100.0)**

5.3.1 Blood pressure average change and state transitions between two time points

Table 5.3 shows the mean change in the BPs and BMI between two observation periods. Between the first two time points, average SBP and DBP per individual changed by about 11.3- and 4.1 mmHg respectively but that change decreased substantially between the 3rd and 4th time points to about 1.7- and 1.1 mmHg. Majority remained in their BP status between observation times but with time (age), the percentage remaining in the hypertension state increased while that of remaining in the normotensive state decreased. Between the first two occasions when the average age at both times was below 45 years, the percentage of those who were normotensive who transited to hypertensive state was 21.5%, while the percentage for the counter transition was 33.3% or a net recovery of 11.8%. By the 4th occasion when the average age was about 50 years, those initially in the non-hypertensive state that transited to hypertensive state were 40.6%, but the counter-transition (recovery) rate was 15.6% or net increase of 25.0% to the hypertensive state.

Table 5.3: Average BP changes and shifts between categories at the four data collection time points.

Time points	Average years apart	BP category	n	BP category		Mean change (SD)	
				Non-hypertensive	Hypertensive	SBP	DBP
2003& 2005/6	2.4	Non-hypertensive	824	647 (78.5)	177 (21.5)	11.3 (19.3)	4.1 (12.1)
		Hypertensive	159	53 (33.3)	106 (66.7)		
		Total	**983**	**700 (71.2)**	**283 (28.8)**		
2005/6& 2007/9	2.0	Non-hypertensive	512	354 (69.1)	158 (30.9)	4.5 (20.4)	6.4 (11.9)
		Hypertensive	237	72 (30.4)	165 (69.6)		
		Total	**749**	**426 (56.9)**	**323 (43.1)**		
2007/9& 2011/14	5.3	Non-hypertensive	234	162 (69.2)	72 (30.8)	1.7 (19.0)	1.1 (11.2)
		Hypertensive	154	39 (25.3)	115 (74.7)		
		Total	**388**	**201 (51.8)**	**187 (48.2)**		
2003& 2007/9	4.4	Non-hypertensive	493	303 (61.5)	190 (38.5)	16.4 (20.9)	10.9 (12.6)
		Hypertensive	99	26 (26.3)	73 (73.7)		
		Total	**592**	**329 (55.6)**	**263 (44.4)**		
2005/6& 2011/14	7.3	Non-hypertensive	460	291 (63.3)	169 (36.7)	8.1 (22.3)	8.1 (12.6)
		Hypertensive	185	49 (26.5)	136 (73.5)		
		Total	**645**	**340 (52.7)**	**305 (47.3)**		
2003& 2011/14	9.7	Non-hypertensive	549	326 (59.4)	223 (40.6)	19.1 (20.4)	12.6 (12.3)
		Hypertensive	96	15 (15.6)	81 (84.4)		
		Total	**645**	**341 (52.9)**	**304 (47.1)**		

Figure 5.1 and Table 5.4 shows how the progression of BPs evolve. A crest (inverted u-shape) marks a negative (decrease) change while a trough (U-shape) marks a positive (increase) change. The figure however shows that the 95% confidence band for ages above 70 years are quite big and therefore the shape in that age group could be spurious. The first crest occurs around 25 years of age and is indicated by the negative coefficients (-1.8 for SBP and -1.5 for DBP) for age (Table 5.4), and the second around 60 years, and shown by the negative coefficient ((-0.004 for SBP and -0.003 for DBP) for age cubed. Similarly, the troughs are identifiable around ages 30 and 70 years and marked by the positive coefficients for age squared and age raised to power 4 (Table 5.4).

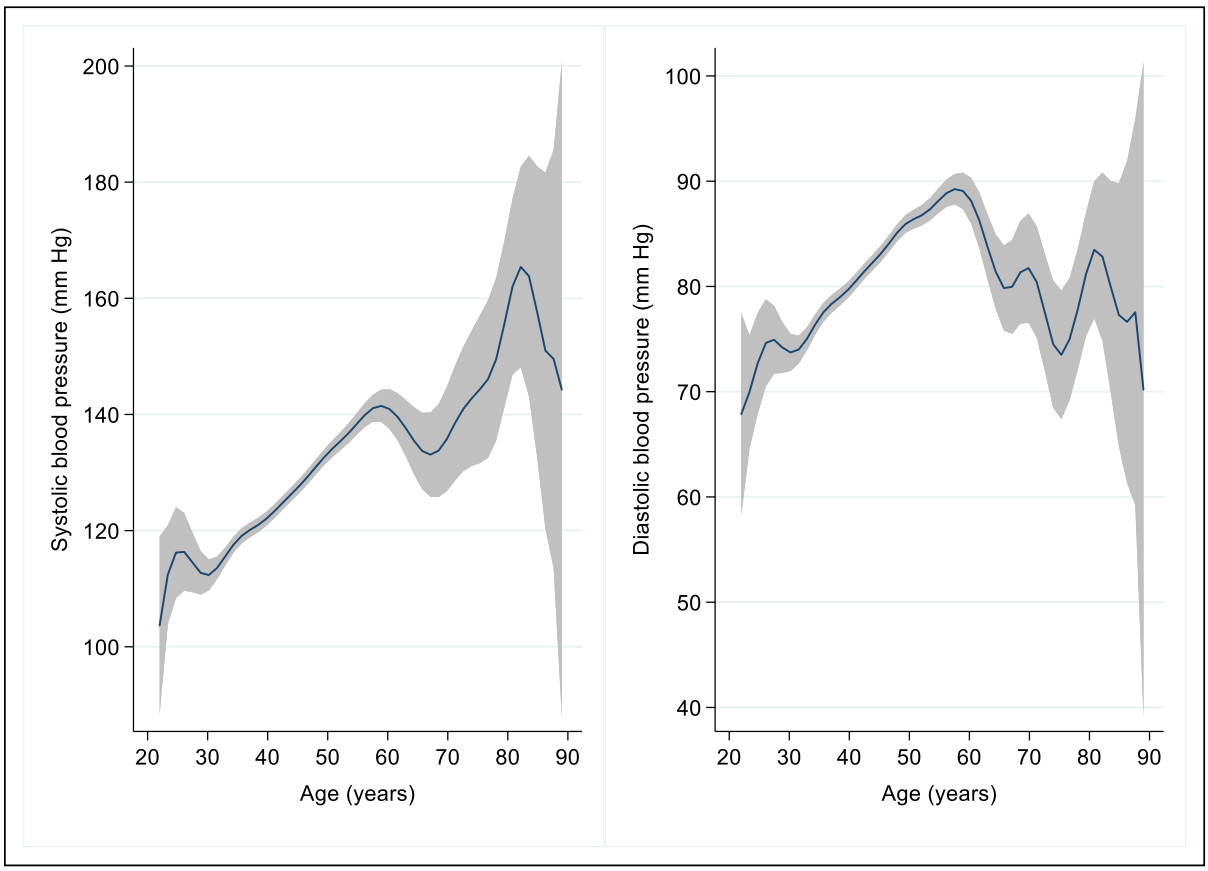


Figure 5.1. SBP and DBP trajectory with 95% confidence (greyed) by age

Model 1 describes the BP trajectories without accounting for the effect of the BMI, while Model 2 and Model 3 show the adjusted changes. The biggest impact of the BMI adjustment was on the intercepts, shifting each BP's mean trajectory downwards (116.2 to 105.0 for SBP, and 75.7 to 63.3 for DBP). Model 2 as shown in Table 5.4 included a random effect in the baseline values (intercept) to address the variability in starting point for each individual in the sample. Model 3 in addition to Model 2, allowed a random BMI effect (slope) for each individual to explain variability in the slope (change by BMI). The estimated SBP and DBP for the whole sample at 22 years of age is 105.0- and 63.3 mmHg respectively, and each individual value varies randomly around these baseline values with 24.3 standard deviations for SBP and 17.5 for DBP. Therefore 95% of the estimated individuals' BPs at age 22 lie between 105.0±1.96×24.3 = (57.4, 152.6) for SBP and 63.3±1.96×17.5= (29.0,96.7) for DBP. The estimated increases in the BPs for every 1 Kg/m^2 increase in BMI are 0.41 for SBP and 0.46 for DBP for the total sample. But the individual slopes (BMI effect) varies randomly around these values with standard deviation of 0.65 for SBP and 0.52 for DBP. Therefore the

95% CI for BMI slopes lie between 0.41±1.96×0.65 = (-0.86,1.68) for SBP and 0.46±1.96×0.52 = (-0.56,1.48) for DBP.

The correlation between the random intercepts and BMI random slopes is strongly inversely proportional (-0.82 for SBP and -0.87 for DBP) implying that higher values of baseline BP at the individual level were associated with a relatively smaller effect of BMI on BP and vice-versa. By including a random BMI effect, the intraclass correlation (correlation among observations within an individual) increased from 0.47 (Model 2) to 0.72 (Model 3) for SBP and from 0.49 to 0.79 for DBP. In addition, the variability in the random intercepts also increased from 14.4 (Model 2) to 24.3 (Model 3) for SBP, and from 9.1 (Model 2) to 17.5 (Model 3) for DBP.

Table 5.4: Coefficients and 95% confidence interval (in parenthesis) for the three models predicting SBP and DBP trajectories with standard deviations (SD) for the random effects.

BP	Fixed effects	Model 1	Model 2	Model 3
Systolic	Intercept	116.2 (106.7,125.7)	105.5 (95.7,115.3)	105.0 (95.1,114.9)
	Age	-1.7 (-3.3,-0.1)	-1.7 (-3.4,-0.1)	-1.8 (-3.4,-0.2)
	Age squared	0.18 (0.08,0.27)	0.17 (0.08,0.27)	0.17 (0.08,0.27)
	Age cubed	-0.004 (-0.006,-0.002)	-0.004 (-0.006,-0.002)	-0.004 (-0.006,-0.002)
	Age to power 4	0.00003 (0.00001,0.00005)	0.00003 (0.00001,0.00005)	0.00003 (0.00001,0.00005)
	BMI		0.39 (0.29,0.49)	0.41 (0.30,0.52)
	Random effects			
	SD (Intercept)	14.5 (13.7,15.2)	14.4 (13.7,15.1)	24.3 (18.4,32.2)
	SD (BMI)			0.65 (0.43,0.96)
	Correlation (BMI, Intercept)			-0.82 (-0.91,-0.66)
	SD (Residual)	15.5 (15.1,15.9)	15.4 (15.0,15.8)	15.2 (14.8,15.7)
	ICC	0.47 (0.43,0.50)	0.47 (0.43,0.50)	0.72 (0.59,0.82)
Diastolic	**Fixed effects**	**Model 1**	**Model 2**	**Model 3**
	Intercept	75.7 (69.8,81.5)	64.5 (58.5,70.4)	63.3 (57.2,69.3)
	Age	-1.4 (-2.4,-0.4)	-1.4 (-2.4,-0.4)	-1.5 (-2.4,-0.5)
	Age squared	0.15 (0.09,0.21)	0.14 (0.08,0.20)	0.14 (0.08,0.20)
	Age cubed	-0.004 (-0.005,-0.002)	-0.003 (-0.005,-0.002)	-0.003 (-0.005,-0.002)
	Age to power 4	0.00003 (0.00001,0.00004)	0.00002 (0.00001,0.00004)	0.00002 (0.00001,0.00004)
	BMI		0.41 (0.35,0.47)	0.46 (0.39,0.53)
	Random effects			
	SD (Intercept)	9.4 (8.9,9.9)	9.1 (8.6,9.5)	17.5 (14.2,21.7)
	SD (BMI)			0.52 (0.41,0.67)
	Correlation (BMI, Intercept)			-0.87 (-0.92,-0.79)
	SD (Residual)	9.4 (9.1,9.6)	9.3 (9.0,9.5)	9.0 (8.8,9.3)
	ICC	0.50 (0.47,0.53)	0.49 (0.46,0.52)	0.79 (0.71,0.85)

5.3.2 BMI adjusted group-based trajectories by average age at observation times

There were three distinct groups from the 1,969 individuals (Figure 5.2). The low BP trajectory group comprised the majority of the study participants (70.4% for SBP and 59.3% for DBP), and showed a trajectory that was initially in the normotensive state but gently rose to the pre-hypertensive region. A medium BP trajectory (24.5% for SBP and 36.0% for DBP) had an initial average BP in the pre-hypertensive state that gradually rose to the hypertensive level, while the third group of about 5.0% had highly elevated increasing BPs throughout. Individuals in the medium and highly elevated BP groups were most likely to be in the ages 40 and above at baseline, while most of those in the low BP group were 40 years and below initially.

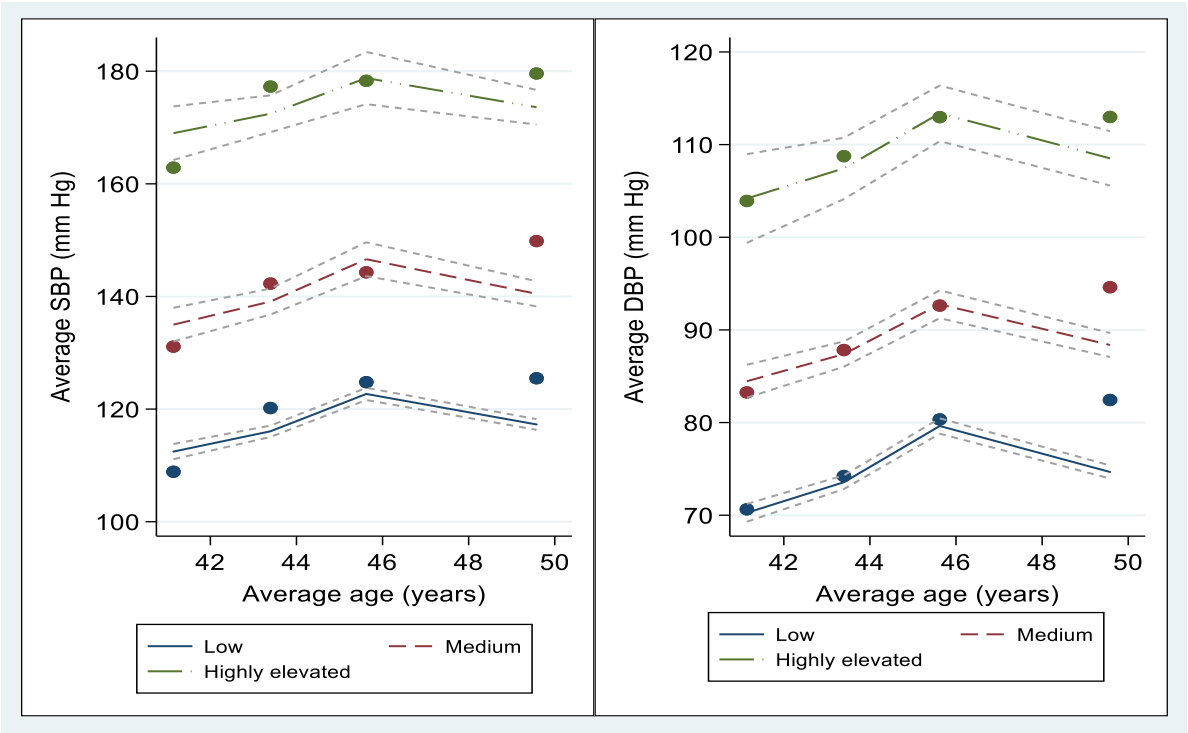


Figure 5.2. Observed and BMI adjusted SBP and DBP trajectories by average age at data collection time points.

5.4 Discussion

This study examined BP life course trajectories for a period of approximately ten years for women from an urban setting in South Africa and how these trajectories were related to changes in BMI. The trajectories were initially characterised by a short instance of decreasing SBP and DBP with age up to around 30 years (Figure 5.1 and Table 5.4). Although our sample

for ages below 30 years was small, which could have affected the shape of the trajectories, other studies have shown small downward changes in BP in early adulthood, which could be associated with capacity for vascular repair or adaptions.[19, 310, 311] Possible vascular repair could be reason for our results showing that the percentage recovering from hypertensive to normotensive state was highest (Table 5.3) in relatively younger ages. A second phase of rapid increases in the trajectories begins from around 30 years up to 60 years. This closely mirrors data from the Framingham Heart Study, which showed that SBP increases continuously between 30 and 84 years, but for DBP the continuous increase was between 30 and 49 years.[16] Increasing SBP and DBP are associated with increased peripheral vascular resistance (PVR) up to around 50 years, while large arterial stiffness (LAS) leads to the steeper rise in SBP after 50 years.[312] Studies have shown that younger women have less stiff arteries compared with men of similar age,[313, 314] but increased stiffness occurs after menopause. Attention for control of BP in post-menopausal women would therefore reduce risk for cerebrovascular and cardiovascular events.[312] Understanding the variation in midlife BP trajectories and factors associated with this acceleration may be important in understanding the development and prevention of CVD risk, and strategies for lowering the BPs as per the National Strategic Plan.[29]

A third phase from around 60 years of age show a flattening or slightly decreasing trajectory for both BPs (Figure 5.1 and Table 5.4). Similar studies have shown a decreasing trend for SBP at ages >65 years,[18] and for DBP from >55 years.[315] A decline in BP in old age has been linked to deteriorating health.[21, 22] Decreasing SBP with age has been associated with dementia, depression, poly-pharmacy (use of a large number of medications), and increased number of comorbidities.[23, 316] A steeper decrease in both SBP and DBP has been associated with diagnosis of diabetes,[317] and an increase in all-cause and cardiovascular mortality.[318] However, longer-term decreases in BP have also been shown to occur with or without the presence of hypertension, heart failure, atrial fibrillation, or stroke,[26] implying that decreasing BP could be due to low cardiac output, a feature of ageing.[319] The deceleration and decline of BP in old age is also associated with use of antihypertensive medication,[19] which we did not account for in this study.

The results of the three group-based trajectories show that the averages for both BPs were either in the prehypertensive or hypertensive levels for the medium and highly elevated BP groups. The proportion of women in these two groups of trajectories aged 45 years or above was more than those in the lower BP trajectory group. Persistently elevated BP and

hypertension trajectories have been associated with increased incidence of atrial fibrillation (AF) with the associations being stronger in women than men.[320] It has also been associated with higher risk of subclinical renal damage (SRD) since evidence shows that the higher the levels of SBP in early life course, the higher the urinary albumin-to-creatinine ratio (uACR) and risk of SRD later in life.[321] Some studies have suggested that individuals with high BPs especially SBP in midlife are at a higher risk of arterial stiffening.[322, 323] Evidence has shown that continuously high BP for years is closely correlated with subclinical atherosclerosis,[324] intima media thickness, and left ventricular mass index.[325]

The unadjusted trajectories reflect the added effect of ageing and the influence of other life course risk factors such as BMI. Generally, the effect of BMI on blood pressure trajectories affected the baseline value (intercept) more than the rate of change (slope). This could be an indication that the effect of BMI on BP is as result of BMI increases that usually and rapidly take place early in life. Accelerated weight gain and increased BMI in childhood and early adult life increase the risk of elevated BP and the development of hypertension in later life.[326, 327] Surveys in South Africa have shown that the average BMI for women by age 30 is more than 28.0 kg/m^3,[181-185] which is in the upper range of the overweight level. Majority of the women in this study were at least 30 years old, and the average BMI at the first encounter was 29.9 kg/m^3. An increase in BMI could lead to arterial stiffness, which may cause development of higher BPs.[328] Higher systolic BP levels reflect the stiffening of the arterial walls in areas exposed to increased pressure,[329] while coronary perfusion of the myocardium may be related to diastolic BP.[330]

Allowing the effect of BMI to vary by individual brought about three more important findings. First, the standard deviation of the random intercepts increased, an indication that baseline BPs by individuals varied greatly. This was evident from the clear distinction in the group trajectories, that did not interact at any time point. Secondly, the results showed that the effect of the BMI on BP changes was higher in women who initially were in the normotensive status (low group), and the effect progressively becoming less in those initially in pre-hypertensive (medium group) and hypertensive (highly elevated) states. The third issue relates to the correlation between measurements from the same individual which became more preeminent after allowing effect of BMI to be specific to individual. A stronger correlation can be helpful in tracking those likely to persistently have high BPs. Tracking of a characteristic is the stability of a certain feature over time or its predictability based on earlier measurements[331, 332] Tracking stability of BPs is of considerable public health interest because

those at high risk to develop hypertension might be identified at an early stage,[333] through screening. The influence of BMI change on BP tracking emphasizes the importance of weight control in early ages. Maintenance of normal weight gain in childhood may prevent clustering of hypertension and cardiovascular disease risk factors in adulthood.[334]

The ideal trajectory for BP is one with minimal fluctuations within the normotensive ranges across all ages. Favourable (less steep trajectory) BP trends are attributed to socially patterned and modifiable BP-related exposures such as lifestyle and diet.[335, 336] Few studies from isolated communities such as forager-farmers have shown minimal age-related BP increases in comparison to western societies.[337] These communities however have adopted a predominantly vegetarian diet with very low salt content, physically active lifestyle, and very low or non-existent obesity levels.[337-339] Individuals who undergo an urban migration from one of these isolated communities have been found to adapt quickly to BP profiles of their adopted communities.[338]

The main limitation to the study was that we were unable to account for subjects on antihypertensive medications which could also have contributed to the decreasing BPs with increasing BMI in higher age groups and the majority of the women (>70.0%) having SBP in the lowest of the three trajectories groups. Nonetheless controlling BMI for this and similar populations should be prioritised as it could be beneficial in many ways and possibly cheaper in BP control than medication alone. Another limitation was that the sample size for women above 60 years at any time point was smaller and this was reason for the volatile trajectory in this age range. Notwithstanding, the major strength was in using repeated BP and anthropometric measurements which helped in analysing long-term trends of BP changes as they are influenced by age and BMI. This can be useful in guiding clinical practitioners to focus on population segments with particular risk profiles. Another strength was the study's result showing that effect of BMI on elevation of BPs was not similar for all individuals and this could help in clinical practice by designing individualised interventions.

5.5 Conclusions

Three subgroups of increasing systolic and diastolic BP trajectories were identified, with majority of the women for each BP type falling in the lowest group that on average were initially in the normotensive state. The effect of BMI on the BP trajectory for age was highest in women who initially had relatively lower (mostly in normotensive state) initial BPs. This

BMI effect gradually dropped in tandem with increasing initial BP. The study also showed that steep increasing trajectories could be avoided if preventive interventions are implemented between 30 and 40 years of age from when BP starts to steeply increase. Follow up study is required to find out if these trajectories would be similar to findings from a larger and more diverse nationally representative sample.

SECTION 3: INTEGRATED DISCUSSION AND CONCLUSION

"After all, you must make careful plans before you fight a battle, and the more good advice you get, the more likely you are to win" (King Solomon, Proverbs 24:6, GNT.)

CHAPTER 6: GENERAL DISCUSSION

This chapter consolidates the research findings based on the aim and specific objectives. It also discusses the emerging themes identified by the research and relevance of findings to the South African and sub-Saharan context. Finally, the thesis limitations and future research focus are highlighted.

6.1 Summary of findings

The main aim of this PhD study was to profile and monitor the spatial and temporal changes of hypertension and body mass index, two major risk factors for noncommunicable diseases, using two sets of longitudinal data. The summary of the findings related to each of the three specific objectives of the study are shown in Table 6.1 below.

