Investigating seasonal variation in abdominal fat indices and hypertension amongst Ellisras population from childhood into adulthood: Ellisras longitudinal study

by

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DISSERTATION

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Writing is not like dancing or modelling; it's not something where-if you missed it by age 19-you're finished. It's never too late. Your writing will only get better as you get older and wiser. If you write something beautiful and important, and the right person somehow discovers it, they will clear room for you on the bookshelves of the world at any age. At least try.”

Elizabeth Gilbert

DEDICATION

I dedicate this dissertation to my daughter (Mkhatshwa Kgetho Nirvana Us'nqobele). Your presence has been a great motivation. You encouraged me to be a better version of myself and reminded me that I can do anything through Christ who strengthens me. I am grateful to my mother (Ndlala Tobhi Esther) who always encouraged me to follow my dreams. To the rest of my family (Mkhatshwa Thulane, Khulile, Mildred, Siphosethu, Thapelo, Ngubane Mnqobi, and Teffo Lebogang), your support throughout my academic journey is appreciated.

DECLARATION

I declare that the dissertation hereby submitted to the University of Limpopo, for the degree of Master of Science (Physiology) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and execution, and that all material contained herein has been duly acknowledged.

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ABSTRACT

Background: Obesity and hypertension have been a global concern, affecting both developing and developed countries. Studies reported seasonal variation as a common risk factor for the development of obesity and blood pressure (BP). However, studies that investigated seasonal variation in obesity and BP over time remain scanty, especially in developing countries.

Aim and objectives: This study was aimed at investigating seasonal variation in obesity and BP among the Ellisras population aged 4−18 years over time. Furthermore, the study investigated whether there is an association between autumn and spring obesity and BP variables among the Ellisras population during a specific period. The study also investigated whether there is a risk associated with the development of obesity and BP (hypertension) between autumn and spring variables among the Ellisras population over time.

Methods: This study forms part of the Ellisras Longitudinal study, of which data was sourced. Anthropometric measurements were measured following the procedure by the International Society for the Advancement of Kinanthropometry. Blood pressure measurements were measured following the procedure by the National High Blood Pressure Education Program (NHBPEP) Working Group on Hypertension Control in Children and Adolescents. At baseline, measurements were collected in the autumn of 1999 with 1 974 (1033 boys and 941 girls) participants. The same participants were followed repeatedly over time (autumn and spring 2000, 2001, 2003). In spring 2003, a total of 1 701 (873 boys and 828 girls) participants were still present in the study. Frequency analysis was used to determine the prevalence of obesity, elevated BP and hypertension in autumn and spring. The generalised estimating equation (GEE) was used to investigate the seasonal association in abdominal fat indices and BP variables in autumn and spring. Furthermore, GEE was used to investigate the risk associated with the development of obesity and BP (hypertension) in autumn and spring during that period.

Results: The results showed that the prevalence of obesity by waist circumference (WC) was mostly markedly ($P \leq 0.05$) higher in autumn (0−30.4%) than spring (0−26.9%) among Ellisras boys and girls aged 4−18 years from 1999−2003. Furthermore, the prevalence of obesity by waist-to-height ratio (WHtR) was mostly significantly (P≤0.05) higher in autumn (0−20.8%) than spring (0−1.3%) among Ellisras boys and girls from 2000−2002. In addition, the prevalence of obesity by waist-to-hip ratio (WHR) was mostly significantly higher in autumn (21.5−95.5%) compared to spring (13.1−88.9%) among Ellisras boys and girls from 1999−2003. Diastolic BP showed the weakest significant (P≤0.05) association (B=0.007, 95% CI: 0.000−0.012) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements when adjusted for age and gender. The strongest significant (P≤0.05) association was observed in WHR (B=0.096, 95% CI: 0.077−0.116) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements. However, in autumn 2003 only WC (B=0.075, 95% CI: 0.056−0.094) and systolic BP (B=0.009 95% CI: 0.003−0.016) were still substantially (P≤0.05) associated with spring measurements (1999−2003) when adjusted for age and gender. Furthermore, WC showed the weakest substantial (P≤0.05) risk (OR=0.003, 95% CI: 0.002−0.011) between baseline measurements (autumn 1999) and subsequent spring measurements (1999−2003) when unadjusted for age and gender. The strongest significant (P≤0.05) risk was observed in obesity by WHtR (OR=0.619, 95% CI: 0.554−0.683) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements when unadjusted for age and gender. In autumn 2003, only systolic BP showed a substantial (P≤0.05) risk (OR=0.036, 95% CI: 0.016−0.057) and (OR=0.033, 95% CI: 0.014−0.054) both unadjusted and adjusted for age and gender respectively.

Conclusion: Seasonal variation in abdominal fat indices and BP was evident in this population of boys and girls and it differs by age group. A significant association between autumn and spring measurements for obesity and BP variables was evident in this study for that period. Furthermore, the development of obesity and BP is associated with seasons.