Table 6.1: Summary of the thesis key findings based on the specific objectives

Objective	**Key findings**	**Conclusions**
Objective 1 (Chapter 3): To estimate and compare the prevalence of hypertension over time and by districts for individuals aged 15 years and above.	▪ The national hypertension prevalence averaged 29.8% between 2008 and 2017 but was lowest in 2017 at 27.9%. By district municipality, it was lowest (19.1%) at Vhembe district of Limpopo province and highest (47.0%) at Central Karoo and Overberg districts of the Western Cape province.	▪ The findings from this study showed that there were significant differences in the prevalence of hypertension at the district level in South Africa. ▪ Lower-than-average prevalence was found in the northern and north-eastern districts of Limpopo, Mpumalanga, and Gauteng provinces, while districts with higher prevalence than average were from the Western Cape and Northern Cape provinces.

Objective	Key findings	Conclusions
		▪ There could have been other risk factors not captured in the data that were associated with hypertension prevalence and were also distributed unequally between the districts.
Objective 2 (Chapter 4): To estimate the transition rates between BMI categories and to assess the factors associated with the transitions across all ages	▪ To transit to an upward BMI, women were 2.56 more likely than men, those with higher level of education 1.69 more likely than those with no education, and those from high income tertile households 1.46 more likely than those from low-income household tertile. ▪ To transit to a downward BMI, women were 1.82 more likely than men, those with higher level of education 1.43 more likely than those with no education, and those from high income tertile households 1.28 more likely than those from	▪ This part of the PhD thesis demonstrated that the proportion of upward transitions to overweight and obese categories in the South African population increases sharply between the ages of 19 and 50 years. ▪ Once overweight or obese, the likelihood of transitioning to a normal BMI is low, particularly for women, those of higher age groups, and those with a higher income and a higher level of education. ▪ Based on these findings, scarce public health resources should be channelled to population segments in which the largest reductions in the

Objective	Key findings	Conclusions
	low-income household tertile.	prevalence of obesity can be made.
Objective 3 (Chapter 5): To profile systolic and diastolic blood pressure changes by age and the effect of body mass index on the changes for women aged 22 to 89 years from an urban township	▪ The ages between 30 to 60 years mark a period of sharp increase for BPs, especially SBP. ▪ The ICC was strong at 0.71 and 0.79 for SBP and DBP, respectively showing that BP measurements from same individual were more similar from one period to another. ▪ Three subgroups of increasing systolic and diastolic BP trajectories were identified, with majority (70.4% for SBP and 59.3% for DBP) of the women for each BP type falling in the 'low' group. ▪ The effect of BMI on the BP trajectory for age was highest in women who initially had relatively lower initial BPs.	▪ Based on these findings, preventive interventions implemented early in life (30 to 40 years of age) from when BP starts to steeply increase could possibly help lower the rate of BP increase with age.

6.2 Themes emerging from the thesis

This thesis' main aim was to profile and monitor two important risk factors for NCDs, that is, hypertension and increased body mass index (overweight/obesity). This hopefully would add to and provide necessary information that can be helpful in the improvements of the SA strategy for prevention and control of NCDs[29] and the strategy for prevention and control of obesity.[64] According to the national NCD strategy, the comprehensive approach to combating NCDs consists of three sub-strategies of which the 3rd was to "Monitor NCDs and their main risk factors and conduct innovative research."[29] Research is also an essential component in the SA strategy for obesity prevention and control to help understand distribution of factors determining its prevalence. This study could be useful in providing information that can contribute to the planning and evaluation of interventions based on the following themes that emerged from the study findings.

i. The results in this thesis show that prevalence of hypertension and overweight/obesity are still high, despite slight decrease in the prevalence of hypertension. This being the case, efforts to reverse the increasing trends especially in the prevalence of obesity should still be prioritised. One way that this could be done is through a strengthened health system, preferably by empowering community health workers and use of technological advancement for improved NCDs prevention and management.
ii. Achievement of set targets relating to these two risk factors for NCD as per the government's strategic plans may not have been achieved by the set time.
iii. There is need for an improved monitoring and surveillance system for the tracking of the risk factors for NCDs.

6.2.1 Strengthening of the health care system for improved NCDs prevention, control, and management

The focus of this PhD study was spatial and temporal changes in BP and BMI, and the result finding identified areas and groups of individuals at increased risk. As pointed out in the literature review and also in this thesis, age is known to be a major determinant for both hypertension and overweigh/obesity. In this thesis, it was further shown the ages when great gains could be made for prevention and control of these two risk factors for NCDs,

where the likelihood to maintain or reverse to a normalised BP or BMI state is highest. Improving interventions tailored to localised needs would therefore be key in achieving the country's set targets for control and prevention of NCDs. An important aspect to do this is through a strengthened health system.

Strengthening of the health system for service availability and readiness in terms of access to care and quality of interventions was core in the SA NCD strategic plan. This was proposed in the strategy and was to be implemented through the district health system (DHS) principles based on prevailing and unique health conditions of each district, where more resources could be committed to those districts with high disease burden and in dire need of preventative and control measures.[340]

Health system's effectiveness in sub-Sahara countries could negatively be impacted due to ripple effect that can occasioned by lack of prevention and control of the common risk factors for overweight/obesity and hypertension. Health systems in LMICs have been reported to focus on curative care at the expense of prevention, even though the high cost of curative services is unaffordable for most individuals in these populations.[341] The importance of primordial and primary prevention of social determinants of health such as poverty, and unhealthy lifestyles (smoking, alcohol use, and physical inactivity) as proposed in the SA NCD Strategy[29] becomes more critical given the ripple and multiplier effect on the health system effectiveness to deal with NCDs. Physical inactivity as proxied in this study by low levels of physical exercise, and socioeconomic factors were strongly associated with obesity, which in turn was a strong determinant of hypertension. A consequence of this is that in most cases patients with hypertension will develop CVD and most likely be diagnosed with diabetes mellitus. Treating multimorbid conditions poses a big challenge as NCDs are known to be costly, and many health systems in African countries may be unable to cope with the rising burden due to limited resources and infrastructure.[342] Health system capacitation especially in the primary health care setting would be key for early diagnosis particularly in the high risk districts and individuals.

It has been noted that there are challenges associated with timely screening and diagnosis for blood pressure and excessive body mass that cause overweight and obesity at the primary health care setting.[343] Among the challenges include inadequate health workforce to undertake these activities, community unawareness regarding BP, overweight/obesity and NCDs and inaccessible health services related to individual circumstances (lack of transport, time, health seeking behaviour).[344] In this study majority of those identified with

hypertension (SBP≥140 or DBP≥90 or current use of antihypertensive drug treatment) had not previously been informed by a health practitioner they were hypertensive. This could be due to the asymptomatic nature of hypertension which could cause those who are in that state not to seek healthcare services. Empowering Community Health Workers (CHWs) can help ease the barriers to healthcare access. CHWs are considered an indispensable asset in the health system set up as they live within the community they serve, and they understand the cultural dynamics of the people who live around them. Adequate training and continuous retraining, could empower CHWs to screen for CVD risks such as raised blood pressure and excessive weight gain, and to make decisions on referrals as necessary.[345] Efficiency, accuracy, and reliability are key in disease monitoring and surveillance, and the use of mobile technology could be useful in empowering the CHWs. The mobile technology has been associated with reduced training for CHWs and CVD risk screening time, elimination of calculation errors of CVD risk score, and end user satisfaction when compared with paper-based application.[346]

Prevention of diseases, reduction of their burden and health promotion is one of the NDoH's goals according to the national development plan (NDP). Health promotion can be supported by using mobile technology to relay health lifestyle education according to the South Africa mHealth strategy 2015-2019.[347] Health messaging is an invaluable tool for health promotion and dissemination of health information that can be used by governments, businesses, public health practitioners and community leaders to inspire behavioural and social change for prevention of non-communicable diseases. An important part of the strategies for NCD and obesity prevention and control is that of raising awareness. For example the strategy for prevention and control of obesity has the following statement: "The public at large should not only be aware of obesity and its consequences, but also be encouraged to become advocates for change, not only in their own lives, but also in the places in which they live, work and play, and to which they travel.[64]" Such awareness can be raised through the mobile technology as a large proportion of the South Africa population have access to a mobile phone and national network coverage is over 90.0%.[348] The department of health recently has proved that it has that capacity as at the onset and peak of the COVID-19 pandemic, it used to send text messages to raise awareness on importance of adhering to the WHO guidelines for prevention and control of the corona virus. It is interesting to note that fast food vendors use the mobile technology to promote their offerings to customers in their database, as the strategy is considered relatively cheap.

6.2.2 Relevance in monitoring of the set targets as per the government's NCD strategies

The SA NDoH had a set of 10 targets in the NCD strategy of which one of them was to "reduce the prevalence of people with raised blood pressure by 20.0% by 2020 (through lifestyle and medication)". The obesity strategy targeted a 3.0% decrease in the prevalence of overweight and obesity by 2017, and a 10.0% decrease by 2020 for all age groups.
The prevalence of hypertension based on risk-factor unadjusted and adjusted results showed a decreasing trend between 2008 and 2017. In absolute terms, the whole sample showed a decrease in the prevalence by approximately 5.0 percentage points between 2012 (when the NCD strategy was put in place) and 2017. Although the target of 20.0% decrease in the prevalence was by 2020, the NDoH may not be close to achieving this target, given that the 5.0% decrease was achieved in a period of 5 years. This decrease could be more attributed to higher hypertension control through medication for those who may have reported being informed by a health professional that they were hypertensive rather than through lifestyle change.
Although this PhD study did not analyse the change in the BMI prevalence cross-sectionally by age, it was able to show that the prevalence of obesity decreased from the tender age to end of teenage life from where it starts to increase. The results showed that the transition rates upwardly were higher than those downwardly for all age groups except for those 6 years and below and the over 55 years age category. This together with the fact that the percentage of those remaining in the obesity state increase with time is an indication that overweight and obesity prevalence has not decreased, which could be as a consequence of non-adoption on lifestyle changes in diet and physical activity. It would be anticipated that if the prevalence of BMI were to decrease as targeted, the prevalence of hypertension would decrease further than what was already found in this study, as BMI was a strong factor associated with hypertension prevalence.

6.2.3 Improvement in the monitoring and surveillance of NCD risk factors

This thesis also demonstrated the usefulness of regularly collected data for the surveillance of changes in the risk factors for NCDs with an indirect inference on how the SA surveillance system for NCDs can be strengthened. Due to the multimorbidity of the NCDs and the interrelationships in their risk factors, an effective surveillance system should allow monitoring of these conditions comprehensively. In this thesis, the NiDS data that have a

national representation only facilitated studying changes in BP and BMI. Measurement data for tracking changes on other important metabolic risk factors such as Hyperglycaemia and hyperlipidaemia were unavailable.

Detailed and regular collection of epidemiological data on NCDs and their risk factors is the basis for good public health monitoring and surveillance activities on health indicators, that could help in improving or modifying intervention strategies over time, place, and population groups. The WHO STEPwise approach to Surveillance (STEPS) is a 3-step method for collecting, analysing, and disseminating NCD risk factor data that has been proposed by WHO for its member states (Figure 6.1.[349]) The three steps for the data collection instruments consist of: Step 1 (questionnaire on self-report measures on socio-economic, tobacco and alcohol use, dietary behaviour and physical inactivity markers), Step 2 (measurements on anthropometry and blood pressure) and Step 3 (biochemical measurements such as total cholesterol, blood glucose and cotinine from blood and urine samples)

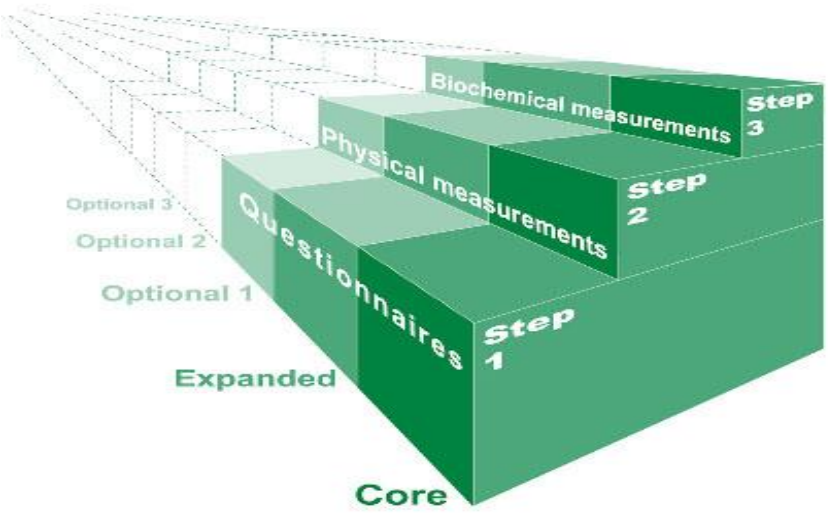


Figure 6.1: WHO STEPwise approach

In South Africa however, formalised WHO STEPS surveys are not conducted, even though some of the STEPS questions are included in the large-scale national surveys such as SADHS, SANHANES, and NiDS. For reliable monitoring and surveillance of NCD lifestyle risk factors, data will need to be comprehensive and regular for it to advise synergistic interventions for control of hypertension, BMI, and consequently NCDs. The NiDS data used in this thesis can be considered as a STEPwise survey consisting of the first two steps, and so far, it has good regularity (2-2½ years). Nevertheless, for NiDS to be more usable in monitoring NCD risk

factors, improvement is needed to make it more detailed and comprehensive by including the biochemical measurements. Dietary behaviour on daily consumption of fruits and vegetables, and salt intake cannot be analysed as such data elements are not included in the NiDS questionnaires. Sadly also, it appears that NiDS questionnaire no longer captures data on alcohol consumption as of wave 5. However, NiDS being a panel survey remains particularly useful in tracking changes in the risk factors at the individual level. SADHS and SANHANES which have national representation are comprehensive and detailed and can be considered equivalent to a complete STEPwise survey with the 3 steps, but they are both irregular. Other site and small-scale comprehensive surveys conducted in SA include HDSS survey in Dikgale HDSS site,[233] and the BT20 Plus study. Prioritising initiatives for improvements in the surveillance system can greatly enable a holistic tracking of NCDs and their risk factors.

6.3 Conceptual framework revisited

The hierarchical conceptual framework (Figure 1.2) including the different levels that describe developmental relationship between the risk factors for NCDs formed the basis of this PhD research. Each level of the hierarchy forms an important point for prevention and control interventions either separately or jointly. The conceptual framework showed demographic and socioeconomic factors are at the first level of the hierarchy forming the distal risk factors for both BMI and hypertension. Education and household income were the most important socioeconomic factors in this thesis. While lower levels of these two factors were risk factors for hypertension, higher education and higher income were risk factors for overweight and obesity (results not reported). This shows a need for differentiated interventions. Low socioeconomic status (SES) can lead to delayed health seeking behaviour due to limitations in accessing healthcare and information, while high SES can lead to more sedentary life.

The behavioural or lifestyle factors (physical inactivity, alcohol use, and smoking) formed the second level in the hierarchy and are usually influenced by demographic and socioeconomic factors. Although data limitation neither allowed analysis of dietary behaviour (salt, fruit and vegetable intake), nor how the other lifestyle factors (alcohol and smoke use, and physical exercise) varied by demographic and socioeconomic factors, literature does show for example, that gender is associated with alcohol use,[350] smoking, physical exercise and

dietary choices.[351] These behavioural factors also differ by socioeconomic factors (income, education and employment.[352]) In this thesis, alcohol use had a positive association with hypertension and a negative association with overweight and obesity.

BMI acting as a proximal risk factor and an intermediary level in the hierarchy between lifestyle factors and hypertension was strongly associated with hypertension, and itself (BMI) as an outcome was positively associated with low level of physical inactivity (proxied in this study by low levels of physical exercise), and negatively associated with smoking. These two lifestyle factors (physical inactivity and smoking) did not show significant correlation with hypertension. While smoking cannot be used as a strategy for weight control, lifestyle interventions for prevention and control of overweight and obesity will inadvertently lead to prevention and control of hypertension.

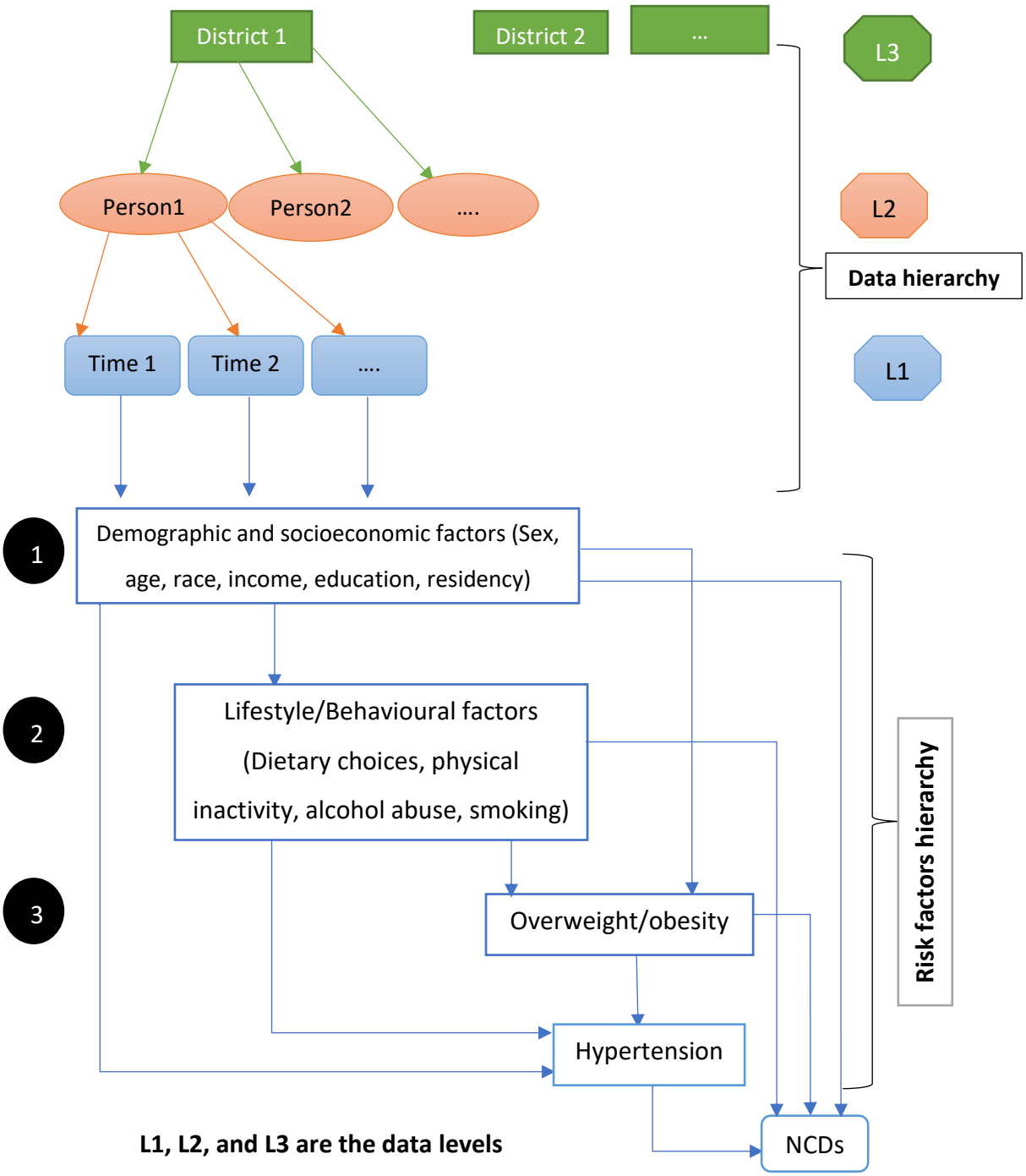


Figure 6.2: Extended conceptual framework with data and risk factors hierarchies

While the thesis confirms this framework, it also adds another dimension in the hierarchical structures as introduced in the analysis strategy, and which can help in improving prevention and control interventions. According to this improved framework, individuals' BMI and hypertension statuses form hierarchies over time, where previous statuses influenced subsequent status. Knowledge of individual history would be beneficial in designing individualised interventions especially for those requiring physician/dietitian counselling.

The other levels of nesting involve these individuals being nested in households which in turn are nested in geographic zones (health districts). As the results from the thesis showed, districts explained variation in the prevalence of hypertension over and above the effect of individual risk factors. This knowledge is of importance as community-based interventions can be implemented through the district health system. The adjusted conceptual framework is shown in Figure 6.2.

6.4 Relevance of the study in SA and African context

It is projected that by the year 2030, deaths arising from the burden due to NCDs in the African countries will exceed that due to infectious, maternal and child causes.[353, 354] In South Africa, the probability of dying from one of the four main NCDs (cardiovascular diseases, cancer, chronic respiratory diseases and diabetes) between ages 30 and 70 is 25.0%.[355] To effectively address these challenges, South Africa and the rest of sub-Saharan Africa require epidemiological data on NCDs and their risk factors,[356] which was the focus of this research.

The availability of data on the major risk factors for NCDs is important in the formulation of policies and strategies for the prevention and control of NCDs in the population. These data are also critical for programme planning, monitoring and evaluation. According to the SA strategies for NCD and obesity, data for monitoring the set targets were to be sourced from various surveys such as General household Surveys by Statistics South Africa, the South African National Health and Nutrition Examination Survey (SANHANES) and the Demographic and Health Survey. They were also be sourced from routine systems such as the District health information System, National cancer registry, and the Chronic Disease Register. The present research sourced data from two important panel/longitudinal studies, that is the NiDS and BT20 plus study to address its aim. This, as noted in section 6.2.3, shows the importance and need for strengthening these data sources so that they can continuously be relevant in providing information necessary to combat the burden of NCDs in South Africa. One of the research priorities according to the SA strategy for prevention and control of NCDs was “Inter-sectoral and multidisciplinary research to understand the influence of the macro-economic and social determinants of NCDs and their risk factors as an important guide for inter-sectoral action at district level”.[29] The results from the first section of this

study looked at the prevalence of hypertension disaggregated at the district level, findings which can be reliably used for programming interventions at this level.

The WHO Global Action Plan on NCDs, the SA NCD strategy and the SA obesity strategy include sections that address the importance of monitoring, evaluation and research on the trends of NCDs and related risk factors in order to determine progress in their prevention and control. One aspect of this monitoring requires establishing a surveillance system by identifying data sets and sources on behavioural and metabolic risk factors. The thesis is therefore relevant in that it used data from already established longitudinal/panel studies to monitor obesity and raised blood pressure. As already mentioned earlier, the NiDS being a national study can further be strengthened by adding collection of other biomarkers such as blood glucose, hyperlipidaemia, nicotine concentrations in the blood, and cardiovascular fitness using the 3-minute step test. The BT20 plus study can also be utilised to collect similar data items on spouses and partners of the women caregivers in this study.

According to the 2011 "UN Political Declaration of the High-level Meeting of the General Assembly on the Prevention and Control of Non-communicable Diseases,"[255] the heads of states and governments, committed to a number of resolutions. One of the resolutions (Number 45 (e)) was to strengthen national policies and health systems by pursuing and promoting "gender-based approaches for the prevention and control of NCDs founded on data disaggregated by sex and age in an effort to address the critical differences in the risks of morbidity and mortality from NCDs for women and men".[255] In this thesis such disaggregation was carried out and it showed the burden of hypertension and BMI changes varied greatly by age and sex. In addition, the disaggregation was taken one step further by adding spatial and temporal dimensions. In the SA "strategy for prevention and control of obesity 2015-2020", the targets set were same for all ages, and as such this may need to be reviewed to practically address the degree of the variation in the burden.

The study section on BMI transitions (Chapter 4) clearly identified the ages (end of teenage) from when transitions to obesity start picking up. These results therefore provide a basis for directing fund allocation and campaigns on improvement of interventions that promote healthy food options post high school years at the tertiary educational institutions, the workplace, and the community at large. National and subnational policies could focus on improving the physical and social environment to make it more accessible and safer for planned physical activities such as walking, jogging, and cycling, especially in the urban environment. These initiatives should support and encourage physical activity for adults (>19

years), and especially for those above 40 years from when the probability for resistance to transit out of obesity state is highest. In the school/education and workplace environments, the time-restricted intervention[357] could be ideal as it may be relatively easier to self-restrict access to foods compared to the home environment. In this type of intervention, meal consumption is restricted to certain hours (8-12) of the day allowing a continuous daily fasting period of more than 12 hours.

Understanding the biological mechanism of how excessive weight and hypertension affects the cardiovascular function may help an appreciation of the benefits for prevention of obesity and hypertension at an early stage in life as recommended from findings in this study. As confirmed in the study, obese individuals had a high prevalence of hypertension. Blood pressure is calculated by multiplying the cardiac output (amount of blood the heart pumps in a minute) by the systemic vascular resistance (the amount of force exerted on circulating blood by the blood vessels of the body.[358, 359]) This relationship is expressed mathematically as:[7]

$$\text{Blood pressure (BP)} = \text{Cardiac output (CO)} \times \text{Systemic vascular resistance (SVR)}$$

BMI is usually used as a proxy measure for excess body fat although it is criticised as it does not differentiate lean muscle mass and body fat mass.[360, 361] BMI therefore represents other causal exposures such as diets high in fat and sodium and low in vegetables and fruits; sedentary lifestyle or a physically inactive lifestyle,[362] all which can contribute to a build-up of fatty plaques (atherosclerosis) to the arterial wall,[363] thereby potentially lowering blood flow due to increased SVR. Although an increase in either CO or SVR can cause increase in BP, augmented SVR is mainly responsible for elevated BP in obese individuals.[7] Obesity is also associated with vascular endothelial dysfunction (impaired vasodilation[364]) by interfering with the production of sufficient nitric oxide which is vital for vascular relaxation, contraction and control of blood clotting (thrombosis.[365]) A decrease in the function of nitric oxide results in vasoconstriction and consequently an increase in vascular resistance that may predispose to risk of raised blood pressure.[7] Insulin resistance is also greatly increased in obese subjects,[366] and this lowers the biologic activity of natriuretic peptide, which leads to retention of sodium causing an increased cardiac output.[367]

As mentioned above, interventions for weight loss through diet and physical exercise are usually recommended in the management of obesity.[4, 366] However, it has been shown that during exercises, obesity is associated with persistence of elevated cardiac filling

pressures.[368] Elevated right ventricular and left ventricular filling pressures contribute to many of the symptoms of patients with advanced heart failure.[369] This reinforces the importance of weight control measures at an early stage in life to prevent transition from a normal weight to overweight and consequently obese state.

Physical exercises such as endurance training helps in the reduction of arterial wall thickness and increased lumen diameter, [370] For individuals maintaining a physically active life, vascular function is improved through increased coronary artery size and dilation capacity.[371] These factors help in maintaining normal SVR, and consequently normal BP measures. Physical activity/exercise also increases insulin sensitivity and glucose metabolism by decreasing production of glucose by the liver and increasing the number of muscle cells that use more glucose than adipose tissue, thereby reducing body fat.[372] Physically active individuals have also been found to have much lower arterial stiffness measures compared with individuals who have a sedentary lifestyle.[373]

6.5 Limitations of the thesis

This thesis had a major strength in that it studied hypothesis relating to differences and similarities of overweight/obesity and hypertension prevalences by person, place, and time, with the larger proportion of the thesis using data at the national level. Nevertheless, there were a few limitations for the thesis.

The second objective, whose findings formed chapter 4 of the thesis focussed on the transition rates within the categories of BMI. While such studies have been done in some countries, no similar studies in the South African context were found for comparative purposes to gauge whether there have been changes in the transition rates over time. However, the findings from this section of the thesis can form a good basis for future comparative studies for tracking changes in the transitions rates.

A second limitation relates to the structuring of the thesis. While the first two objectives (Chapters 3 & 4) focus on the national level, the third objective (Chapter 5) focus on a much smaller geography and demography (women). Nevertheless, future work can focus on such growth curve analysis for both BPs and BMI using nationally representative data to find out how the BT20 Plus results compare with findings at the bigger scale. In addition, since the spatial and temporal changes observed for both excess weight and high blood pressure involve an underlying biological process, clustering of such processes geographically and age-

wise should be explored in the future as more data especially genomic data becomes available at the population level.

6.6 Future research direction

This section outlines future research priorities relating to the monitoring of the risk factors for NCDs which can be done by using readily available data sets.

An important aspect in the prevention and control of NCDs and their risk factors is timely identification of warning signs through continuous screening as this is vital in reducing the development of hypertension. In a similar line of thought to the first objective of this thesis, an important research question along the line of blood pressure screening would be how it has evolved especially since the promulgation of the 2013-2017 NCD Strategic Plan. The investigation again can be over time and how it differs across the various administrative divisions (districts) through which healthcare services are delivered in South Africa. An important measure in this case would be the proportion of health facility clients (headcount) screened for hypertension, and how this is affected by type of facility type (clinic, community health centre, etc.), geographical location of the facility, nurses' and doctors' workloads, facility utilisation rate and budgetary allocation at the facility. Data can be sourced from the District Health Information System (DHIS). This would be important in identifying the under resourced and incapacitated health facilities, and if there has been any improvements in increasing the number screened in primary care setting.

Another aspect of future research building on the current one relate to the target to halt the rise in diabetes and obesity according the Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013-2020.[4] Although in this thesis it was shown that overweight/obesity was strongly associated with hypertension for the objective dealing with the spatial and temporal prevalence of hypertension, it may be pre-emptive to assume that overweight and or obesity will be similarly distributed. Therefore, for research to find out if there is a halting of the rise in obesity and diabetes, an important research question would be "Whether over time, the prevalence of overweight/obesity has decreased uniformly across the South African districts"? It is known that BMI has shortcoming as a proxy measure for body fat as it cannot differentiate fat and lean body mass.[374] In line with the South Africa 2015 Strategy for Prevention and Control of Obesity,[64] waist circumferences, which is considered a good estimate of excess abdominal body fat can therefore be used to study distribution

of those at risk of chronic diseases due to excess adiposity. A similar question for diabetes can be focus of inquiry. Data from the NiDS can be used to answer these research questions. Since the NiDS data does not have actual measurements on blood sugars from study participants, self-reported data on whether one has ever been informed by a health practitioner (doctor or nurse) that they have diabetes can be used in the analysis. Multilevel statistical modelling can once again be used to do this analysis. The General Household Survey (GHS) repeated cross-sectional data by Statistics South Africa which collects similar data elements can be used to validate the results on the prevalence of diabetes due to shortcomings (recall bias) associated with self-report data.

6.7 Conclusions based on the postulated hypotheses for the PhD research

6.7.1 Hypotheses re-visited

There were three main hypotheses that were stated for this thesis, and here the conclusions based on the result findings from each objective are provided.

Hypothesis 1: The prevalence of hypertension in South Africa has remained constant between 2008 and 2017 across the 52 districts.

The hypotheses of constant prevalence of hypertension over time across the districts of South is rejected and conclude that on average prevalence declined between 2008 and 2017, and consistently differed greatly across the district municipalities. Districts with lower-than-average prevalence remained in the North/North-Eastern parts of South Africa, and those with higher-than-average prevalence in South-West parts of the country.

Hypothesis 2: There is no difference between the proportion of individuals transiting to an upward or downward BMI level by categories of any of the risk factors.

This hypothesis of equal proportions of individuals transiting upwardly or downwardly is rejected. The findings based on the specific objective for this hypothesis showed that the proportion transiting upwardly was in most instances higher than that transiting downwardly by gender, age, and socioeconomic (household income and level of education) factors.

Hypothesis 3: Systolic and diastolic BPs increase throughout life for women caregivers in the BT20 Plus study

The hypothesis of continuous increase in BPs throughout life is rejected and conclude that both SBP and DBP do not increase throughout life. There is a slight decrease in the BPs before 30 years, from where there is an increasing trajectory to around 60 years. Thereafter, the BPs plateau and slightly decrease.

6.7.2 Final remarks

In conclusion, this research demonstrated the importance of sub-national analysis of health outcomes specifically for hypertension and BMI at the district level as the results showed that there were great variabilities between the districts. These results therefore could be used in designing localised interventions programs. The thesis also highlighted the importance of investigating the transition rates between the BMI categories. Upward mobility rates were found to exceed downward mobility rates, and this appears to contribute to the ever increasing overweight and obesity prevalence. The BMI transition results together with blood pressure trajectories identified ages when obesity prevalence and blood pressure start to increase, thereby providing an opportunity for timely implementation of preventive interventions. In short, by using long-term spatial and temporal analyses of existing SA survey data, the present PhD thesis has revealed geographical areas and socio-demographic groups where public health interventions for NCDs should be focused, and resources concentrated.

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APPENDICES

Appendix 1: Ethical clearance

R14/49 Mr Muchiri Wandai

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M170866

NAME: (Principal Investigator)	Mr Muchiri Wandai
DEPARTMENT:	Paediatrics
PROJECT TITLE:	Screening, Treatment and Prevalence of Hypertension and Transition of Body Mass Index in South Africa
DATE CONSIDERED:	25/08/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Prof Shane Norris
APPROVED BY:	Professor P Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	02/10/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004,10th floor, Senate House/3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review August and will therefore be due in the month of August each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

Date 04-10-2017

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix 2: Change of title

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Private Bag 3 Wits, 2050

Tel: 02711 7172076

Reference: Mrs Sandra Benn
E-mail: sandra.benn@wits.ac.za

22 September 2020
Person No: 1786322
TAA

Mr ME Wandai
F101/45
Riviera Close
James Clark Street, Riviera
0084
South Africa

Dear Mr Muchiri Wandai

Doctor of Philosophy: Change of title of research

I am pleased to inform you that the following change in the title of your Thesis for the degree of **Doctor of Philosophy** has been approved:

From:	**Screening and prevalence of hypertension, and transition of body mass index in South Africa**
To:	**Prevalence and Transition of blood pressure and body mass index in South Africa**

Yours sincerely

Mrs Sandra Benn
Faculty Registrar
Faculty of Health Sciences

Appendix 3: Journal Paper 1

Cardiovascular Topics

Geographical influence on the distribution of the prevalence of hypertension in South Africa: a multilevel analysis

Muchiri E Wandai, Shane A Norris, Jens Aagaard-Hansen, Samuel OM Manda

Abstract

Background: As a response to the growing burden of non-communicable diseases, the South African government has set targets to reduce the prevalence of people with raised blood pressure, through lifestyle changes and medication, by 20% by the year 2020. It has also recognised that the prevalence varies at local administrative level. The study aim was to determine the geographical variation by district of the prevalence of hypertension among South African adults aged 15 years and above.

Methods: Data from all five waves of the National income Dynamics Study, a panel survey, were used for estimation by both design-based and multilevel analysis methods. In the multilevel analysis, a three-level hierarchy was used with panel participants in the first level, repeated measurements on patients in the second level, and districts in the third level.

Results: After accounting for demographic, behavioural, socio-economic and environmental factors, significant variation remained in the prevalence of hypertension at the district level. Districts with higher-than-average prevalence were found mostly in the south-western part of the country, while those with a prevalence below average were found in the northern area. Age, body mass index and race were the individual factors found to have a strong effect on hypertension prevalence for this sample.

Conclusions: There were significant differences in hypertension prevalence between districts and therefore the method of analysis and the results could be useful for more targeted preventative and control programmes.

Keywords: hypertension prevalence, district variability, random effects, multilevel analysis

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Hypertension is a major risk factor and consistent predictor for cardiovascular diseases, such as coronary heart disease, stroke, transient ischaemic attack and congestive heart failure.[1,2] A study based on data from the 36-year follow-up Framingham study pointed out the urgent need for primary prevention of hypertension by addressing associated risk factors through weight control, exercise and reduced salt and alcohol intake.[3]

In 2015, global age-standardised prevalence of raised blood pressure was estimated to be 24.1% (21.4–27.1) of men and 20.1% (17.8–22.5) of women. The number of adults with raised blood pressure has increased from 594 million in 1975 to 1.13 billion in 2015, with the increase largely in low- and middle-income countries (LMICs).[4] According to the 2012 South African National Health and Nutritional and Health Examination Survey (SANHANES), the prevalence of hypertension was approximately 26.0%,[5] and the 2016 Demographic Health Survey estimated the prevalence to be 46.0 and 44.0% for women and men, respectively.[6] A number of studies have reported higher-than-global average prevalence in LMICs,[7-9] and this has been attributed to non-compliance with treatment, urbanisation, population ageing and behavioural risk factors, including tobacco and alcohol use, poor diet and physical inactivity.[7,9,10]

In 2013, the South African National Department of Health developed a strategic plan for the prevention and control of non-communicable diseases, which targets reducing the prevalence of people with raised blood pressure by 20% by the year 2020, through lifestyle change and medication.[11] While prevalence has been estimated at both provincial and national levels, little is known on the prevalence of hypertension at levels below the province due to limited data that can reliably be used for estimation.

In South Africa, existing surveillance and estimation of hypertension and other non-communicable disease (NCD)-related risk factors are overwhelmingly focused at the first (national) or second (provincial) level geographies,[5,12-14] but gaining a better understanding of variations at the finer resolutions (district level in particular) could be important in decision making for improving the effectiveness and efficiency in the response to hypertension.

While efforts have been made to estimate hypertension prevalence at the district level, the method used has fallen short as it does not account for factors that are known to be associated with prevalence. In one study, district-based prevalence of cardiovascular co-morbidities, including hypertension, were estimated using an outdated data set (1998 South African Demographic Health Survey).[15] National prevalence of disease can conceal important differences in prevalence in sub-national areas.[16] In most high-income countries where data are available to finer geographies such as counties, NCD-related studies have shown substantial heterogeneity in the prevalence of these diseases and associated risk factors between sub-regions within a country.[17-19]

The aim of this study was therefore to profile the variations in hypertension prevalence between districts in South Africa after controlling for the individual's demographic, social, economic, behavioural and environmental variables.

Methods

The 2008, 2010/11, 2012, 2014/15 and 2017 samples for adults aged 15 years and above from the National income Dynamics Study (NiDS) panel survey were used in the study. The survey provides a large nationally representative sample that is stratified by the country's 52 districts.

The target population was adult (15+ years) individuals in private households and residents in workers' hostels, convents and monasteries, but excluded other living quarters such as students' hostels, old-age homes, hospitals, prisons and military barracks. The sampling technique employed in the panel study is exhaustively discussed elsewhere.[20] The sample retained for the study includes respondents who had at least two blood pressure (BP) measurements taken at the time of the survey.

The outcome of interest was hypertension prevalence for individuals with systolic/diastolic BP of more than 140/90 mmHg or on medication for hypertension. BP measurements for each panel were taken twice from each survey respondent. Valid BP measurements were determined according to previously applied criteria[13,21] as follows: (1) if the second systolic or diastolic BP differed by more than 5 mmHg, the first BP reading was excluded; and (2) a set of BP readings (systolic and diastolic) was retained in the data set if the systolic BP was 80 mmHg or higher AND if the systolic BP was at least 15 mmHg higher than the diastolic BP level. A final systolic/diastolic blood pressure was calculated as the average of the valid BP measurements (Table 1).

Several risk factors known to be associated with hypertension and recorded in the NiDS data were adjusted for in estimating the prevalence of hypertension, using multilevel logistic regression. Important factors at the individual level were (1) demographic factors: age, gender and race (self-identification as African, Coloured, white, Asian/Indian); (2) biological factors: specifically body mass index (BMI); (3) behavioural factors: alcohol use (never used and past/current user), smoking status (never and past/current) and physical exercise (none or some exercise); (4) social and economic factors: education level (≤ primary school, high school, and post high school), employment status (employed, unemployed or economically inactive), medical cover status (membership subscription to a registered medical aid provider), residency type (urban and traditional/farms), and income tertile calculated from equivalised per-capita household income (household income divided by square root of number of people in household); and (5) one environmental factor: the season (summer, autumn, winter and spring) when the BP measurements were taken.

Subjects self-identifying as whites or Indians/Asians were combined in the analysis as they had relatively smaller sample sizes. The alcohol use variable was not available for wave 5 (2017), and so the last observed status (from previous waves) was used, or indicated as unknown if the subject was not in previous waves.

Ethics approval was granted by the Human Research and Ethics Committee of the University of the Witwatersrand, Johannesburg, South Africa

Statistical analysis

The prevalence of hypertension was estimated using the following two statistical methods reporting results at the district level.

Design-based estimates used the survey's post-stratification weights. This first step of the analysis was to estimate the prevalence of hypertension nationally and by the levels of each explanatory variable on univariate basis, followed by the estimation of the prevalence by districts.

A three-level analysis model was used where periodic (survey waves or the repeated measurements) hypertension statuses (first level) are nested in individual respondents (second level), nested within districts (third level). The risk factors listed above were adjusted for in the model.

- Level-specific distribution of hypertension variance. This step aimed at estimating the distribution of the hypertension prevalence variance between the three levels, and the proportion of variance explained by the individual-level demographic, behavioural and socio-economic risk factors. This involved first fitting a multilevel model without the covariates (a null model), which allowed partitioning the variance between the hierarchical levels. This was followed by constructing a full model that adjusted for the risk factors (covariates) stated above. The variance structure was described by the variance partition coefficient (VPC) and the level-specific change in variance ($\Delta\sigma^2$). The VPC measures the proportion of variance explained by each level within the model, and the $\Delta\sigma^2$ measures the proportion of change in variance for each level

Table 1. Sample by wave for participants 15 years and above

Wave	*Valid hypertension data*	*Total sample*	*Percentage valid*
2008	14 135	18 617	75.9
2010/11	15 128	21 943	68.9
2012	18 393	25 228	72.9
2014/15	22 526	28 460	79.1
2017	23 605	32 123	73.5
Total	93 787	126 371	74.2

between the null and the adjusted model. Together, these two measures describe how much of the variation is explained by the variables included in the model.

- Association of hypertension prevalence with individual-level risk factors. Using the fully adjusted model, odds ratios (OR) and *p*-values were calculated for each risk factor in the model.
- Estimation of adjusted hypertension prevalence at the district units involved using the predicted individual probability for hypertension in estimating the prevalence at district level. The estimated prevalences and 95% confidence intervals (CI) were graphically presented to profile districts. This procedure allowed a visualisation of which units were significantly different from the national prevalence. Further analysis was done allowing for hypertension prevalence to vary by age and BMI at the geographic (district) level. This analysis was used to graphically identify units with relatively steeper slopes by age and BMI.

All analyses were performed using Stata version 15. For design-based prevalence estimate, the 'svy: tab' command for two-way tabulation was used, while the mixed-effect logit (melogit) command was used for multilevel analysis.

Results

Design-based (unadjusted) prevalence of hypertension: the univariate (weighted) analysis (Table 2) shows a decreased trend

Table 2. Percentage (95% CI) of hypertension prevalence in South Africa by covariate and period

Characteristic	*2008*	*2010/11*	*2012*	*2014/15*	*2017*	*Average (all)*
Gender						
Female	33.7 (31.7–35.7)	31.9 (30.2–33.7)	33.5 (31.8–35.2)	29.4 (27.8–31.0)	28.5 (27.1–29.9)	31.2 (30.1–32.4)
Male	28.7 (26.5–30.9)	27.8 (25.5–30.2)	30.4 (28.0–32.9)	26.8 (24.7–28.9)	27.3 (25.6–29.1)	28.1 (26.5–29.8)
Age group						
≤ 40 years	16.4 (14.8–18.1)	16.0 (14.6–17.5)	17.3 (15.8–18.9)	13.8 (12.4–15.4)	13.9 (12.8–15.0)	15.3 (14.4–16.3)
> 40 years	58.0 (55.5–60.4)	55.0 (52.6–57.3)	57.2 (54.8–59.5)	53.0 (51.0–55.0)	52.7 (50.6–54.7)	55.0 (53.5–56.4)
Race						
African	29.2 (27.5–30.9)	28.2 (26.8–29.6)	30.0 (28.3–31.7)	25.6 (24.4–26.9)	25.4 (24.3–26.6)	27.5 (26.5–28.5)
Mixed race	41.7 (37.4–46.1)	41.1 (35.1–47.3)	40.2 (34.7–45.9)	39.3 (35.8–42.8)	38.3 (34.3–42.5)	39.9 (36.2–43.7)
Asian/Caucasian	40.6 (35.8–45.7)	35.7 (29.0–43.1)	40.1 (35.1–45.4)	36.5 (29.5–44.2)	39.9 (35.7–44.3)	38.6 (34.7–42.6)
Residency						
Urban	33.4 (31.2–35.6)	32.6 (30.6–34.7)	33.0 (30.8–35.2)	29.5 (27.5–31.6)	29.3 (27.8–30.9)	31.3 (29.9–32.7)
Traditional/farms	28.8 (26.8–30.9)	26.2 (24.6–27.9)	30.6 (28.6–32.7)	25.9 (24.5–27.3)	25.2 (23.8–26.7)	27.3 (26.2–28.5)
Education level						
≤ Primary	46.1 (43.4–48.8)	45.3 (43.1–47.6)	48.9 (46.3–51.4)	48.1 (45.9–50.3)	47.9 (45.5–50.4)	47.2 (45.4–49.0)
High school	24.7 (22.6–26.8)	23.4 (21.6–25.3)	25.6 (23.6–27.8)	21.5 (19.7–23.4)	21.5 (20.1–23.0)	23.2 (21.8–24.7)
Certificate/diploma/bachelors'+	28.1 (24.6–31.9)	28.3 (24.1–32.9)	31.0 (27.8–34.5)	26.8 (24.0–29.9)	29.4 (27.1–31.8)	28.7 (26.8–30.7)
Income tertile						
Low	29.1 (27.3–31.0)	27.3 (25.7–28.9)	28.7 (26.5–30.9)	24.4 (22.5–26.4)	23.5 (20.6–26.7)	27.3 (26.1–28.5)
Medium	33.3 (30.7–36.0)	31.8 (29.4–34.3)	32.4 (30.4–34.4)	27.7 (25.9–29.6)	26.1 (24.6–27.6)	29.9 (28.6–31.2)
High	34.3 (31.3–37.4)	32.0 (29.1–35.0)	34.4 (31.8–37.1)	29.8 (27.7–32.0)	29.8 (28.3–31.3)	31.4 (29.9–32.9)
Employment status						
Employed	32.8 (30.6–35.1)	31.4 (28.8–34.2)	32.9 (30.7–35.2)	28.6 (26.6–30.7)	27.8 (26.2–29.4)	30.3 (29.0–31.8)
Unemployed	24.4 (21.8–27.1)	23.1 (19.9–26.7)	23.4 (20.6–26.5)	19.8 (16.8–23.1)	19.9 (17.4–22.7)	22.2 (20.6–23.9)
Economically inactive	33.8 (31.3–36.3)	31.2 (29.5–33.0)	34.6 (32.5–36.7)	30.3 (28.5–32.1)	30.4 (28.8–32.1)	31.9 (30.5–33.3)
Medical aid						
Yes	35.7 (31.3–40.4)	31.7 (26.7–37.2)	36.8 (32.7–41.0)	33.2 (28.9–37.9)	33.3 (30.0–36.7)	29.0 (28.0–30.1)
No	30.8 (29.2–32.5)	29.7 (28.3–31.2)	31.3 (29.7–32.9)	27.2 (25.9–28.6)	26.9 (25.7–28.2)	34.1 (31.4–36.9)
Body mass index						
Below overweight	21.5 (19.7–23.3)	20.1 (18.5–21.7)	21.2 (19.4–23.1)	16.8 (15.4–18.2)	17.1 (15.8–18.5)	19.1 (18.1–20.2)
Overweight/obese	40.7 (38.5–42.9)	38.7 (36.7–40.8)	41.9 (39.7–44.0)	38.6 (36.6–40.7)	38.2 (36.6–39.7)	39.5 (38.2–40.9)
Exercise						
Never exercise	34.2 (32.5–36.0)	32.2 (30.5–33.9)	34.0 (32.3–35.8)	31.1 (29.5–32.6)	30.7 (29.4–32.1)	32.3 (31.3–33.4)
Some exercise	26.7 (24.0–29.5)	25.4 (22.7–28.4)	27.8 (24.9–30.8)	23.1 (20.8–25.6)	22.8 (21.1–24.5)	24.9 (23.2–26.7)
Alcohol use						
Yes	34.1 (31.5–36.9)	30.5 (27.4–33.8)	33.3 (30.7–36.0)	29.8 (27.4–32.3)	30.3 (27.7–33.0)	29.5 (28.3–30.8)
No	30.6 (28.8–32.4)	29.9 (28.3–31.5)	31.6 (29.9–33.3)	27.3 (25.9–28.9)	28.4 (27.0–29.8)	31.4 (29.7–33.2)
Unknown	–	–	–	–	23.5 (21.2–26.0)	23.5 (21.2–26.0)
Smoking status						
Never smoked	30.6 (29.0–32.3)	29.2 (27.7–30.8)	31.0 (29.3–32.7)	26.7 (25.3–28.2)	26.9 (25.7–28.1)	28.7 (27.7–29.8)
Ever smoked	33.9 (31.2–36.7)	33.2 (29.8–36.9)	35.9 (32.2–39.8)	32.3 (29.2–35.6)	30.9 (28.6–33.4)	33.1 (31.0–35.3)
Season of BP measurement						
Summer	29.3 (26.8–31.8)	24.4 (21.3–27.8)	25.3 (20.4–30.9)	25.4 (24.0–26.9)	24.7 (23.0–26.5)	26.1 (25.0–27.3)
Winter	35.8 (32.8–39.0)	31.9 (29.8–34.1)	32.9 (30.7–35.2)	32.2 (27.9–36.8)	31.3 (29.2–33.4)	32.5 (31.2–33.9)
Autumn/spring	32.2 (29.7–34.9)	28.8 (26.6–31.2)	31.6 (29.4–33.9)	30.5 (27.9–33.3)	29.0 (27.1–30.9)	30.4 (29.0–31.8)
All	31.5 (29.9–33.1)	30.0 (28.6–31.5)	32.1 (30.5–33.8)	28.2 (26.8–29.6)	27.9 (26.7–29.1)	29.8 (28.7–30.9)

in hypertension prevalence, except for a slight increase in the 2012 period. On a period-by-period basis, the prevalence of hypertension in females was higher than that of males. Age, BMI status and educational level had the highest differentials, with those relatively older (40+ years) having a prevalence that was about four times that of the younger adults (< 40 years), and those whose BMI was 25 kg/m² or above (overweight or obese) having a prevalence almost double that of those with a BMI less than 25 kg/m² (normal weight).

Subjects who had primary-level education or no education had a significantly higher prevalence compared to those with relatively higher educational levels, and those who were unemployed had lower prevalence compared with the employed and economically inactive. The African race had a lower prevalence compared with the other races. Urban dwellers, and those who had a medical aid, or engaged in no physical exercise, or had ever smoked, or had ever used alcohol, or whose BP measurements were taken in winter had hypertension prevalences higher than their respective counterparts. Those who were higher in the income band had prevalences significantly higher than those in the lower income level.

Fig. 1 shows the unadjusted weighted hypertension prevalence and 95% CI for South African districts. The average national prevalence was 29.8% (95% CI: 28.7–30.9%: green band). Approximately eight districts showed a prevalence that was lower than that of the national level, while about 16 districts showed a prevalence that was significantly higher than that of the national level. However these estimates are imprecise as characterised by the large confidence intervals.

Except for A Nzo and OR Tambo (both in the Eastern Cape Province), the districts with a lower-than-average prevalence were found in the north-eastern provinces of Limpopo and Mpumalanga. By contrast, the districts with a higher prevalence than average were from the Western and Northern Cape provinces. In between these two extremes lay the majority of the districts whose prevalence was approximately equal to the average. These districts were mostly found in KwaZulu-Natal, Gauteng, parts of the Free State and Eastern Cape, and North West provinces.

Factors associated with hypertension: after accounting for other factors, the greatest effect on hypertension was shown to be basically from the demographic factors of age and race, where the OR was approximately 5.5 times more for every five years increase in age, while the Coloured and black African populations, respectively, were about 2.5 and 1.5 times more

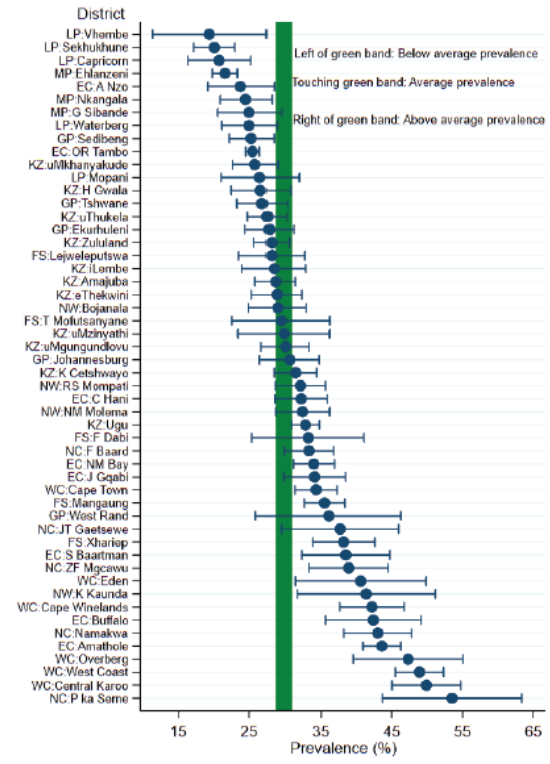


Fig. 1. Design-based hypertension prevalence rates by districts in South Africa.

Table 3. Fixed and random effects associated with hypertension prevalence in South Africa

Factor	*Odds ratio (95% CI)*	*p-value*
Period/year (vs 2008)		
2010/11	0.72 (0.66–0.78)	0.000
2012	0.81 (0.75–0.88)	0.000
2014/15	0.75 (0.70–0.81)	0.000
2017	0.64 (0.59–0.70)	0.000
Gender (vs male)		
Female	0.86 (0.80–0.92)	0.000
Age	1.11 (1.10–1.11)	0.000
Race (vs Asian/Caucasian)		
African	1.52 (1.30–1.78)	0.000
Mixed race	2.56 (2.13–3.07)	0.000
Residency (vs traditional/farms)		
Urban	1.12 (1.03–1.22)	0.011
Education level (vs pry and below)		
High school	0.86 (0.80–0.93)	0.000
Certificate/diploma/Bachelors'+	0.76 (0.68–0.84)	0.000
Income tertile (vs low)		
Medium	0.90 (0.85–0.96)	0.001
High	0.96 (0.89–1.03)	0.231
Employment status (vs employed)		
Unemployed	0.97 (0.90–1.04)	0.375
Economically inactive	0.93 (0.87–0.99)	0.014
Has medical aid	1.01 (0.91–1.11)	0.861
BMI (vs ≤ normal weight)		
Overweight/obesity (≥ 25 kg/m²)	2.29 (2.16–2.42)	0.000
Physical exercise (vs no exercise)		
Some exercise	0.98 (0.92–1.03)	0.438
Alcohol use (vs never used)		
Yes	1.25 (1.17–1.33)	0.000
Unknown	1.06 (0.93–1.20)	0.384
Smoking status (vs never smoked)		
Ever smoked	1.00 (0.93–1.08)	0.920
Season (vs autumn/spring)		
Summer	0.80 (0.76–0.85)	0.000
Winter	1.33 (1.26–1.40)	0.000
Random effects		
District	0.11 (0.07–0.18)	
Repeated observations	3.32 (3.13–3.51)	

likely to be hypertensive compared with the combined races of whites and Asians.

Other factors associated with hypertension prevalence were BMI (OR = 2.29, $p = 0.001$ for those with BMI at least 25.0 kg/m^2), alcohol use (OR = 1.25, $p < 0.001$), season (OR = 1.33, $p < 0.001$ for winter vs autumn/spring) and residence (urban vs traditional/farm, OR = 1.12, $p \leq 0.011$). Adjusted prevalence was more likely to be lower for females compared with males and decreased with level of education. Medical aid and smoking status were not found to be significant predictors of hypertension prevalence for these samples.

Hypertension variance: Table 3 presents the distribution of hypertension variance at the individual and district levels. Most of the variance for both the unadjusted and adjusted models was at the individual level. The VPC shows the proportion of hypertension prevalence variation at the district level to be 3.5%. When adjusting for the explanatory variables, about 1.9% (3.5–1.6) of the variance in the higher level (district) is explained by the geographic distribution of demographic, behavioural, socio-economic and environmental factors (Table 4). Level 1 variance (within individuals' observation) is the fixed value 3.29 ($\pi^2/3$), which is the value assigned for a multilevel logistic regression.

Adjusted prevalence at the district level: the risk-factor adjusted prevalence estimates, unlike the unadjusted (weighted) prevalence, had narrower confidence intervals, and only about 10 districts had a prevalence approximately equal to the average prevalence. A common scenario under both estimation methods was that most of the districts with a lower-than-average prevalence were found in the northern and north-eastern part of the country, while those with a higher-than-average prevalence were mostly in the south and south-western parts of the country (the 'Cape' provinces). All the districts in the Western Cape, except Cape Town, and all the provinces in Northern Cape except Frances Baard had prevalences above average. All districts in Limpopo, Mpumalanga and Gauteng had prevalences below average (Fig 2).

Random district slopes for age and BMI: the effect of age for some districts was lower (districts whose slopes were below the red horizontal line in Fig. 3) than its overall effect. These districts included all from the Limpopo Province, and most of those in Kwa-Zulu Natal and Eastern Cape. The effect of BMI was relatively stronger in most of the districts in Limpopo, Free State, Northern Cape and Kwa-Zulu Natal, and least for most districts in the Eastern Cape.

Discussion

The purpose of this study was to analyse the degree of hypertension prevalence variation for adults aged 15 years and above at the district level before and after adjusting for risk factors associated with hypertension. According to the results of the multilevel model, factors that explained variation in hypertension status in this study were found to be consistent in certain aspects with previous research. For example, age and BMI were the two strongest factors affecting hypertension prevalence in this study, which is in agreement with other studies.[22-26]

The effect of gender on hypertension has been conflicting, with some studies showing a weak association, with females having a lower prevalence of hypertension than males,[25-27] while other studies have showed no association.[23,24,28] The results of the multivariate analysis in this study showed that females had a lower hypertension prevalence compared with males.

Alcohol use (past or current) has also been found to increase the risk of hypertension in some studies,[24,29,30] while in another study no relationship was found.[25] Smoking status, education, and employment status have also yielded conflicting results from various studies.[23,25]

The mixed race and Africans were found in the multilevel logistic regression to have increased prevalence of hypertension compared with Asians/Caucasians. This is consistent with a study done in the United States of America where there are such mixed races.[31]

Univariate analysis showed that prevalence of hypertension for those who had subscription to a medical aid provider was

Table 4. Variance partition and specific-level change in variance between the null and the adjusted model

Variance component	*Null model: variance (SE)*	*Adjusted model: variance (SE)*	*Change in variance (%) (Ds²)*
Individual	8.47 (0.224)	3.32 (0.0963)	–60.8
District	0.430 (0.082)	0.110 (0.026)	–74.4
Individual VPC (%)	69.4	49.4	
Geographic VPC (%)	3.5	1.6	

VPC: variance partition coefficient.

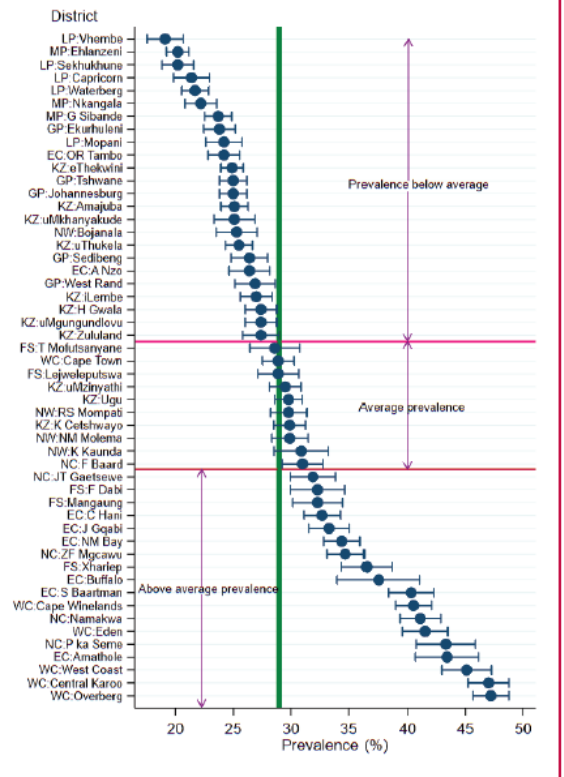


Fig. 2. Mean difference in hypertension prevalence and 95% CI for South African districts (adjusted model).

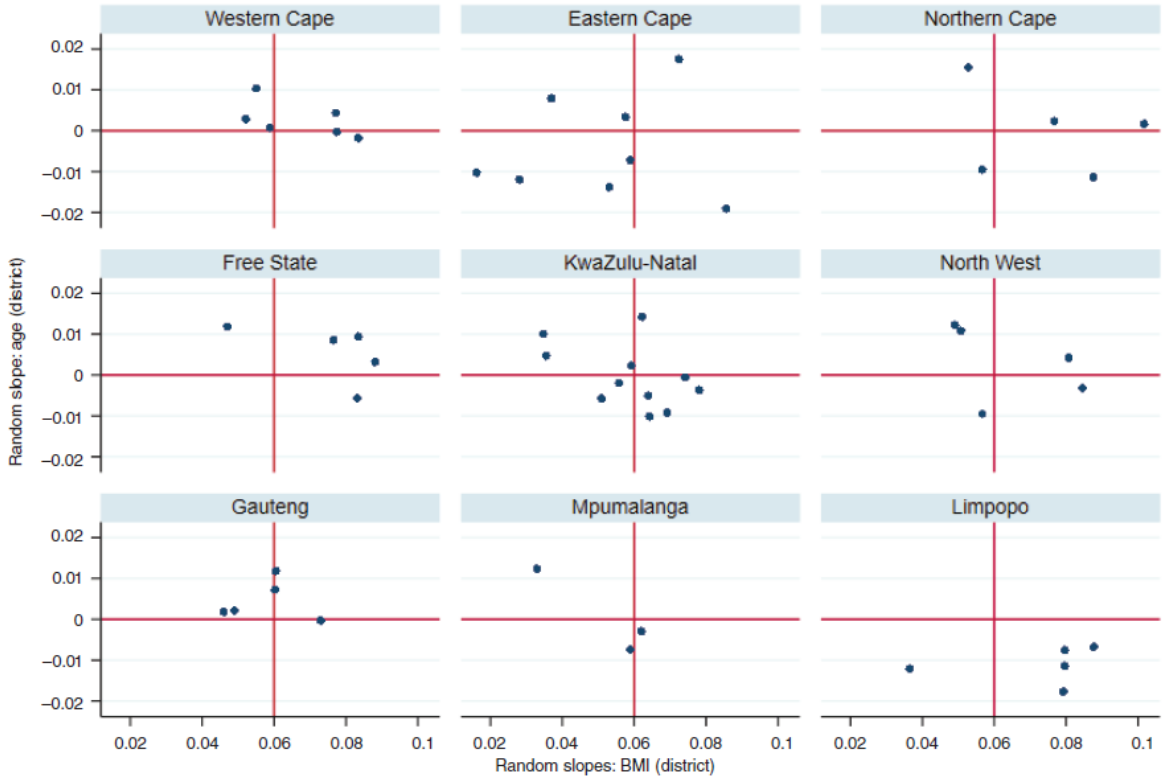


Fig. 3. Scatter plot for districts' random slopes for age and BMI.

higher compared to those without medical aid, but multivariate analysis showed no association. This is possibly because its confounding effect was reduced by income level and education. The percentage of those subscribed to a medical aid cover increased with higher income and educational level.

The study also found seasonal effects with the odds of increased hypertension prevalence being higher in the winter months compared with summer. This is consistent with other studies that have shown cold ambient temperatures to be associated with elevated blood pressure,[32-35] and therefore the effect has also been found to be larger in winter than in summer.[36-38]

Analyses of variance at the individual and district level showed differences in the hypertension prevalence variance distribution at the higher level (district), with a VPC of 3.8 and 2.1% for the null and the risk-factor-adjusted models, respectively. After adjusting for the effect of risk factors, the level-specific change in variance (Ds^2) was equally important at both the individual and district level.

This implies that the risk factors were unequally distributed between individuals and between districts. This could possibly be the reason for the difference in race-wise results between the unadjusted and adjusted estimates. The unadjusted prevalence showed that prevalence was highest in Asian/Caucasians, followed by the mixed race, and lowest in Africans, while the adjusted estimates showed lower chances of hypertension in Asians/Caucasians. This most likely was due to the reduced confounding effect of age, whose average was highest in Asians/Caucasians, followed by the mixed race and lowest for Africans. A previous study found age-standardised self-reported hypertension to be highest in mixed-race women followed by African women.[39]

There were important geographic variations in hypertension prevalence between districts in South Africa, even after controlling for socio-demographic and behavioural background factors. Districts with a lower-than-average prevalence were mostly in the north-eastern part of the country (Limpopo, Mpumalanga and Gauteng provinces) while those with a higher-than-average prevalence were mostly found in the Western, Eastern and Northern Cape provinces. Most of these districts are coastal districts in close vicinity to the Atlantic Ocean. A previous study that limited geographic variation of hypertension to the provincial level found similar clustering of hypertension prevalence.[22]

Identifying districts (sub-units) with high and low hypertension prevalence could be useful in programming public health interventions. Districts with a high hypertension burden could be considered for targeted prevention and control programmes, rather than one national intervention programme. As governments, especially in LMICs, are faced with multiple needs and limited resources, their role of ensuring that all people have equitable access to preventative, curative and rehabilitative health services involves preventing them from developing hypertension and its complications.[40-42] Our study has shown that, although the majority of South African districts had

approximately the same burden of hypertension, some had a heavier burden than others, even after accounting for risk factors documented to have a strong influence on hypertension prevalence.

The effects of age and BMI on hypertension prevalence were found to vary from district to district, showing their slopes were higher in some districts relative to others. Health services that address the risks of hypertension, for example body mass, should target such areas.

Strengths and limitations

To the best of our knowledge this is the only study to have estimated the prevalence of hypertension at the district level, taking into consideration the associated risk factors. The study, however, has a few limitations. First, while the study sample was large enough to allow credible estimates of hypertension at the national level, the samples at the district level were not large enough and this resulted in wide confidence intervals for the estimated prevalence rates. Second, although we adjusted for seasonal variation when BP measurements were taken for each subject, it was not possible to fully adjust for ambient temperatures since these measurements were not available in our data set.

Third, although we adjusted for race in the analysis, it is possible that there could be differences within the same race, especially for black South Africans, who are also characterised by different ethnicities/tribes. The data set did not have details on ethnicity or tribe. A few studies in sub-Saharan Africa have shown variability of hypertension by ethnicity. In Nigeria, prevalence of hypertension was found to differ significantly by ethnicity after adjusting for age, gender, place of residence and socio-economic status.[43] Similarly, some evidence of ethnic variation has been reported in Kenya where statistically significant differences between ethnic groups were reported after adjusting for sociodemographic and other cardiovascular risk factors,[44] but a study from Nigeria and Cameroon did not find any association of hypertension with ethnicity.[45] It may be interesting to analyse other aspects of diet and cultural differences in food intake, such as salt and sugar consumption, both of which were not available in our data set, and are known for their strong influence on hypertension.

Conclusions

The results from this study show that there were significant differences in the prevalence of hypertension at the district level. Districts with a higher-than-average prevalence appeared to be clustered together, as were those with a lower-than-average prevalence. An implication of these results is that there could have been other risk factors not captured in the data that were associated with hypertension prevalence and were also distributed unequally between the districts.

It could also mean that there were differentials in the clusters of districts in prevention, management and control of hypertension. Effective management without complete control could imply people living longer with the condition, thereby increasing the prevalence of hypertension. On the other hand, districts with a low prevalence could indicate poor management, which could result in hypertension-related deaths. Alternatively, low prevalence could be a result of either low incidence or effective prevention and control interventions. These could be issues for further related research and in particular an examination of the impact of district-level covariates/factors.

The data sets analysed during the current study are available in the NiDS DataFirst repository: https://www.datafirst.uct.ac.za/dataportal/index.php/catalog/NIDS. We acknowledge the NiDS for providing access to data used for this study.

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Research

Transitions between body mass index categories, South Africa

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Objective To profile the prevalence of the three body mass index (BMI) categories by sociodemographic characteristics, and to calculate the percentage transitioning (or not) from one BMI category to another, to inform South African health policy for the control of obesity and noncommunicable diseases.

Methods We used data from the National Income Dynamics Study, including sociodemographic characteristics and BMI measurements collected in 2008, 2010, 2012, 2014 and 2017. For each data collection wave and each population group, we calculated mean BMI and prevalence by category. We also calculated the percentage making an upwards transition (e.g. from overweight to obese), a downwards transition or remaining within a particular category. We used a multinomial logistic regression model to estimate transition likelihood.

Findings Between 2008 and 2017, mean BMI increased by 2.3 kg/m^2. We calculated an increased prevalence of obesity from 19.7% (3686/18 679) to 23.6% (3412/14 463), with the largest increases in prevalence for those aged 19–24 years and those with at least high school education. The percentages of upwards transitions to overweight or obese categories increased sharply between the ages of 19 and 50 years. Once overweight or obese, the likelihood of transitioning to a normal BMI is low, particularly for women, those of higher age groups, and those with a higher income and a higher level of education.

Conclusion In the development of national strategies to control obesity and noncommunicable diseases, our results will allow limited public health resources to be focused on the relevant population groups.

Abstracts in العربية, 中文, Français, Русский and Español at the end of each article.

Introduction

The mean body mass index (BMI) of the African population is increasing,[1] resulting in a steady rise of the prevalence of people being overweight or obese across Africa, with the southern part of Africa being most affected.[1,2] In 2016, the prevalence of the population aged ≥ 15 years being overweight or obese in South Africa was 68% for women and 31% for men.[3]

Global efforts to combat obesity include the World Health Organization (WHO) *Global strategy on diet, physical activity and health*,[4] the *Global action plan for the prevention and control of noncommunicable diseases 2013–2020*[5] and the United Nations (UN) *High-level meetings of the General Assembly on prevention and control of non-communicable diseases*.[6,7] The *Global action plan* proposes the promotion of healthy diets by Member States to halt the rise in the prevalence of school children, adolescents and adults being overweight or obese. Similarly, the 2011 Sixty-sixth session of the UN Political Declaration of the High-level Meeting of the General Assembly on the Prevention and Control of Non-communicable Diseases committed to strengthening national policies and health systems by promoting multisectoral and multistakeholder engagement to reverse, stop and decrease the rising trends of obesity in child, youth and adult populations.[6] In line with global strategies and policies, the South African Department of Health developed the *Strategic plan for the prevention and control of non-communicable diseases 2013–2017*[8] and the *Strategy for the prevention and control of obesity in South Africa 2015–2020*;[9] the targets of these strategic plans were to reduce obesity prevalence by 3% by 2017 and by 10% by 2020 in all age groups. These two strategic plans are aligned with the agenda of the country's 2030 *National development plan* for the promotion of healthy diets and physical activity at schools, workplaces and in the general community.[10]

Promotion and support through research is an essential component of global and national strategies for prevention and control of obesity and noncommunicable diseases.[4,5,8,9] We anticipate that a better understanding of transitions between the BMI categories – normal, overweight and obese (Table 1)[11] – will allow the improvement of interventions to reduce the prevalence of obesity. Our objectives are: (i) to profile the prevalence of the three BMI categories within a study population according to various sociodemographic characteristics, and to estimate the percentage of these population groups that underwent transitions (or not) between BMI categories; (ii) to identify the factors associated with transitions between BMI categories; and (iii) to discuss the key public health implications of our findings for national obesity control strategies.

Methods

Study population

The National Income Dynamics Study, first conducted in 2008, is a nationally representative panel study that collects information on a wide variety of social, demographic, economic and health characteristics of the civilian non-institutionalized population.[12,13] We used data from the five completed waves of the panel survey (the subsequent four waves were conducted in 2010, 2012, 2014 and 2017) from participants for which anthropometric measurements had also been recorded. In the first wave in 2008, the survey recorded weight and height measurements for the calculation of BMI for 21 002 individuals; 2323 (11.1%) were immediately lost to follow-up. Of the remaining 2008 sample of 18 679 individuals for which at least a second BMI calculation was recorded, 13 298 (71.2%), 15 331 (82.1%), 15 623 (83.6%) and 14 463 (77.4%) are represented in the 2010, 2012, 2014 and 2017 waves, respectively.

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Study variables

Our main study variable of interest is whether transition occurred from one BMI category to another during a particular period in time. This derived variable has seven possible outcomes: two downwards transitions (either from obese to overweight or from overweight to normal); two upwards transitions (either from normal to overweight or from overweight to obese); and three no-transition outcomes, when a person's BMI category does not change from either normal, overweight or obese between two waves of the survey. If a population is experiencing a higher number of upwards than downwards transitions, the prevalence of adverse conditions will increase.

Our independent time-invariant variables were sex and race, and baseline time-variant variables were age, whether urban or rural residence, education level, equivalized income level and frequency of physical exercise. To account for the economies of scale in household consumption, we used the equivalization method of the Organisation for Economic Co-operation and Development of dividing household income by the square root of the number of people within the household.[14]

Statistical analysis

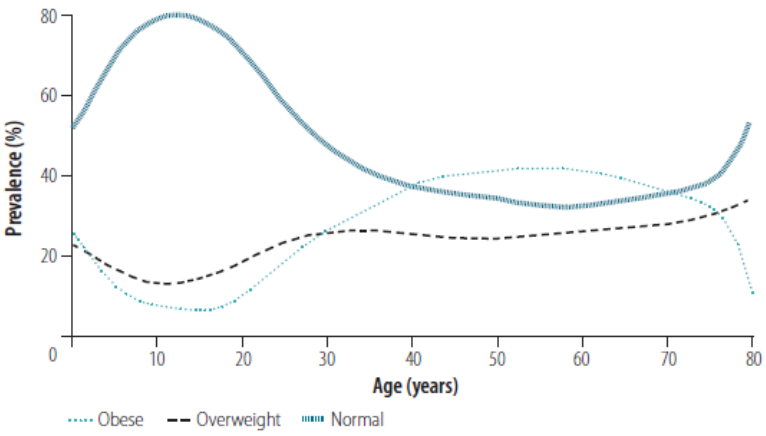
For each BMI category and for each of the five waves of data collection, we calculated both average BMI with 95% confidence intervals and prevalence. To visualize how prevalence varies with age, we calculated the prevalence of all three BMI categories for all ages and averaged over all five data collection waves (2008–2017). We also calculated the percentage within each population subgroup either transitioning to an upwards or downwards BMI category or remaining within the same category during the four periods between subsequent waves (i.e. ending in 2010, 2012, 2014 and 2017). We used a multinomial logistic regression to model the probability of transitioning (or not) from one BMI category to another, relative to the probability of remaining within the normal category. We performed all statistical analyses using Stata SE Version 15.0 (StataCorp, College Station, United States of America).

Table 1. **Body mass index categories for children and adults, according to WHO[11]**

BMI category	*z*-BMI of children (≤ 18 years)	BMI of adults (> 19 years) (kg/m²)
Normal	> –2SD to ≤ 1SD	≥ 18.5 to < 25
Overweight	> 1SD to ≤ 2SD	≥ 25 to < 30
Obese	> 2SD	≥ 30

BMI: body mass index; SD: standard deviation of mean BMI; WHO: World Health Organization; *z*-BMI: *z* score for BMI = (BMI – mean BMI)/SD.

Fig. 1. **Prevalence of body mass index categories by age, South Africa**



Note: Data are averaged over the five waves (2008, 2010, 2012, 2014 and 2017) of the National Income Dynamics Study data collection.

Results

Average BMI and prevalence

Between 2008 and 2017, mean BMI increased by 2.3 kg/m², from 23.1 to 25.4 kg/m². We observed that the age group 7–13 years experienced the highest increase (by 4.7 kg/m²), followed by the age groups 14–18 years (3.3 kg/m²) and 19–24 years (3.2 kg/m²; Table 2; available at: http://www.who.int/bulletin/volumes/98/12/20-255703). We note that the groups that demonstrated at least an average increase in mean BMI (i.e. ≥ 2.3 kg/m²) include women, Africans and Caucasians, rural dwellers, those with some education and those whose level of physical exercise was unknown. When examining the data by income, those with the lowest income demonstrated the largest increase in mean BMI (2.5 kg/m²). We also observed that women, those aged ≥ 25 years, Caucasians, urban dwellers, those with no formal schooling, those with a high school education or more, those within the highest-income tertile and those exercising < 3 times per week had an average BMI of > 25.0 kg/m² for most, if not all, of the study period, contributing to the high prevalence of people being overweight and obese (Table 2).

Our data show an increase in the prevalence of obesity from 19.7% (3686/18 679) in 2008 to 23.6% (3412/14 463) in 2017. In terms of age group, we observed the highest increase in the prevalence of obesity over this period in those aged 19–24 years from 10.9% (227/2079) to 28.4% (449/1581). In terms of education level, those with the most education (high school and above) demonstrated the largest increase in the prevalence of obesity from 25.2% (708/2811) to 40.1% (840/2093). The prevalence of people being overweight and obese was lowest for those aged around 11–18 years (Fig. 1). The prevalence of obesity increases steeply after this age up to around 50 years, when it reaches a plateau (Fig. 1). Between the ages of 40 and 70 years, the prevalence of obesity is higher than that of normal BMI.

Transitions between categories

We provide percentages of the study population groups who transitioned (or not) from one BMI category to another during the four periods ending 2010, 2012, 2014 and 2017 in Table 3 (avail-

Table 4. **Probability of transitioning from one body mass index category to another (or not) by sociodemographic characteristics and year of end of transition period, South Africa, 2010–2017**

Sociodemographic factor/year of end of transition period	OR (*P*) relative to that of retaining a normal BMI		
	Transition upwards[a]	Transition downwards[b]	Remain obese or overweight
End of transition period			
2010	1.00	1.00	1.00
2012	0.93 (0.032)	1.24 (0.000)	1.13 (0.000)
2014	0.77 (0.000)	0.93 (0.066)	1.28 (0.000)
2017	0.50 (0.000)	0.59 (0.000)	1.56 (0.000)
Sex			
Male	1.00	1.00	1.00
Female	2.56 (0.000)	1.82 (0.000)	4.81 (0.000)
Baseline age (years)			
0–6	1.00	1.00	1.00
7–13	0.93 (0.565)	0.72 (0.009)	1.14 (0.435)
14–18	1.21 (0.196)	0.71 (0.021)	1.50 (0.028)
19–24	1.40 (0.029)	0.81 (0.180)	2.75 (0.000)
25–34	1.59 (0.003)	1.19 (0.276)	4.92 (0.000)
35–44	1.65 (0.001)	1.54 (0.007)	8.33 (0.000)
45–54	1.67 (0.001)	1.75 (0.001)	10.44 (0.000)
≥ 55	1.65 (0.001)	2.17 (0.000)	9.68 (0.000)
Race			
African	1.00	1.00	1.00
Mixed ancestry	0.64 (0.000)	0.54 (0.000)	0.68 (0.000)
Asian	0.68 (0.005)	0.60 (0.001)	0.71 (0.003)
Caucasian	1.39 (0.002)	1.26 (0.043)	1.21 (0.037)
Residence			
Rural	1.00	1.00	1.00
Urban	0.85 (0.000)	0.92 (0.005)	1.08 (0.002)
Education level			
None	1.00	1.00	1.00
Pre-school	1.11 (0.448)	1.50 (0.003)	1.76 (0.001)
Primary school[c]	1.16 (0.005)	1.18 (0.002)	1.50 (0.000)
High school and above	1.69 (0.000)	1.43 (0.000)	2.27 (0.000)
Income level			
Low	1.00	1.00	1.00
Middle	0.98 (0.623)	0.94 (0.066)	1.18 (0.000)
High	1.46 (0.000)	1.28 (0.000)	2.06 (0.000)
Physical exercise			
< 3 times per week	1.00	1.00	1.00
≥ 3 times per week	0.93 (0.160)	0.86 (0.014)	0.83 (0.000)
Unknown	0.77 (0.001)	0.91 (0.322)	0.66 (0.000)

BMI: body mass index; OR: odds ratio.
[a] Transition from normal to overweight, or overweight to obese.
[b] Transition from obese to overweight, or overweight to normal.
[c] Includes those who may have started high school but dropped out before completing.

able at: http://www.who.int/bulletin/volumes/98/12/20-255703). As the cohort for each risk factor aged throughout the study period, the percentages transitioning generally decreased as the percentages remaining within a particular BMI category increased. The exceptions to this general observation, that is, the groups that demonstrated decreasing percentages of retaining a normal BMI, included those of age 14–18 years (from 61.7%; 1086/1761 to 54.6%; 984/1803) and 19–24 years (from 51.6%; 751/1455 to 41.0%; 648/1581), Asians (from 51.6%; 66/128 to 38.6%; 56/145), individuals with at least a high school education (from 34.3%; 671/1958 to 28.1%; 589/2093) and those who reported physical exercise ≥ 3 times per week (from 53.0%; 522/985 to 48.6%; 505/1040). Within all these groups, our data show that the decreasing percentages of those retaining a normal BMI was accompanied by upwards transition percentages that were much higher than downwards transition percentages. For example, for the age group 19–24 years, the percentage transitioning upwards by 2010 (22.4%; (187+139)/1455) was more than double that of those transitioning downwards (10.1%; (100+47)/1455). The percentage of those retaining a normal BMI remained relatively constant throughout the study period for women (~35%) and for those aged > 35 years (~28%). At the end of every period, the percentage of those who retained a normal BMI was higher for those who exercised ≥ 3 times per week (e.g. for the period ending 2010, 53.0%; 522/985) compared with those who exercised < 3 times per week (e.g. for the period ending 2010, 36.1%; 2868/7950).

Likelihood of transitions

The probability of transitioning upwards or downwards to another BMI category decreased with time, while the probability of remaining within the overweight or obese categories increased with time. The particular groups that demonstrated the largest probabilities of remaining within the overweight or obese categories, compared with other groups, also demonstrated the greatest likelihoods of transitioning either upwards or downwards. These groups included women, Caucasians, and those with at least a high school education and with a high income (Table 4).

We note that the likelihood of either transitioning upwards or downwards, or of remaining within the overweight or obese categories, relative to that of retaining a normal BMI, increased with age. Our data show that women were 2.56 and 1.82 times more likely than men to transition upwards and downwards, respectively, and 4.81 times more likely than men to remain within the overweight or obese category. Men were therefore more likely to retain a normal BMI.

We note that Caucasians were 1.39 and 1.26 times more likely than Africans to transition upwards and downwards,

respectively, and 1.21 times more likely than Africans to remain within the overweight or obesity category. Those of mixed ancestry and Asians demonstrated a higher probability of retaining a normal BMI than Africans and Caucasians. Urban dwellers were slightly more likely (1.08 times) than rural dwellers to remain within the overweight or obese categories, but less likely to transition upwards or downwards. We observed that individuals with a high school education and greater were more likely than the other education-level groups to either transition upwards or downwards or to remain within the overweight or obese categories. Compared with those with a low or middle income, high-income groups were more likely to transition upwards or downwards and remain within the overweight or obese categories; high-income groups were therefore less likely to retain a normal BMI than lower-income groups. Those who exercised ≥ 3 times per week and those whose frequency of physical exercise was unknown (data were unavailable for those of age < 15 years) were less likely to remain within the overweight or obese categories, and therefore more likely to retain a normal BMI, compared with those who exercised < 3 times per week.

Discussion

Our data show a sharply rising prevalence of obesity coinciding with entry into adulthood in the community at large. We note that the prevalence of obesity increased by the greatest amount for the group aged 19–24 years between 2008 and 2017. This age group also reported the highest percentage of upwards transitions, as well as the largest difference between the percentage transitioning upwards and the percentage transitioning downwards. Although this age group had a normal-category mean BMI during the first two study periods, the subsequent sharp increase in BMI resulted in an increased prevalence of being overweight and obese with time.

The South African Department of Health targeted a 3% reduction in the prevalence of obesity by 2017 for all age groups through diet and physical activity.[8,9] To determine whether this target was achieved, we must compare data from different individuals of the same age at different times. However, by examining how BMI values change as a particular cohort ages, we were able to identify periods of increased obesity prevalence within a person's lifetime during which interventions may be critical. Our data show that there exists a decreasing trend in prevalence of being overweight or obese from birth to the age of 18 years, when most children usually leave high school. As our results are not capable of attributing this downwards trajectory from birth to age 18 years to the effectiveness of national strategies for obesity prevention and control (our data were obtained from an observational study), further research is required.

Guidance for healthy eating for the population aged ≤ 18 years is provided in South Africa by the *Guidelines for early childhood development services*,[15,16] and the *National school nutrition programme annual report*[17] and *Guidelines for tuck shop operators*.[18] The teaching of life skills in primary and high schools, which includes nutrition education, is aimed at educating students to make nutritious food choices and develop healthy eating habits.[9] In averaging our data for all ages over the period 2008–2017, we found that the lowest combined prevalence of being overweight and obese was for those aged 7–18 years; the fact that prevalence rises steadily after this age highlights that, despite these strategies on controlling obesity, there remain substantial problems in communicating healthy food choices to children and adolescents. Other studies have also shown that these strategies are not functioning optimally.[19–21] A synthesis of studies conducted between 2006 and 2014 on the South African school food environment revealed that over half (from 51.1%; 1233/2412 to 69.3%; 330/476) of the students bought available and unhealthy foods from either tuck shops or vendors in their neighbourhood.[22] The population of age 15–24 years has also been identified as the largest consumers of sugar-sweetened beverages.[23]

Low levels of physical activity, especially in female adolescents (aged 10–19 years)[24] and in older teenagers (aged 16–18 years) of both sexes, could also be contributing to the existing prevalence of being overweight and obese.[25] Physical activity policies include the *Strategic plan 2009–2013: An active and winning nation*,[26] of which one of the aims was to facilitate the implementation of sports in schools. In the *National sport and recreation plan*, one of the objectives is to maximize access to sport, recreation and physical education in every school.[27] Consolidated findings on the level of physical activity in children aged 3–19 years (e.g. early childhood physical activity, organized sport participation, active play and active transportation) showed an average participation of around 50%, although the percentage of those in early childhood (age 3–6 years) participating in physical activity was generally found to be high (~80%).[25] Since pre-school children are naturally active, a physical activity intervention for this age group was only deemed necessary for promoting the engagement of teachers and parents or caregivers, and for outcomes such as cognitive development.[28]

The South African noncommunicable disease strategy[8] targeted an increase in the prevalence of physical activity (150 minutes of moderate-intensity physical activity per week, or equivalent) by 10% by 2020, and the WHO global action plan for noncommunicable diseases[5] targeted a 10% relative reduction in the prevalence of insufficient physical activity by 2020. Although our data do not allow a detailed analysis of types of physical activity, we demonstrated the importance of physical exercise. About half of those who exercised ≥ 3 times per week maintained a normal BMI even as the cohort aged. However, the fact that the proportion of this group who maintained a normal BMI decreased slightly over time may reflect decreasing levels of energy expenditure with age. Interventions that increase physical activity may therefore be necessary to reduce the large percentages of groups who remain either overweight or obese. Studies on obesity, especially in women, have identified obese participants who meet the WHO guidelines on physical activity but have very poor cardiorespiratory fitness, possibly attributable to a lack of high-intensity physical activity.[29,30] Suggested interventions include encouraging participation in high-intensity activities, such as sports and aerobics, and discouraging sedentary behaviour.[31]

The recent introduction of higher tax on products such as sugar-sweetened beverages[32] will probably reduce consumption and consequently reduce the percentages transitioning upwards. However, the life course approach, the basis of many WHO strategies and recommendations for disease prevention and control,[5,33] may be a better strategy for maintaining normal BMI from this

age. The life course approach stresses the importance of early intervention by considering which stages, transitions and settings of a person's life are critical for promoting or restoring health.[34] For example, the workplace has been found to be an important setting for health promotion during adulthood.[35] Effective interventions include the promotion of healthy food options in canteens, and the provision of nutrition education and counselling.[36] Similar interventions in settings such as community centres, churches and recreational facilities should also be promoted.[37] Barriers to leisure activity participation, including lack of time and facilities, safety issues and negative community perceptions regarding weight loss, may also need to be addressed,[38] along with the accessibility and affordability of healthy food options through subsidies.[37]

Population groups that demonstrated a higher probability of remaining within the obese category included women, higher age groups (> 35 years), and those with a higher income and higher level of education. These groups are usually the target of public interventions and of the weight management programmes of private health-care providers.[39] However, our data show a high resistance to a downwards transition from either overweight or obese categories, and this resistance increases with time. Other studies have shown that although weight loss can be achieved through lifestyle changes,[40,41] maintaining this weight loss over the longer term can be difficult; only approximately one-fifth (20.6%; 47/228)[42] of those who achieve weight loss maintain it for ≥ 1 year,[42,43] and the majority of those who embark on a weight-loss programme give up before achieving success.[44–47] Our results indicate that, despite considerable percentages of the cohort transitioning downwards, any reductions in the prevalence of obesity were cancelled out by the larger percentages of these population groups transitioning upwards; we therefore believe that the South African target[9] of achieving a 10% reduction in the prevalence of obesity by 2020 will not be met.

The main strength of our study was our analysis of BMI transitions within a nationally representative sample of participants from a panel survey spanning birth to adulthood. However, our study had limitations. Some of the risk factors associated with higher BMI categories in this study, such as household income, education level and amount of physical exercise, were self-reported and therefore prone to minor errors that may have affected our results. A second limitation was loss to follow-up from one wave of data collection to another. Since we assume those lost to follow-up were randomly distributed throughout the study population, and the remaining numbers at each subsequent data collection wave were sufficiently high, we consider our results to be free of bias.

To conclude, we have demonstrated that the proportion of upwards transitions to overweight and obese categories in the South African population increases sharply between the ages of 19 and 50 years. Once overweight or obese, the likelihood of transitioning to a normal BMI is low, particularly for women, those of higher age groups, and those with a higher income and a higher level of education. With this evidence, we provide essential guidance for the South African Department of Health in the development of strategies to control obesity and noncommunicable diseases. Our study results will allow limited public health resources to be focused on the necessary population segments in which the largest reductions in the prevalence of obesity can be made. ■

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ملخص

التحولات بين فئات مؤشر كتلة الجسم، جنوب إفريقيا

الغرض تحديد مدى انتشار فئات مؤشر كتلة الجسم الثلاث (BMI) حسب الخصائص الاجتماعية السكانية، وحساب النسبة المئوية للتحول (أو عدم التحول) من فئة مؤشر كتلة جسم إلى أخرى، لإطلاع السياسة الصحية لجنوب إفريقيا لمكافحة السمنة والأمراض غير المعدية.

الطريقة استخدمنا بيانات من دراسة ديناميكيات الدخل القومي، بما في ذلك الخصائص الاجتماعية السكانية وقياسات مؤشر كتلة الجسم (BMI) التي تم جمعها في أعوام 2008 و2010 و2012 و2014 و2017. لكل موجة من مجموعات البيانات وكل مجموعة سكانية، قمنا بحساب متوسط مؤشر كتلة الجسم والانتشار حسب الفئة. قمنا أيضًا بحساب النسبة المئوية التي تقوم بالتحول لأعلى (على سبيل المثال من زيادة الوزن إلى السمنة)، أو التحول لأسفل، أو البقاء ضمن فئة معينة. لقد استخدمنا نموذجًا للتحوف اللوجيستي متعدد الحدود لتقدير احتمالية التحول.

النتائج بين عامي 2008 و2017، زاد متوسط مؤشر كتلة الجسم بمعدل 2.3 كجم/متر^2. قمنا بحساب انتشار متزايد في السمنة من 19.7% (18679/3686) إلى 23.6% (14463/3412)، مع أكبر زيادات في الانتشار لمن تتراوح أعمارهم بين 19 و24 عامًا وأولئك الذين حصلوا على تعليم في المدرسة الثانوية على الأقل. زادت النسب المئوية للتحولات إلى أعلى، أو إلى فئات الوزن الزائد أو السمنة، بشكل حاد بين سني 19 و50 عامًا. بمجرد الوجود في فئة زيادة الوزن أو السمنة، يكون احتمال الانتقال إلى مؤشر كتلة الجسم العادي منخفضًا، خاصة بالنسبة للنساء، وكذلك ذوي الفئات العمرية الأعلى، وذوي الدخل المرتفع والمستوى التعليمي الأعلى.

الاستنتاج عند تطوير الاستراتيجيات الوطنية للسيطرة على السمنة والأمراض غير المعدية، سوف تسمح النتائج لدينا بتركيز موارد الصحة العامة المحدودة على المجموعات السكانية ذات الصلة.

摘要

南非：身体质量指数类别间的转换

目的 通过社会人口统计学特征，分析三类身体质量指数 (BMI) 的患病率，并计算从 BMI 某个类别转换（或不转）为另一类的比例，从而为南非控制肥胖和非传染性疾病的卫生政策提供依据。

方法 我们利用国民收入动态追踪调查研究数据，包括 2008 年、2010 年、2012 年、2014 年以及 2017 年收集的社会人口统计学特征和 BMI 测量结果。针对各数据收集曲线和各人口群体，我们计算出各类 BMI 平均值和患病率。还分别计算出向上转换（例如，从超重到肥胖）、向下转换或维持在特定类别的比例。我们使用多类别逻辑回归模型预估转换可能性。

结果 2008 年至 2017 年间，BMI 平均值增长了 2.3 kg/m^2。我们计算出，肥胖患病率从 19.7% (3686/18 679) 上升到 23.6% (3412/14 463)，其中 19-24 岁人群和具有中学以上学历的人群患病率增幅最大。19 至 50 岁间向上转换为超重或肥胖类别的比例急剧增加。一旦超重或肥胖，再转换为正常 BMI 的可能性较小，特别是女性、年龄较大的人群，以及收入较高和受教育程度较高的人群。

结论 制定控制肥胖和非传染性疾病的国家策略时，我们的结果有助于将有限的公共卫生资源集中用于相关人群。

Résumé

Transitions entre différentes catégories d'indice de masse corporelle en Afrique du Sud

Objectif Établir la prévalence des trois catégories d'indice de masse corporelle (IMC) en fonction des caractéristiques sociodémographiques, et calculer le pourcentage de transition (ou d'absence de transition) d'une catégorie d'IMC à l'autre, afin de renseigner les politiques de santé sud-africaines visant à lutter contre l'obésité et les maladies non transmissibles.

Méthodes Nous avons exploité les données provenant de l'Enquête nationale sur la dynamique des revenus (NIDS), notamment les caractéristiques sociodémographiques et les mesures de l'IMC récoltées en 2008, 2010, 2012, 2014 et 2017. Pour chaque vague de collecte de données et chaque groupe de population, nous avons calculé l'IMC moyen et la prévalence par catégorie. Nous avons également déterminé le pourcentage de passages vers la catégorie supérieure (en surpoids à obèse par exemple), de passages vers la catégorie inférieure et de maintien au sein d'une catégorie spécifique. Enfin, nous avons employé un modèle de régression logistique multinomiale pour estimer la probabilité de transition.

Résultats Entre 2008 et 2017, l'IMC moyen a augmenté de 2,3 kg/m^2. Nous avons observé une prévalence accrue pour l'obésité, passée de 19,7% (3686/18 679) à 23,6% (3412/14 463). Cette hausse touche principalement les 19–24 ans et ceux possédant au moins un diplôme d'études secondaires. Le pourcentage de passage à la catégorie supérieure, vers le surpoids ou l'obésité, a fortement augmenté chez les personnes âgées de 19 à 50 ans. Une fois en surpoids ou obèse, la probabilité de repasser à un IMC normal est faible, surtout chez les femmes, les personnes plus âgées, ceux dont les revenus sont plus importants et dont le niveau d'éducation est plus élevé.

Conclusion Dans le cadre du développement de stratégies nationales destinées à lutter contre l'obésité et les maladies non transmissibles, nos résultats permettront d'affecter des ressources de santé publique limitées aux groupes de population les plus touchés.

Резюме

Переходы между категориями индекса массы тела, Южная Африка

Цель Составить профиль распространенности трех категорий индекса массы тела (ИМТ) по социально-демографическим характеристикам и рассчитать процент перехода (или отсутствия такового) из одной категории ИМТ в другую, чтобы предоставить информацию для политики здравоохранения Южной Африки в целях борьбы с ожирением и неинфекционными заболеваниями.

Методы Авторы использовали данные Национального исследования динамики доходов, включая социально-демографические характеристики и измерения ИМТ, которые были собраны в 2008, 2010, 2012, 2014 и 2017 годах. Для каждого цикла сбора данных и каждой группы населения был рассчитан средний ИМТ с разбивкой показателей по категориям. Авторы также рассчитали процент восходящих переходов (например, из категории избыточного веса в категорию ожирения), нисходящих переходов и процент постоянно пребывающих в определенной ИМТ-категории. Для оценки вероятности перехода между категориями использовалась модель мультиномиальной логистической регрессии.

Результаты В период с 2008 по 2017 год средний показатель ИМТ увеличился на 2,3 кг/м^2. Авторы рассчитали рост распространенности ожирения с 19,7% (3686/18 679) до 23,6% (3412/14 463), при этом наибольший рост распространенности ожирения наблюдается среди лиц в возрасте 19–24 лет и лиц, имеющих уровень образования не ниже среднего. Процент восходящих переходов в категории с избыточным весом или ожирением резко увеличился в возрастной категории от 19 до 50 лет. После попадания в категорию избыточного веса или ожирения вероятность перехода к нормальному ИМТ является низкой, особенно для женщин, лиц старших возрастных групп и лиц с более высоким доходом и более высоким уровнем образования.

Вывод При разработке национальных стратегий борьбы с ожирением и неинфекционными заболеваниями полученные результаты позволят сосредоточить внимание ограниченных ресурсов общественного здравоохранения на соответствующих группах населения.

Resumen

Transiciones entre las categorías del índice de masa corporal, Sudáfrica

Objetivo Describir la prevalencia de las tres categorías del índice de masa corporal (IMC) por características sociodemográficas y calcular el porcentaje que pasa (o no) de una categoría del IMC a otra con el fin de fundamentar la política sanitaria de Sudáfrica para controlar la obesidad y las enfermedades no transmisibles.

Métodos Se usaron los datos del Estudio nacional de la dinámica de los ingresos (NIDS, por sus siglas en inglés), incluidas las características sociodemográficas y las mediciones del IMC que se obtuvieron en 2008, 2010, 2012, 2014 y 2017. Se calculó el IMC medio y la prevalencia por categoría para cada fase de recopilación de datos y cada grupo de población. También se calculó el porcentaje que hace una transición ascendente (por ejemplo, del sobrepeso a la obesidad), una transición descendente o que permanece dentro de una categoría en particular. En este contexto, se aplicó un modelo de regresión logística polinomial para estimar la probabilidad de la transición.

Resultados Entre 2008 y 2017, el IMC medio aumentó en 2,3 kg/m^2. Se calculó un aumento de la prevalencia de la obesidad del 19,7 % (3686/18 679) al 23,6 % (3412/14 463), siendo los mayores aumentos de la prevalencia para las personas de 19 a 24 años de edad y las que habían cursado al menos estudios secundarios. Los porcentajes de transiciones ascendentes a las categorías de sobrepeso u obesidad aumentaron de manera considerable entre los 19 y los 50 años de edad. Cuando se tiene sobrepeso o se es obeso, la probabilidad de pasar a un IMC normal es baja, en especial en el caso de las mujeres, las de los grupos de edad avanzada y las que tienen mayores ingresos y un nivel de educación más alto.

Conclusión Los resultados obtenidos permitirán destinar los recursos limitados de la salud pública a los grupos de población correspondientes en la elaboración de estrategias nacionales para controlar la obesidad y las enfermedades no transmisibles.

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Table 2. **Mean body mass index and percentage of study population within each body mass index category by sociodemographic characteristics and data collection wave, South Africa, 2008–2017**

Sociodemographic property/ data collection wave	*n*	Mean BMI, kg/m^2 (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
Sex					
Female					
2008	10 687	24.8 (24.5–25.1)	5 444 (50.9)	2 374 (22.2)	2 869 (26.8)
2010	7 887	26.3 (25.9–26.6)	3 504 (44.4)	1 881 (23.8)	2 502 (31.7)
2012	8 936	26.4 (26.1–26.7)	4 033 (45.1)	2 270 (25.4)	2 633 (29.5)
2014	9 040	27.3 (27.0–27.7)	3 853 (42.6)	2 154 (23.8)	3 033 (33.6)
2017	8 461	27.9 (27.5–28.2)	3 473 (41.0)	2 057 (24.3)	2 931 (34.6)
Male					
2008	7 992	21.1 (20.8–21.3)	5 885 (73.6)	1 290 (16.1)	817 (10.2)
2010	5 411	22.2 (21.9–22.6)	3 737 (69.1)	1 054 (19.5)	620 (11.5)
2012	6 395	22.4 (22.0–22.7)	4 539 (71.0)	1 196 (18.7)	660 (10.3)
2014	6 583	22.4 (22.1–22.7)	4 985 (75.7)	1 036 (15.7)	562 (8.5)
2017	6 002	22.5 (22.2–22.7)	4 552 (75.8)	969 (16.1)	481 (8.0)
Baseline age (years)					
0–6					
2008	2 770	16.8 (16.6–17.0)	1 792 (64.7)	544 (19.6)	434 (15.7)
2010	1 627	16.7 (16.4–16.9)	1 106 (68.0)	275 (16.9)	246 (15.1)
2012	2 468	17.0 (16.8–17.3)	1 780 (72.1)	387 (15.7)	301 (12.2)
2014	2 571	17.9 (17.6–18.1)	2 090 (81.3)	321 (12.5)	160 (6.2)
2017	2 479	19.2 (18.9–19.4)	2 029 (81.8)	314 (12.7)	136 (5.5)
7–13					
2008	3 458	17.8 (17.4–18.1)	2 781 (80.4)	378 (10.9)	299 (8.6)
2010	2 327	19.8 (19.4–20.2)	1 733 (74.5)	359 (15.4)	235 (10.1)
2012	2 973	20.7 (20.5–21.0)	2 306 (77.6)	485 (16.3)	182 (6.1)
2014	3 026	21.8 (21.5–22.0)	2 375 (78.5)	459 (15.2)	192 (6.3)
2017	2 807	22.5 (22.2–22.8)	2 128 (75.8)	442 (15.7)	237 (8.4)
14–18					
2008	2 384	21.5 (21.2–21.8)	1 899 (79.7)	329 (13.8)	156 (6.5)
2010	1 761	23.1 (22.7–23.4)	1 230 (69.8)	358 (20.3)	173 (9.8)
2012	1 803	23.7 (23.3–24.0)	1 254 (69.6)	368 (20.4)	181 (10.0)
2014	1 953	24.2 (23.9–24.5)	1 253 (64.2)	387 (19.8)	313 (16.0)
2017	1 803	24.8 (24.4–25.3)	1 070 (59.3)	392 (21.7)	341 (18.9)
19–24					
2008	2 079	23.5 (23.2–23.9)	1 445 (69.5)	407 (19.6)	227 (10.9)
2010	1 455	24.6 (24.1–25.1)	871 (59.9)	334 (23.0)	250 (17.2)
2012	1 563	25.5 (24.9–26.1)	847 (54.2)	395 (25.3)	321 (20.5)
2014	1 703	26.2 (25.7–26.7)	838 (49.2)	431 (25.3)	434 (25.5)
2017	1 581	26.7 (26.1–27.2)	718 (45.4)	414 (26.2)	449 (28.4)
25–34					
2008	2 199	25.8 (25.5–26.2)	1 184 (53.8)	536 (24.4)	479 (21.8)
2010	1 597	26.4 (25.9–26.9)	721 (45.1)	430 (26.9)	446 (27.9)
2012	1 721	26.9 (26.5–27.4)	741 (43.1)	493 (28.6)	487 (28.3)
2014	1 831	27.6 (27.1–28.0)	749 (40.9)	458 (25.0)	624 (34.1)
2017	1 705	27.4 (26.9–27.9)	689 (40.4)	425 (24.9)	591 (34.7)
35–44					
2008	1 966	27.7 (27.3–28.2)	790 (40.2)	495 (25.2)	681 (34.6)
2010	1 514	28.4 (27.8–29.0)	539 (35.6)	387 (25.6)	588 (38.8)
2012	1 634	28.6 (28.0–29.1)	562 (34.4)	425 (26.0)	647 (39.6)
2014	1 647	28.8 (28.2–29.4)	560 (34.0)	376 (22.8)	711 (43.2)
2017	1 556	28.7 (28.1–29.2)	507 (32.6)	379 (24.4)	670 (43.1)

(*continues. . .*)

(*. . .continued*)

Sociodemographic property/ data collection wave	*n*	Mean BMI, kg/m² (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
45–54					
2008	1 687	28.8 (28.2–29.3)	630 (37.3)	400 (23.7)	657 (38.9)
2010	1 305	29.3 (28.6–29.9)	424 (32.5)	330 (25.3)	551 (42.2)
2012	1 415	29.4 (28.8–30.0)	458 (32.4)	378 (26.7)	579 (40.9)
2014	1 370	29.6 (28.9–30.2)	425 (31.0)	343 (25.0)	602 (43.9)
2017	1 260	29.5 (28.9–30.2)	403 (32.0)	320 (25.4)	537 (42.6)
> 55					
2008	2 136	28.4 (27.9–28.9)	808 (37.8)	575 (26.9)	753 (35.3)
2010	1 712	28.4 (27.9–28.9)	617 (36.0)	462 (27.0)	633 (37.0)
2012	1 754	28.0 (27.6–28.4)	624 (35.6)	535 (30.5)	595 (33.9)
2014	1 522	28.1 (27.5–28.7)	548 (36.0)	415 (27.3)	559 (36.7)
2017	1 272	28.0 (27.4–28.6)	481 (37.8)	340 (26.7)	451 (35.5)
Race					
African					
2008	15 621	22.9 (22.6–23.1)	9 592 (61.4)	3 049 (19.5)	2 980 (19.1)
2010	11 536	24.3 (24.0–24.6)	6 262 (54.3)	2 569 (22.3)	2 705 (23.4)
2012	12 941	24.2 (24.0–24.5)	7 312 (56.5)	2 937 (22.7)	2 692 (20.8)
2014	13 228	24.8 (24.5–25.0)	7 581 (57.3)	2 714 (20.5)	2 933 (22.2)
2017	12 317	25.3 (25.0–25.5)	6 945 (56.4)	2 557 (20.8)	2 815 (22.9)
Mixed ancestry					
2008	2 360	24.0 (23.3–24.6)	1 441 (61.1)	405 (17.2)	514 (21.8)
2010	1 400	24.4 (23.6–25.2)	821 (58.6)	254 (18.1)	325 (23.2)
2012	1 887	24.9 (24.3–25.4)	1 091 (57.8)	356 (18.9)	440 (23.3)
2014	1 923	25.4 (24.9–26.0)	1 087 (56.5)	332 (17.3)	504 (26.2)
2017	1 770	25.8 (25.3–26.3)	949 (53.6)	348 (19.7)	473 (26.7)
Asian					
2008	199	23.4 (22.9–23.9)	116 (58.3)	46 (23.1)	37 (18.6)
2010	128	23.8 (22.9–24.7)	72 (56.3)	31 (24.2)	25 (19.5)
2012	141	25.5 (25.0–26.0)	66 (46.8)	45 (31.9)	30 (21.3)
2014	152	24.4 (23.5–25.2)	77 (50.7)	42 (27.6)	33 (21.7)
2017	145	24.0 (22.9–25.1)	63 (43.4)	49 (33.8)	33 (22.8)
Caucasian					
2008	499	25.7 (24.6–26.8)	180 (36.1)	164 (32.9)	155 (31.1)
2010	234	26.9 (25.1–28.7)	86 (36.8)	81 (34.6)	67 (28.6)
2012	362	27.8 (26.8–28.8)	103 (28.5)	128 (35.4)	131 (36.2)
2014	320	28.2 (26.8–29.6)	93 (29.1)	102 (31.9)	125 (39.1)
2017	231	28.3 (26.8–29.7)	68 (29.4)	72 (31.2)	91 (39.4)
Residence					
Rural					
2008	10 849	22.2 (21.9–22.5)	6 916 (63.7)	2 060 (19.0)	1 873 (17.3)
2010	7 937	23.8 (23.5–24.1)	4 374 (55.1)	1 791 (22.6)	1 772 (22.3)
2012	8 420	23.6 (23.3–23.9)	4 912 (58.3)	1 916 (22.8)	1 592 (18.9)
2014	8 152	24.2 (23.9–24.4)	4 825 (59.2)	1 646 (20.2)	1 681 (20.6)
2017	7 501	24.7 (24.4–25.0)	4 369 (58.2)	1 546 (20.6)	1 586 (21.1)
Urban					
2008	7 830	24.0 (23.7–24.3)	4 413 (56.4)	1 604 (20.5)	1 813 (23.2)
2010	5 361	25.1 (24.6–25.5)	2 867 (53.5)	1 144 (21.3)	1 350 (25.2)
2012	6 911	25.3 (24.9–25.7)	3 660 (53.0)	1 550 (22.4)	1 701 (24.6)
2014	7 471	25.7 (25.4–26.1)	4 013 (53.7)	1 544 (20.7)	1 914 (25.6)
2017	6 962	25.8 (25.5–26.2)	3 656 (52.5)	1 480 (21.3)	1 826 (26.2)
Education					

(*continues. . .*)

(. . .*continued*)

Sociodemographic property/ data collection wave	*n*	Mean BMI, kg/m² (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
None					
2008	1 761	25.2 (24.8–25.6)	921 (52.3)	382 (21.7)	458 (26.0)
2010	1 391	26.3 (25.8–26.7)	638 (45.9)	324 (23.3)	429 (30.8)
2012	1 437	25.8 (25.4–26.1)	687 (47.8)	384 (26.7)	366 (25.5)
2014	1 345	25.9 (25.5–26.2)	672 (50.0)	316 (23.5)	357 (26.5)
2017	1 168	26.1 (25.7–26.5)	583 (49.9)	274 (23.5)	311 (26.6)
Pre-school					
2008	2 603	16.8 (16.6–16.9)	1 666 (64.0)	522 (20.1)	415 (15.9)
2010	1 508	16.7 (16.5–16.9)	1 020 (67.6)	251 (16.6)	237 (15.7)
2012	2 324	16.9 (16.8–17.1)	1 677 (72.2)	358 (15.4)	289 (12.4)
2014	2 418	17.5 (17.4–17.7)	1 969 (81.4)	295 (12.2)	154 (6.4)
2017	2 338	18.9 (18.7–19.0)	1 919 (82.1)	290 (12.4)	129 (5.5)
Primary school[a]					
2008	11 504	23.0 (22.9–23.2)	7 356 (63.9)	2 043 (17.8)	2 105 (18.3)
2010	8 441	24.6 (24.5–24.7)	4 760 (56.4)	1 823 (21.6)	1 858 (22.0)
2012	9 335	24.8 (24.7–24.9)	5 374 (57.6)	2 057 (22.0)	1 904 (20.4)
2014	9 573	25.4 (25.3–25.6)	5 416 (56.6)	1 953 (20.4)	2 204 (23.0)
2017	8 864	25.9 (25.7–26.0)	4 848 (54.7)	1 884 (21.3)	2 132 (24.1)
High school and above					
2008	2 811	26.3 (26.1–26.6)	1 386 (49.3)	717 (25.5)	708 (25.2)
2010	1 958	27.4 (27.1–27.6)	823 (42.0)	537 (27.4)	598 (30.5)
2012	2 235	27.9 (27.6–28.2)	834 (37.3)	667 (29.8)	734 (32.8)
2014	2 287	28.6 (28.3–28.9)	781 (34.1)	626 (27.4)	880 (38.5)
2017	2 093	29.0 (28.7–29.3)	675 (32.3)	578 (27.6)	840 (40.1)
Income level					
Low					
2008	11 220	22.1 (21.9–22.4)	7 236 (64.5)	2 055 (18.3)	1 929 (17.2)
2010	8 162	23.7 (23.6–23.9)	4 625 (56.7)	1 771 (21.7)	1 766 (21.6)
2012	9 264	23.4 (23.3–23.6)	5 548 (59.9)	2 019 (21.8)	1 697 (18.3)
2014	9 582	24.0 (23.9–24.1)	5 861 (61.2)	1 858 (19.4)	1 863 (19.4)
2017	8 974	24.6 (24.4–24.7)	5 371 (59.9)	1 770 (19.7)	1 833 (20.4)
Middle					
2008	4 564	23.5 (23.1–23.9)	2 738 (60.0)	868 (19.0)	958 (21.0)
2010	3 243	24.6 (24.4–24.9)	1 777 (54.8)	683 (21.1)	783 (24.1)
2012	3 780	24.6 (24.3–24.8)	2 094 (55.4)	809 (21.4)	877 (23.2)
2014	3 776	25.1 (24.9–25.4)	2 060 (54.6)	757 (20.0)	959 (25.4)
2017	3 501	25.5 (25.3–25.8)	1 866 (53.3)	745 (21.3)	890 (25.4)
High					
2008	2 895	25.0 (24.6–25.5)	1 355 (46.8)	741 (25.6)	799 (27.6)
2010	1 893	26.1 (25.7–26.4)	839 (44.3)	481 (25.4)	573 (30.3)
2012	2 287	26.5 (26.2–26.7)	930 (40.7)	638 (27.9)	719 (31.4)
2014	2 265	27.0 (26.7–27.3)	917 (40.5)	575 (25.4)	773 (34.1)
2017	1 988	27.5 (27.2–27.8)	788 (39.6)	511 (25.7)	689 (34.7)
Physical exercise					
< 3 times per week					
2008	10 452	26.3 (26.0–26.5)	5 342 (51.1)	2 404 (23.0)	2 706 (25.9)
2010	7 950	27.2 (27.0–27.3)	3 521 (44.3)	2 002 (25.2)	2 427 (30.5)
2012	8 315	27.5 (27.3–27.6)	3 503 (42.1)	2 239 (26.9)	2 573 (30.9)
2014	8 444	27.8 (27.7–28.0)	3 440 (40.7)	2 068 (24.5)	2 936 (34.8)

(*continues. . .*)

(. . .*continued*)

Sociodemographic property/ data collection wave	*n*	Mean BMI, kg/m² (95% CI)	No. (%) within each category		
			Normal	Overweight	Obese
2017	7 742	28.1 (27.9–28.3)	3 056 (39.5)	1 935 (25.0)	2 751 (35.5)
≥ 3 times per week					
2008	1 460	24.0 (23.5–24.6)	981 (67.2)	274 (18.8)	205 (14.0)
2010	985	24.7 (24.3–25.0)	591 (60.0)	228 (23.1)	166 (16.9)
2012	1 135	25.2 (24.9–25.5)	646 (56.9)	288 (25.4)	201 (17.7)
2014	1 143	25.6 (25.2–25.9)	623 (54.5)	266 (23.3)	254 (22.2)
2017	1 040	25.8 (25.4–26.1)	550 (52.9)	255 (24.5)	235 (22.6)
Unknown					
2008	6 767	17.6 (17.4–17.8)	5 006 (74.0)	986 (14.6)	775 (11.5)
2010	4 363	19.0 (18.8–19.1)	3 129 (71.7)	705 (16.2)	529 (12.1)
2012	5 881	19.3 (19.1–19.4)	4 423 (75.2)	939 (16.0)	519 (8.8)
2014	6 036	20.2 (20.0–20.3)	4 775 (79.1)	856 (14.2)	405 (6.7)
2017	5 681	21.2 (21.0–21.3)	4 419 (77.8)	836 (14.7)	426 (7.5)
Total					
2008	18679	23.1 (22.9–23.4)	11 329 (60.7)	3 664 (19.6)	3 686 (19.7)
2010	13 298	24.5 (24.2–24.7)	7 241 (54.5)	2 935 (22.1)	3 122 (23.5)
2012	15 331	24.6 (24.3–24.8)	8 572 (55.9)	3 466 (22.6)	3 293 (21.5)
2014	15 623	25.1 (24.8–25.3)	8 838 (56.6)	3 190 (20.4)	3 595 (23.0)
2017	14 463	25.4 (25.1–25.6)	8 025 (55.5)	3 026 (20.9)	3 412 (23.6)

BMI: body mass index; CI: confidence interval.
[a] Includes those who may have started high school but dropped out before completing.

Table 3. **Number and percentage of study population transitioning from one body mass index category to another (or not) by sociodemographic characteristics and year of end of transition period, South Africa, 2010–2017**

Sociodemographic characteristic/end of transition period	*n*	No. (%)						
		Transitioned upwards		Transitioned downwards		Unchanged		
		Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
Sex								
Female								
2010	7 887	750 (9.5)	845 (10.7)	526 (6.7)	575 (7.3)	2752 (34.9)	782 (9.9)	1657 (21.0)
2012	8 936	844 (9.4)	790 (8.8)	602 (6.7)	826 (9.2)	3097 (34.7)	934 (10.5)	1843 (20.6)
2014	9 040	775 (8.6)	876 (9.7)	546 (6.0)	470 (5.2)	3142 (34.8)	1074 (11.9)	2157 (23.9)
2017	8 461	521 (6.2)	481 (5.7)	382 (4.5)	364 (4.3)	3022 (35.7)	1241 (14.7)	2450 (29.0)
Male								
2010	5 411	563 (10.4)	390 (7.2)	361 (6.7)	285 (5.3)	3201 (59.2)	381 (7.0)	230 (4.3)
2012	6 395	559 (8.7)	362 (5.7)	531 (8.3)	441 (6.9)	3725 (58.2)	479 (7.5)	298 (4.7)
2014	6 583	388 (5.9)	227 (3.4)	530 (8.1)	359 (5.5)	4224 (64.2)	520 (7.9)	335 (5.1)
2017	6 002	288 (4.8)	142 (2.4)	269 (4.5)	164 (2.7)	4232 (70.5)	568 (9.5)	339 (5.6)
Baseline age (years)								
0–6								
2010	1 627	128 (7.9)	168 (10.3)	189 (11.6)	177 (10.9)	806 (49.5)	81 (5.0)	78 (4.8)
2012	2 468	165 (6.7)	223 (9.0)	254 (10.3)	309 (12.5)	1333 (54.0)	106 (4.3)	78 (3.2)
2014	2 571	142 (5.5)	92 (3.6)	243 (9.5)	247 (9.6)	1668 (64.9)	111 (4.3)	68 (2.6)
2017	2 479	130 (5.2)	62 (2.5)	116 (4.7)	80 (3.2)	1868 (75.4)	149 (6.0)	74 (3.0)
7–13								
2010	2 327	244 (10.5)	178 (7.6)	137 (5.9)	130 (5.6)	1501 (64.5)	80 (3.4)	57 (2.4)
2012	2 973	278 (9.4)	117 (3.9)	224 (7.5)	227 (7.6)	1914 (64.4)	148 (5.0)	65 (2.2)
2014	3 026	237 (7.8)	114 (3.8)	220 (7.3)	125 (4.1)	2068 (68.3)	184 (6.1)	78 (2.6)
2017	2 807	181 (6.4)	109 (3.9)	128 (4.6)	50 (1.8)	1984 (70.7)	227 (8.1)	128 (4.6)
14–18								
2010	1 761	237 (13.5)	128 (7.3)	105 (6.0)	68 (3.9)	1086 (61.7)	92 (5.2)	45 (2.6)
2012	1 803	219 (12.1)	102 (5.7)	157 (8.7)	90 (5.0)	1043 (57.8)	113 (6.3)	79 (4.4)
2014	1 953	202 (10.3)	188 (9.6)	133 (6.8)	63 (3.2)	1095 (56.1)	147 (7.5)	125 (6.4)
2017	1 803	162 (9.0)	112 (6.2)	76 (4.2)	46 (2.6)	984 (54.6)	194 (10.8)	229 (12.7)
19–24								
2010	1 455	187 (12.9)	139 (9.6)	100 (6.9)	47 (3.2)	751 (51.6)	120 (8.2)	111 (7.6)
2012	1 563	209 (13.4)	144 (9.2)	102 (6.5)	78 (5.0)	713 (45.6)	140 (9.0)	177 (11.3)
2014	1 703	190 (11.2)	171 (10.0)	107 (6.3)	63 (3.7)	708 (41.6)	201 (11.8)	263 (15.4)

(*continues...*)

(...*continued*)

Sociodemographic characteristic/end of transition period	*n*	No. (%)						
		Transitioned upwards		Transitioned downwards		Unchanged		
		Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
2017	1 581	118 (7.5)	97 (6.1)	62 (3.9)	50 (3.2)	648 (41.0)	254 (16.1)	352 (22.3)
25–34								
2010	1 597	186 (11.6)	175 (11.0)	97 (6.1)	90 (5.6)	590 (36.9)	188 (11.8)	271 (17.0)
2012	1 721	199 (11.6)	165 (9.6)	117 (6.8)	113 (6.6)	583 (33.9)	222 (12.9)	322 (18.7)
2014	1 831	148 (8.1)	167 (9.1)	116 (6.3)	75 (4.1)	612 (33.4)	256 (14.0)	457 (25.0)
2017	1 705	84 (4.9)	85 (5.0)	80 (4.7)	70 (4.1)	598 (35.1)	282 (16.5)	506 (29.7)
35–44								
2010	1 514	121 (8.0)	147 (9.7)	84 (5.5)	112 (7.4)	423 (27.9)	186 (12.3)	441 (29.1)
2012	1 634	110 (6.7)	156 (9.5)	89 (5.4)	123 (7.5)	439 (26.9)	226 (13.8)	491 (30.0)
2014	1 647	91 (5.5)	141 (8.6)	82 (5.0)	80 (4.9)	458 (27.8)	225 (13.7)	570 (34.6)
2017	1 556	65 (4.2)	64 (4.1)	60 (3.9)	77 (4.9)	438 (28.1)	246 (15.8)	606 (38.9)
45–54								
2010	1 305	92 (7.0)	130 (10.0)	64 (4.9)	96 (7.4)	334 (25.6)	168 (12.9)	421 (32.3)
2012	1 415	91 (6.4)	111 (7.8)	67 (4.7)	130 (9.2)	355 (25.1)	193 (13.6)	468 (33.1)
2014	1 370	68 (5.0)	113 (8.2)	66 (4.8)	78 (5.7)	343 (25.0)	213 (15.5)	489 (35.7)
2017	1 260	32 (2.5)	48 (3.8)	53 (4.2)	64 (5.1)	344 (27.3)	230 (18.3)	489 (38.8)
≥ 55								
2010	1 712	118 (6.9)	170 (9.9)	111 (6.5)	140 (8.2)	462 (27.0)	248 (14.5)	463 (27.0)
2012	1 754	132 (7.5)	134 (7.6)	123 (7.0)	197 (11.2)	442 (25.2)	265 (15.1)	461 (26.3)
2014	1 522	85 (5.6)	117 (7.7)	109 (7.2)	98 (6.4)	414 (27.2)	257 (16.9)	442 (29.0)
2017	1 272	37 (2.9)	46 (3.6)	76 (6.0)	91 (7.2)	390 (30.7)	227 (17.8)	405 (31.8)
Race								
African								
2010	11536	1192 (10.3)	1134 (9.8)	777 (6.7)	764 (6.6)	5129 (44.5)	969 (8.4)	1571 (13.6)
2012	12941	1225 (9.5)	981 (7.6)	1033 (8.0)	1130 (8.7)	5709 (44.1)	1152 (8.9)	1711 (13.2)
2014	13228	1021 (7.7)	950 (7.2)	971 (7.3)	746 (5.6)	6234 (47.1)	1323 (10.0)	1983 (15.0)
2017	12317	696 (5.7)	531 (4.3)	583 (4.7)	451 (3.7)	6251 (50.8)	1521 (12.3)	2284 (18.5)
Mixed ancestry								
2010	1 400	86 (6.1)	78 (5.6)	88 (6.3)	71 (5.1)	696 (49.7)	134 (9.6)	247 (17.6)
2012	1 887	130 (6.9)	116 (6.1)	77 (4.1)	107 (5.7)	975 (51.7)	158 (8.4)	324 (17.2)
2014	1 923	109 (5.7)	122 (6.3)	70 (3.6)	56 (2.9)	1001 (52.1)	183 (9.5)	382 (19.9)
2017	1 770	91 (5.1)	76 (4.3)	48 (2.7)	63 (3.6)	892 (50.4)	203 (11.5)	397 (22.4)
Asian								

(*continues*...)

(...continued)

Sociodemographic characteristic/end of transition period	*n*	No. (%)						
		Transitioned upwards		Transitioned downwards		Unchanged		
		Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
2010	128	10 (7.8)	5 (3.9)	5 (3.9)	4 (3.1)	66 (51.6)	18 (14.1)	20 (15.6)
2012	141	13 (9.2)	8 (5.7)	7 (5.0)	5 (3.5)	58 (41.1)	28 (19.9)	22 (15.6)
2014	152	13 (8.6)	9 (5.9)	11 (7.2)	7 (4.6)	65 (42.8)	23 (15.1)	24 (15.8)
2017	145	11 (7.6)	7 (4.8)	7 (4.8)	6 (4.1)	56 (38.6)	32 (22.1)	26 (17.9)
Caucasian								
2010	234	25 (10.7)	18 (7.7)	17 (7.3)	21 (9.0)	62 (26.5)	42 (17.9)	49 (20.9)
2012	362	35 (9.7)	47 (13.0)	16 (4.4)	25 (6.9)	80 (22.1)	75 (20.7)	84 (23.2)
2014	320	20 (6.3)	22 (6.9)	24 (7.5)	20 (6.3)	66 (20.6)	65 (20.3)	103 (32.2)
2017	231	11 (4.8)	9 (3.9)	13 (5.6)	8 (3.5)	55 (23.8)	53 (22.9)	82 (35.5)
Residence								
Rural								
2010	7 937	882 (11.1)	826 (10.4)	536 (6.8)	508 (6.4)	3585 (45.2)	654 (8.2)	946 (11.9)
2012	8 420	801 (9.5)	625 (7.4)	711 (8.4)	793 (9.4)	3780 (44.9)	743 (8.8)	967 (11.5)
2014	8 152	609 (7.5)	572 (7.0)	639 (7.8)	515 (6.3)	3920 (48.1)	788 (9.7)	1109 (13.6)
2017	7 501	410 (5.5)	289 (3.9)	365 (4.9)	283 (3.8)	3929 (52.4)	928 (12.4)	1297 (17.3)
Urban								
2010	5 361	431 (8.0)	409 (7.6)	351 (6.5)	352 (6.6)	2368 (44.2)	509 (9.5)	941 (17.6)
2012	6 911	602 (8.7)	527 (7.6)	422 (6.1)	474 (6.9)	3042 (44.0)	670 (9.7)	1174 (17.0)
2014	7 471	554 (7.4)	531 (7.1)	437 (5.8)	314 (4.2)	3446 (46.1)	806 (10.8)	1383 (18.5)
2017	6 962	399 (5.7)	334 (4.8)	286 (4.1)	245 (3.5)	3325 (47.8)	881 (12.7)	1492 (21.4)
Education								
None								
2010	1 391	115 (8.3)	145 (10.4)	84 (6.0)	104 (7.5)	506 (36.4)	153 (11.0)	284 (20.4)
2012	1 437	134 (9.3)	105 (7.3)	102 (7.1)	156 (10.9)	519 (36.1)	160 (11.1)	261 (18.2)
2014	1 345	90 (6.7)	85 (6.3)	107 (8.0)	76 (5.7)	543 (40.4)	172 (12.8)	272 (20.2)
2017	1 168	52 (4.5)	36 (3.1)	65 (5.6)	53 (4.5)	506 (43.3)	181 (15.5)	275 (23.5)
Pre-school								
2010	1 508	116 (7.7)	160 (10.6)	181 (12.0)	165 (10.9)	735 (48.7)	74 (4.9)	77 (5.1)
2012	2 324	153 (6.6)	212 (9.1)	245 (10.5)	295 (12.7)	1247 (53.7)	95 (4.1)	77 (3.3)
2014	2 418	127 (5.3)	87 (3.6)	224 (9.3)	238 (9.8)	1571 (65.0)	104 (4.3)	67 (2.8)
2017	2 338	118 (5.0)	59 (2.5)	106 (4.5)	78 (3.3)	1768 (75.6)	139 (5.9)	70 (3.0)
Primary school[a]								
2010	8 441	868 (10.3)	718 (8.5)	505 (6.0)	477 (5.7)	4041 (47.9)	692 (8.2)	1140 (13.5)

(*continues...*)

(...continued)

Sociodemographic characteristic/end of transition period	*n*	No. (%)					
		Transitioned upwards		Transitioned downwards		Unchanged	
		Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
2012	9 335	865 (9.3)	617 (6.6)	657 (7.0)	671 (7.2)	4389 (47.0)	849 (9.1)	1287 (13.8)
2014	9 573	753 (7.9)	685 (7.2)	631 (6.6)	415 (4.3)	4608 (48.1)	962 (10.0)	1519 (15.9)
2017	8 864	518 (5.8)	402 (4.5)	405 (4.6)	317 (3.6)	4391 (49.5)	1101 (12.4)	1730 (19.5)
High school and above								
2010	1 958	214 (10.9)	212 (10.8)	117 (6.0)	114 (5.8)	671 (34.3)	244 (12.5)	386 (19.7)
2012	2 235	251 (11.2)	218 (9.8)	129 (5.8)	145 (6.5)	667 (29.8)	309 (13.8)	516 (23.1)
2014	2 287	193 (8.4)	246 (10.8)	114 (5.0)	100 (4.4)	644 (28.2)	356 (15.6)	634 (27.7)
2017	2 093	121 (5.8)	126 (6.0)	75 (3.6)	80 (3.8)	589 (28.1)	388 (18.5)	714 (34.1)
Income level								
Low								
2010	8 162	897 (11.0)	803 (9.8)	555 (6.8)	529 (6.5)	3798 (46.5)	617 (7.6)	963 (11.8)
2012	9 264	894 (9.7)	647 (7.0)	779 (8.4)	811 (8.8)	4330 (46.7)	753 (8.1)	1050 (11.3)
2014	9 582	733 (7.6)	644 (6.7)	747 (7.8)	541 (5.6)	4827 (50.4)	871 (9.1)	1219 (12.7)
2017	8 974	525 (5.9)	373 (4.2)	418 (4.7)	298 (3.3)	4876 (54.3)	1024 (11.4)	1460 (16.3)
Middle								
2010	3 243	276 (8.5)	254 (7.8)	216 (6.7)	187 (5.8)	1486 (45.8)	295 (9.1)	529 (16.3)
2012	3 780	294 (7.8)	297 (7.9)	238 (6.3)	289 (7.6)	1734 (45.9)	348 (9.2)	580 (15.3)
2014	3 776	271 (7.2)	266 (7.0)	216 (5.7)	174 (4.6)	1769 (46.8)	387 (10.2)	693 (18.4)
2017	3 501	193 (5.5)	140 (4.0)	154 (4.4)	148 (4.2)	1673 (47.8)	443 (12.7)	750 (21.4)
High								
2010	1 893	140 (7.4)	178 (9.4)	116 (6.1)	144 (7.6)	669 (35.3)	251 (13.3)	395 (20.9)
2012	2 287	215 (9.4)	208 (9.1)	116 (5.1)	167 (7.3)	758 (33.1)	312 (13.6)	511 (22.3)
2014	2 265	159 (7.0)	193 (8.5)	113 (5.0)	114 (5.0)	770 (34.0)	336 (14.8)	580 (25.6)
2017	1 988	91 (4.6)	110 (5.5)	79 (4.0)	82 (4.1)	705 (35.5)	342 (17.2)	579 (29.1)
Physical exercise								
<3 times per week								
2010	7 950	769 (9.7)	792 (10.0)	487 (6.1)	497 (6.3)	2868 (36.1)	902 (11.3)	1635 (20.6)
2012	8 315	799 (9.6)	724 (8.7)	530 (6.4)	648 (7.8)	2754 (33.1)	1011 (12.2)	1849 (22.2)
2014	8 444	636 (7.5)	784 (9.3)	502 (5.9)	412 (4.9)	2823 (33.4)	1135 (13.4)	2152 (25.5)
2017	7 742	399 (5.2)	387 (5.0)	354 (4.6)	349 (4.5)	2653 (34.3)	1236 (16.0)	2364 (30.5)
≥3 times per week								
2010	985	125 (12.7)	64 (6.5)	51 (5.2)	40 (4.1)	522 (53.0)	81 (8.2)	102 (10.4)

(. . .*continued*)

Sociodemographic characteristic/end of transition period	*n*	No. (%)						
		Transitioned upwards		Transitioned downwards		Unchanged		
		Normal to overweight	Overweight to obese	Overweight to normal	Obese to overweight	Normal	Overweight	Obese
2012	1 135	119 (10.5)	73 (6.4)	85 (7.5)	57 (5.0)	546 (48.1)	127 (11.2)	128 (11.3)
2014	1 143	102 (8.9)	87 (7.6)	75 (6.6)	35 (3.1)	536 (46.9)	141 (12.3)	167 (14.6)
2017	1 040	64 (6.2)	47 (4.5)	38 (3.7)	38 (3.7)	505 (48.6)	160 (15.4)	188 (18.1)
Unknown								
2010	4 363	419 (9.6)	379 (8.7)	349 (8.0)	323 (7.4)	2563 (58.7)	180 (4.1)	150 (3.4)
2012	5 881	485 (8.2)	355 (6.0)	518 (8.8)	562 (9.6)	3522 (59.9)	275 (4.7)	164 (2.8)
2014	6 036	425 (7.0)	232 (3.8)	499 (8.3)	382 (6.3)	4007 (66.4)	318 (5.3)	173 (2.9)
2017	5 681	346 (6.1)	189 (3.3)	259 (4.6)	141 (2.5)	4096 (72.1)	413 (7.3)	237 (4.2)
Total								
2010	13298	1313 (9.9)	1235 (9.3)	887 (6.7)	860 (6.5)	5953 (44.8)	1163 (8.7)	1887 (14.2)
2012	15331	1403 (9.2)	1152 (7.5)	1133 (7.4)	1267 (8.3)	6822 (44.5)	1413 (9.2)	2141 (14.0)
2014	15623	1163 (7.4)	1103 (7.1)	1076 (6.9)	829 (5.3)	7366 (47.1)	1594 (10.2)	2492 (16.0)
2017	14463	809 (5.6)	623 (4.3)	651 (4.5)	528 (3.7)	7254 (50.2)	1809 (12.5)	2789 (19.3)

[a] Includes those who may have started high school but dropped out before completing.

Appendix 5: Journal Paper 3

Cardiovascular Topics

Long-term blood pressure trajectories and associations with age and body mass index among urban women in South Africa

Muchiri E Wandai, Samuel OM Manda, Jens Aagaard-Hansen, Shane A Norris

Abstract

Background: Blood pressure (BP) is known to increase inevitably with age. Understanding the different ages at which great gains could be achieved for intervention to prevent and control BP would be of public health importance.

Methods: Data collected between 2003 and 2014 from 1 969 women aged 22 to 89 years were used in this study. Growth curve models were fitted to describe intra- and inter-individual trajectories. For BP tracking, the intra-class correlation coefficient (ICC) was used to measure dependency of observations from the same individual.

Results: Four patterns were identified: a slow decrease in BP with age before 30 years; a period of gradual increase in midlife up to 60 years; a flattening and slightly declining trend; and another increase in BP in advanced age. These phases persisted but at slightly lower levels after adjustment for body mass index. Three groups of increasing trajectories were identified. The respective number (%) in the low, medium and highly elevated BP groups were 1 386 (70.4%), 482 (24.5%) and 101 (5.1%) for systolic BP; and 1 167 (59.3%), 709 (36.0%) and 93 (4.7%) for diastolic BP. The ICC was strong at 0.71 and 0.79 for systolic and diastolic BP, respectively.

Conclusion: These results show that BP preventative and control measures early in life would be beneficial for control later in life, and since increase in body mass index may worsen hypertension, it should be prevented early and independently.

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Keywords: blood pressure, hypertension, body mass index, trajectory, intra-class correlation coefficient

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Hypertension is a major risk factor for non-communicable diseases (NCDs), especially stroke and heart attack,[1] and in South Africa, it was estimated to account for 19.0% of cardiovascular disease deaths in 2016.[2] The prevalence of hypertension in women aged 15 years and older was also estimated at 28.5%,[3] and increased steeply with age, with 84.0% of women aged 65 years and older having hypertension.[4] Urban populations have been shown to have a higher prevalence of hypertension compared with their rural counterparts,[3] and women in such dwellings have also been reported to have higher percentages than men.[5,6]

Accelerated global efforts for the prevention and control of NCDs began during the high-level meeting of heads of state and governments at the 66th session of the United Nations General Assembly in September 2011.[7] Following this, the South African Department of Health developed a strategy in line with the declaration in 2013, of which one of the 10 goals and targets was to 'reduce the prevalence of people with raised blood pressure by 20.0% by 2020 (through lifestyle and medication)'.[8]

Changes in both systolic (SBP) and diastolic blood pressure (DBP) with age are known to show an increasing trajectory that mostly starts between 30 and 40 years.[9-11] However, from approximately 50 years, DBP may plateau and thereafter start to decline.[10,11] An individual's BP trajectory can be used as an indicator for age-related vascular stiffening or for the existence of an underlying disease.[12]

Growth curves (trajectories) play an important role in life-course epidemiology,[13] and can be used in identifying groups of individuals at risk of developing high BP using known risk factors.[14] In addition, population subgroups with different BP trajectories can be useful in selecting people who might benefit most from intervention for the prevention of cardiovascular disease (CVD) risk.[15]

Although age is highly correlated with an increasing BP trajectory, some studies have however reported a decrease in SBP and DBP at the population level, especially for communities in the developed countries of western Europe, Australasia and

North America,[16-18] and this decrease is usually attributed to lifestyle and pharmacological interventions.[18]

Understanding how individuals' BPs change and how fast these changes occur (intra-individual change) through their life course, and the patterns for people with different attributes (inter-individual differences in the intra-individual change) could be important in determining best methods for prevention at the appropriate timing. The aim of this study was therefore to find out the association of age with long-term BP observations. The study had three specific objectives: (1) to identify groups of women with similar SBP and DBP between 22 and 89 years of age; (2) to find out how the trajectories are affected by body mass index (BMI); and (3) identify critical ages when intervention measures would be more appropriate in slowing down a steep upward trajectory.

Methods

Ethical approval (M170866) was granted by the Human Research and Ethics Committee of the University of the Witwatersrand, Johannesburg, South Africa.

The study consisted of four measurement time points of data collection on African women dwelling in urban Soweto, Johannesburg, who were care givers of children in the Birth to Twenty Plus cohort study. The majority of the caregivers were the mothers, however a few of the participants included other close relatives such as sisters, aunts and grandmothers.

Data included four waves collected between 2003 and 2014. The four waves provided a sample of 1 969 individuals who had at least one wave of measurements for SBP, DBP, body weight and height, resulting in 4 554 observations. BP measurements were taken in a seated position after 30 minutes of seated rest. The SBP and DBP were measured twice on the right arm using a standard mercury sphygmomanometer and appropriately sized cuff. A final systolic/diastolic BP was calculated by taking the average of the BPs at each time point. Hypertension was defined as systolic/diastolic BP of more than 140/90 mmHg, and BMI was classified according to World Health Organisation as underweight (< 18.5 kg/m^2), normal weight (≥ 18.5– < 25 kg/m^2), overweight (≥ 25– < 30 kg/m^2) and obese (≥ 30 kg/m^2).

Statistical analysis

Multilevel (ML) growth-curve models (a technique to describe and explain an individual's change over time) were used to describe the intra-individual BP trajectories, and the inter-individual differences in the intra-individual changes with age were used as the time metric. Three models were used to describe the patterns of change. The first (model 1) had time effect as the only covariate, model 2 described the changes by adjusting for BMI, and model 3 built on model 2 by allowing effect of BMI to also vary randomly between individuals.

To estimate the mean SBP and DBP trajectories as a function of age, quadratic and cubic non-linear models were used in the analysis, as growth trajectories are known to take a variety of shapes other than linear,[19] mostly characterised by increases or decreases. Age was centred at the minimum age of 22 years to help in the interpretation of the models' intercepts. As BMI is generally known to increase with age, it was included as a time-varying covariate in the second stage of modelling to find out its effect on the BP trajectories. The intra-class correlation coefficient (ICC) was used to measure the degree of dependency among observations within an individual. A group-based trajectory model was used to identify distinct groups for the BPs.

Table 1. Mean and standard deviation for age, SBP, DBP and BMI at the four data-collection time points

Time point	*Number*	*Age (years)*	*SBP (mmHg)*	*DBP (mmHg)*	*BMI (kg/m^2)*
2003	1358	41.1 (7.9)	116.0 (20.1)	76.0 (12.4)	29.9 (6.4)
2005/6	1343	43.4 (8.0)	128.9 (21.6)	80.6 (13.5)	30.7 (7.0)
2007/9	854	45.6 (8.2)	133.5 (21.0)	86.8 (12.9)	30.5 (7.1)
2011/14	999	49.6 (5.7)	134.1 (21.9)	88.7 (12.6)	33.2 (7.2)

SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index.

Results

Summary measures for age, BP and BMI at the four time points are shown in Table 1. The mean age at the first occasion (2003) was 41.1 years, and 49.6 years in the fourth occasion. Systolic and diastolic BPs increased from one time point to another, but the increases became smaller with time, and remained almost unchanged, especially for SBP, between the third and fourth occasions. Mean BMI for the four occasions was high, at obesity level, and remained almost constant between the first and third waves, but increased by at least 2.5 kg/m^2 by the fourth occasion. There is an indication of constant variation in BP and BMI across the measurement occasions.

Table 2 shows the percentage of hypertension by BMI category at each data-collection time point. The percentage of subjects who had hypertension in 2003 was 16.7% and by 2014, this had increased to 47.1%. At each time point it was highest for those with an obese BMI, as expected. The greatest

Table 2. Hypertension percentages by BMI categories at the four data-collection time points

			Blood pressure category		
	BMI		*Non-hypertensive*	*Hypertensive*	
Time point	*Category*	n *(%)*	n *(%)*	n *(%)*	*Total* n *(%)*
2003	Underweight	24 (1.8)	22 (91.7)	2 (8.3)	24 (100.0)
	Normal	300 (22.1)	263 (87.7)	37 (12.3)	300 (100.0)
	Overweight	405 (29.8)	349 (86.2)	56 (13.8)	405 (100.0)
	Obese	629 (46.3)	497 (79.0)	132 (21.0)	629 (100.0)
	Total	1358 (100.0)	1131 (83.3)	227 (16.7)	1358 (100.0)
2005/6	Underweight	19 (1.4)	12 (63.2)	7 (36.8)	19 (100.0)
	Normal	269 (20.0)	202 (75.1)	67 (24.9)	269 (100.0)
	Overweight	343 (25.5)	252 (73.5)	91 (26.5)	343 (100.0)
	Obese	712 (53.0)	467 (65.6)	245 (34.4)	712 (100.0)
	Total	1343 (100.0)	933 (69.5)	410 (30.5)	1343 (100.0)
2007/9	Underweight	10 (1.2)	5 (50.0)	5 (50.0)	10 (100.0)
	Normal	188 (22.0)	125 (66.5)	63 (33.5)	188 (100.0)
	Overweight	226 (26.5)	146 (64.6)	80 (35.4)	226 (100.0)
	Obese	430 (50.4)	212 (49.3)	218 (50.7)	430 (100.0)
	Total	854 (100.0)	488 (57.1)	366 (42.9)	854 (100.0)
2011/14	Underweight	7 (0.7)	4 (57.1)	3 (42.9)	7 (100.0)
	Normal	116 (11.6)	77 (66.4)	39 (33.6)	116 (100.0)
	Overweight	217 (21.7)	127 (58.5)	90 (41.5)	217 (100.0)
	Obese	659 (66.0)	320 (48.6)	339 (51.4)	659 (100.0)
	Total	999 (100.0)	528 (52.9)	471 (47.2)	999 (100.0)

BMI, body mass index. Due to approximation to one decimal place, some percentages may fall below or exceed 100% by 0.1.

Table 3. Average BP changes and shifts between categories at the four data-collection time points

Time points	Average years apart	BP category	n	BP category: Non-hypertensive	BP category: Hypertensive	Mean change (SD): SBP	Mean change (SD): DBP
2003 & 2005/6	2.4	Non-hypertensive	824	647 (78.5)	177 (21.5)	11.3 (19.3)	4.1 (12.1)
		Hypertensive	159	53 (33.3)	106 (66.7)		
		Total	983	700 (71.2)	283 (28.8)		
2005/6 & 2007/9	2.0	Non-hypertensive	512	354 (69.1)	158 (30.9)	4.5 (20.4)	6.4 (11.9)
		Hypertensive	237	72 (30.4)	165 (69.6)		
		Total	749	426 (56.9)	323 (43.1)		
2007/9 & 2011/14	5.3	Non-hypertensive	234	162 (69.2)	72 (30.8)	1.7 (19.0)	1.1 (11.2)
		Hypertensive	154	39 (25.3)	115 (74.7)		
		Total	388	201 (51.8)	187 (48.2)		
2003 & 2007/9	4.4	Non-hypertensive	493	303 (61.5)	190 (38.5)	16.4 (20.9)	10.9 (12.6)
		Hypertensive	99	26 (26.3)	73 (73.7)		
		Total	592	329 (55.6)	263 (44.4)		
2005/6 & 2011/14	7.3	Non-hypertensive	460	291 (63.3)	169 (36.7)	8.1 (22.3)	8.1 (12.6)
		Hypertensive	185	49 (26.5)	136 (73.5)		
		Total	645	340 (52.7)	305 (47.3)		
2003 & 2011/14	9.7	Non-hypertensive	549	326 (59.4)	223 (40.6)	19.1 (20.4)	12.6 (12.3)
		Hypertensive	96	15 (15.6)	81 (84.4)		
		Total	645	341 (52.9)	304 (47.1)		

percentage increase was between the first and the second occasions (after approximately 2.4 years), where it almost doubled. For those with normal or overweight BMI statuses, the percentage of hypertension almost tripled between the first and fourth occasions. Between the third and fourth time points (approximately 5.3 years), the percentage of those with hypertension among participants in the obese category remained almost unchanged (50.7% in the third occasion and 51.4% in the fourth occasion), even though the percentage of obesity increased by more than 15.6 points (50.4 to 66.0%) between the two occasions.

Table 3 shows the mean change in BP and BMI between two observation periods. Between the first two time points, average SBP and DBP per individual changed by about 11.3 and 4.1 mmHg, respectively but that change decreased substantially between the third and fourth time points to about 1.7 and 1.1 mmHg, respectively. The majority remained in their BP status between observation times but with time (age), the percentage remaining in the hypertension state increased, while the percentage remaining in the normotensive state decreased.

Between the first two occasions when the average age at both times was below 45 years, the percentage of those who were normotensive who transited to the hypertensive state was 21.5%, while the percentage for the counter-transition was 33.3%, or a net recovery of 11.8%. By the fourth occasion when the average age was about 50 years, those initially in the non-hypertensive state who transited to hypertensive state were 40.6%, but the counter-transition (recovery) rate was 15.6%, or a net increase of 25.0% to the hypertensive state.

Fig. 1 and Table 4 show how the progression of BP evolves. A crest (inverted U-shape) marks a negative change (decrease) while a trough (U-shape) marks a positive change (increase). Fig. 1 however shows that the 95% confidence band for ages above 70 years are quite large and therefore the shape in that age group could be spurious. The first crest occurs around 25 years of age and is indicated by negative coefficients (–1.8 for SBP and –1.5 for DBP) for age (Table 4), and the second around

Table 4. Coefficients (95% confidence interval) for the three models predicting SBP and DBP trajectories with standard deviations (SD) for the random effects

BP	Variables	Model 1	Model 2	Model 3
Systolic	Fixed effects			
	Intercept	116.2 (106.7, 125.7)	105.5 (95.7, 115.3)	105.0 (95.1,114.9)
	Age	–1.7 (–3.3, –0.1)	–1.7 (–3.4, –0.1)	–1.8 (–3.4, –0.2)
	Age^2	0.18 (0.08, 0.27)	0.17 (0.08, 0.27)	0.17 (0.08 ,0.27)
	Age^3	–0.004 (–0.006, –0.002)	–0.004 (–0.006, –0.002)	–0.004 (–0.006, –0.002)
	Age^4	0.00003 (0.00001, 0.00005)	0.00003 (0.00001, 0.00005)	0.00003 (0.00001, 0.00005)
	BMI		0.39 (0.29, 0.49)	0.41 (0.30, 0.52)
	Random effects			
	SD (intercept)	14.5 (13.7, 15.2)	14.4 (13.7, 15.1)	24.3 (18.4, 32.2)
	SD (BMI)			0.65 (0.43, 0.96)
	Correlation (BMI, intercept)			–0.82 (–0.91, –0.66)
	SD (residual)	15.5 (15.1, 15.9)	15.4 (15.0, 15.8)	15.2 (14.8, 15.7)
	ICC	0.47 (0.43, 0.50)	0.47 (0.43, 0.50)	0.72 (0.59, 0.82)
Diastolic	Fixed effects			
	Intercept	75.7 (69.8, 81.5)	64.5 (58.5, 70.4)	63.3 (57.2, 69.3)
	Age	–1.4 (–2.4, –0.4)	–1.4 (–2.4, –0.4)	–1.5 (–2.4, –0.5)
	Age^2	0.15 (0.09, 0.21)	0.14 (0.08, 0.20)	0.14 (0.08, 0.20)
	Age^3	–0.004 (–0.005, –0.002)	–0.003 (–0.005, –0.002)	–0.003 (–0.005, –0.002)
	Age^4	0.00003 (0.00001, 0.00004)	0.00002 (0.00001, 0.00004)	0.00002 (0.00001, 0.00004)
	BMI		0.41 (0.35, 0.47)	0.46 (0.39, 0.53)
	Random effects			
	SD (intercept)	9.4 (8.9, 9.9)	9.1 (8.6, 9.5)	17.5 (14.2, 21.7)
	SD (BMI)			0.52 (0.41, 0.67)
	Correlation (BMI, intercept)			–0.87 (–0.92, –0.79)
	SD (residual)	9.4 (9.1, 9.6)	9.3 (9.0, 9.5)	9.0 (8.8, 9.3)
	ICC	0.50 (0.47, 0.53)	0.49 (0.46, 0.52)	0.79 (0.71, 0.85)

SBP, systolic blood pressure; DBP, diastolic blood pressure; ICC, intraclass correlation coefficient.

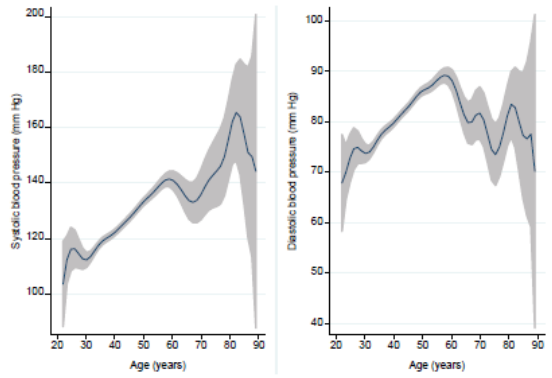


Fig. 1. SBP and DBP trajectories with 95% confidence interval (greyed) by age.

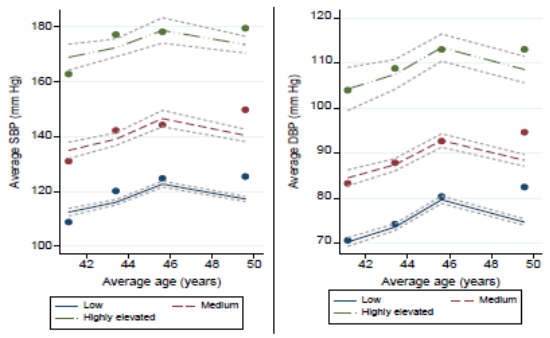


Fig. 2. Observed and BMI-adjusted SBP and DBP trajectories by average age at data-collection time points.

60 years, and is shown by negative coefficients (–0.004 for SBP and –0.003 for DBP) for age cubed. Similarly, the troughs are identifiable around ages 30 and 70 years and marked by the positive coefficients for age squared and age raised to the power of four (Table 4).

Model 1 describes the BP trajectories without accounting for the effect of BMI, while models 2 and 3 show the adjusted changes. The biggest impact of the BMI adjustment was on the intercepts, shifting each BP's mean trajectory downwards (116.2 to 105.0 mmHg for SBP, and 75.7 to 63.3 mmHg for DBP). Model 2, as shown in Table 4, includes a random effect in the baseline values (intercept) to address the variability in starting point for each individual in the sample. Model 3 in addition to model 2, allowed a random BMI effect (slope) for each individual to explain variability in the slope (change by BMI).

The estimated SBP and DBP for the whole sample at 22 years of age was 105.0 and 63.3 mmHg, respectively, and each individual value varied randomly around these baseline values with 24.3 mmHg standard deviations for SBP and 17.5 mmHg for DBP. Therefore 95% of the estimated individual's BPs at age 22 years lies between $105.0 \pm 1.96 \times 24.3 = (57.4–152.6)$ for SBP and $63.3 \pm 1.96 \times 17.5 = (29.0–96.7)$ for DBP. The estimated increases in BP for every 1 kg/m^2 increase in BMI are 0.41 mmHg for SBP and 0.46 mmHg for DBP for the total sample. But the individual slopes (BMI effect) vary randomly around these values with standard deviations of 0.65 mmHg for SBP and 0.52 mmHg for DBP. Therefore the 95% CI for BMI slopes lie between $0.41 \pm 1.96 \times 0.65 = (–0.86–1.68)$ for SBP and $0.46 \pm 1.96 \times 0.52 = (–0.56–1.48)$ for DBP.

The correlation between the random intercepts and BMI random slopes is strongly inversely proportional (–0.82 for SBP and –0.87 for DBP) implying that higher values of baseline BP at the individual level were associated with a relatively smaller effect of BMI on BP, and vice versa. By including a random BMI effect, the ICC (correlation among observations within an individual) increased from 0.47 (model 2) to 0.72 (model 3) for SBP and from 0.49 to 0.79 for DBP. In addition, the variability in the random intercepts also increased from 14.4 (model 2) to 24.3 (model 3) for SBP, and from 9.1 (model 2) to 17.5 (model 3) for DBP.

There were three distinct groups from the 1 969 individuals (Fig. 2). The low-BP trajectory group comprised the majority of the study participants (70.4% for SBP and 59.3% for DBP), and showed a trajectory that was initially in the normotensive state but gently rose to the pre-hypertensive region. A medium BP trajectory (24.5% for SBP and 36.0% for DBP) had an initial average BP in the pre-hypertensive state that gradually rose to the hypertensive level, while the third group of about 5.0% had highly elevated increasing BPs throughout. Individuals in the medium and highly elevated BP groups were most likely to be aged 40 years and above at baseline, while most of those in the low-BP group were 40 years and below initially.

Discussion

This study examined BP life-course trajectories for a period of approximately 10 years in women from an urban setting in South Africa, and how these trajectories were related to changes in BMI. The trajectories were initially characterised by a short instance of decreasing SBP and DBP with age up to around 30 years (Fig. 1, Table 4). Although our sample for ages below 30 years was small, which could have affected the shape of the trajectories, other studies have shown small downward changes in BP in early adulthood, which could be associated with capacity for vascular repair or adaptations.[20-22] Possible vascular repair could be a reason for our results showing that the percentage of subjects recovering from the hypertensive to the normotensive state was highest (Table 3) in the relatively younger ages.

A second phase of rapid increase in the trajectories began from around 30 up to 60 years. This closely mirrors data from the Framingham Heart Study, which showed that SBP increased continuously between 30 and 84 years, but for DBP the continuous increase was between 30 and 49 years.[23] Increasing SBP and DBP are associated with increased peripheral vascular resistance up to around 50 years, while large arterial stiffness leads to the steeper rise in SBP after 50 years.[24] Studies have shown that younger women have less stiff arteries compared with men of a similar age,[25,26] but increased stiffness occurs after menopause. Attention for control of BP in post-menopausal women would therefore reduce the risk for cerebrovascular and cardiovascular events.[24] Understanding the variation in midlife BP trajectories, and factors associated with this acceleration,

may be important in understanding the risk of development and the prevention of CVD, and to implement strategies for lowering BP, as per the National Strategic Plan.[8]

A third phase from around 60 years of age showed a flattening or slightly decreasing trajectory for both BPs (Fig. 1, Table 4). Similar studies have shown a decreasing trend for SBP at ages > 65 years,[27] and for DBP from > 55 years.[28] A decline in BP in old age has been linked to deteriorating health.[29,30] Decreasing SBP with age has been associated with dementia, depression, polypharmacy (use of a large number of medications) and increased number of co-morbidities.[31,32] A steeper decrease in both SBP and DBP has been associated with a diagnosis of diabetes,[33] and an increase in all-cause and cardiovascular mortality.[34] However, longer-term decreases in BP have also been shown to occur with or without the presence of hypertension, heart failure, atrial fibrillation or stroke,[35] implying that decreasing BP could be due to low cardiac output, a feature of ageing.[36] The deceleration and decline in BP in old age is also associated with use of antihypertensive medication,[22] which we did not account for in this study.

The results of the three group-based trajectories show that the averages for both BPs were either at the pre-hypertensive or hypertensive levels for the medium and highly elevated BP groups. The proportion of women in these two groups of trajectories aged 45 years or above was more than those in the lower BP trajectory group. Persistently elevated BP and hypertension trajectories have been associated with increased incidence of atrial fibrillation, with the associations being stronger in women than men.[37] It has also been associated with a higher risk of subclinical renal damage (SRD) since evidence shows that the higher the levels of SBP in early life, the higher the urinary albumin-to-creatinine ratio and risk of SRD later in life.[38] Some studies have suggested that individuals with high BP, especially SBP in midlife, are at a higher risk of arterial stiffening.[39,40] Evidence has shown that continuously high BP for years is closely correlated with subclinical atherosclerosis,[41] intima–media thickness and left ventricular mass index.[42]

The unadjusted trajectories reflect the added effect of ageing and the influence of other life-course risk factors such as BMI. Generally, the effect of BMI on BP trajectories affected the baseline value (intercept) more than the rate of change (slope). This could be an indication that the effect of BMI on BP is as a result of BMI increases that usually and rapidly take place early in life. Accelerated weight gain and increased BMI in childhood and early adult life increase the risk of elevated BP and the development of hypertension in later life.[43,44]

Surveys in South Africa have shown that the average BMI for women by age 30 years is more than 28.0 kg/m^2,[45-49] which is in the upper range of the overweight level. The majority of the women in this study were at least 30 years old, and the average BMI at the first encounter was 29.9 kg/m^2. An increase in BMI could lead to arterial stiffness, which may cause the development of higher BP levels.[50] Higher SBP levels reflect the stiffening of the arterial walls in areas exposed to increased pressure,[51] while coronary perfusion of the myocardium may be related to DBP.[52]

Allowing the effect of BMI to vary by individual brought about three more important findings. First, the standard deviation of the random intercepts increased, an indication that baseline BPs varied greatly by individual. This was evident from the clear distinction in the group trajectories, which did not interact at any time point. Second, the results showed that the effect of BMI on BP changes was higher in women who initially were in the normotensive status (low BP group), and the effect progressively became less in those initially in the pre-hypertensive (medium BP group) and hypertensive (highly elevated BP) states.

The third issue relates to the correlation between measurements from the same individual, which became more pre-eminent after allowing the effect of BMI to be specific to each individual. A stronger correlation can be helpful in tracking those likely to have persistently high BP. Tracking of a characteristic is the stability of a certain feature over time or its predictability based on earlier measurements.[53,54] Tracking the stability of BPs is of considerable public health interest because those at high risk of developing hypertension could be identified at an early stage,[55] through screening. The influence of change in BMI on BP tracking emphasises the importance of weight control at an early age. Maintenance of normal weight gain in childhood may prevent clustering of hypertension and CVD risk factors in adulthood.[56]

The ideal trajectory for BP is one with minimal fluctuations within the normotensive ranges across all ages. Favourable (less steep trajectory) BP trends are attributed to socially patterned and modifiable BP-related exposures such as lifestyle and diet.[57,58] Few studies from isolated communities such as forager-farmers, have shown minimal age-related BP increases in comparison to Western societies.[59] These communities however have adopted a predominantly vegetarian diet with very low salt content, a physically active lifestyle, and very low or non-existent obesity levels.[59-61] Individuals who undergo an urban migration from one of these isolated communities have been found to adapt quickly to BP profiles of their adopted communities.[60]

The main limitation to the study was that we were unable to account for subjects on antihypertensive medications, which could also have contributed to the decreasing BPs with increasing BMI in higher age groups, and the majority of the women (> 70.0%) having SBP in the lowest of the three trajectory groups. Nonetheless, controlling BMI for this and similar populations should be prioritised as it could be beneficial in many ways and possibly cheaper for BP control than medication alone. Another limitation was that the sample size for women above 60 years at any time point was small and this was the reason for the volatile trajectory in this age range.

Notwithstanding, the major strength was in using repeated BP and anthropometric measurements, which helped in analysing long-term trends in BP changes as they were influenced by age and BMI. This could be useful in guiding clinical practitioners to focus on population segments with particular risk profiles. Another strength was the study result showing that the effect of BMI on elevation of BP was not similar for all individuals, and this could help in clinical practice by designing individualised interventions.

Conclusions

Three subgroups of increasing SBP and DBP trajectories were identified, with the majority of the women in each BP type falling in the lowest group, which on average was initially in the normotensive state. The effect of BMI on the BP trajectory for age was highest in women who initially had relatively lower (mostly in the normotensive state) initial BPs. This BMI effect gradually dropped in tandem with increasing initial BP. The

study also showed that steep increasing trajectories could be avoided if preventative interventions are implemented between 30 and 40 years of age from when the BP starts to increase steeply. Follow-up study is required to find out if these trajectories would be similar to findings from a larger and more diverse nationally representative sample.

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