Key concepts: Seasonal variation, blood pressure, obesity, Ellisras, South Africa

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LIST OF ABBREVIATION

ACE	Angiotensin-converting enzyme
BDNF	Brain-derived neurotrophic factor
BMI	Body Mass Index
BP	blood pressure
COVID-19	Coronavirus disease 2019
DBP	Diastolic blood pressure
ELS	Ellisras Longitudinal Study
GEE	Generalised estimating equation
HC	Hip circumference
ISAK	International Society for the Advancement of Kinanthropometry
LEP	Leptin
LEPR	Leptin receptor
NCDs	Non-communicable diseases
NHBPEP	National High Blood Pressure Education Programme
PA	Physical activity
PCSK1	Preproconvertase
POMC	Proopiomelanocortin
RAAS	Renin-angiotensin-aldosterone system
SA	South Africa
SBP	Systolic blood pressure
SPSS	Statistical Package for the Social Sciences
VAF	Visceral abdominal fat
WC	Waist circumference
WHO	World Health Organisation
WHR	Waist-to-hip ratio
WHtR	Waist-to-height ratio

CHAPTER 1

1. PROBLEM STATEMENT AND AIMS OF THE STUDY

1.1 PROBLEM STATEMENT

Obesity is a growing pandemic affecting both developed and developing countries (Bluher, 2019). According to the World Health Organisation (WHO), approximately 1.9 billion adults who are over 18 years old were obese in 2016 (WHO, 2021). Obesity is associated with conditions such as several cancers, sleep apnoea, diabetes mellitus, myocardial infarction, stroke, and hypertension (Bluher, 2019). Hypertension is defined as an increase in arterial blood pressure (BP) above 140 mmHg systolic and 90 mmHg diastolic BP among adults (WHO, 2021). Children are mostly diagnosed as hypertensive when both the systolic and diastolic BP are greater or equal to the 95th percentile by age and gender (National High Blood Pressure Education Program (NHBPEP) Working Group on High Blood Pressure in Children and Adolescents, 2004). Both obesity and BP are reported to be affected by seasonal variation as risk factors (Kobayashi and Kobayashi, 2006; Hozawa *et al.,* 2011; Stergiou *et al.,* 2015). Seasonal variation is defined as the physiological, behavioural, and psychological changes in humans' response to seasonal changes (APA, 2022). Seasonal variation is reported to results in changes in the sympathetic nervous system, and physiological thermoregulation (Stergiou *et al.,* 2020). Seasonal variation also causes changes in circadian rhythms, physical activity (PA), dietary habits, sleep duration, and weight gain which indirectly causes changes in BP (Covassin *et al.,* 2016; Modesti *et al.,* 2018). Furthermore, seasonal variation was reported to result in a higher prevalence of both obesity and hypertension in winter than in summer in other countries such as Japan and India (Kobayashi and Kobayashi, 2006; Goyal *et al.,* 2018). However, little is known in South African rural areas on how seasonal variation affects obesity and hypertension.

1.2 RATIONALE

Obesity is defined as excess storage of body fat in adipose tissue due to energy imbalance between energy input and energy output (Jung and Choi, 2014). In Ga-Mothapo village of the Limpopo Province, the prevalence of obesity is reported to be 23.6% (Sengwayo *et al*., 2012). Among Lephalale (formerly known as Ellisras until 2002) children aged 6–14 years, abdominal obesity ranges from 0−6.2% in boys, and 0−5.0% in girls (Monyeki *et al*., 2017). The relationship between obesity and hypertension has long been observed in all age groups (Jiang *et al*., 2016). Wu *et al*., (2019) reported that waist circumference (WC), waist-to-height ratio (WHtR), and waist-to-hip ratio (WHR) as obesity indices effective in predicting hypertension.

The relationship between obesity and hypertension is observed because they both have similar risk factors. These risk factors include ethnicity, genetics, PA, poor diet, and seasonal variation (Stergiou *et al*., 2015; Wang *et al*., 2017; Mills *et al*., 2020). Both obesity and elevated BP prevalence were reported to be higher in winter in other countries such as Japan, London, and Italy (Kobayashi and Kobayashi, 2006; Cuspidi *et al*., 2012; Modesti *et al*., 2013). Nika *et al*., (2019) reported a higher prevalence of hypertension in spring (5.5%) and winter (5%) compared to summer (4%) and autumn (2.5%) in Northern Greece. This variation in the prevalence is due to seasonal variations in behavioural factors such as diet, duration of sleep, and PA (Modesti *et al*., 2018).

Seasonal variation results in changes in blood lipid, body weight, bone mass, and bone density (Ma *et al*., 2006; Stergiou *et al*., 2020). Seasonal variation also results in many physiological changes such as changes in coagulation profile, arterial stiffness, increased sympathetic activity, and endothelial dysfunction leading to increased BP (Youn *et al*., 2007; Cuspidi, *et al*., 2012; Goyal *et al*., 2018). Although obesity and hypertension are growing concerns in South African cities, less is known regarding their incidence and risk factors in the country's rural areas (Alberts *et al*., 2015). Moreover, few studies exist that investigated seasonal variation as a risk factor for non-communicable diseases (NCDs), and to the best of our knowledge, none have investigated seasonal variation in abdominal fat indices and hypertension among South Africans.

1.2.1 Aim and objectives

Aim of the study

This study aims to investigate seasonal variation in abdominal fat indices (WC, WHtR, and WHR) and BP amongst the Ellisras population from age 4−18 years over time (May 1996 to November 2003).

The objectives of this study are to:

I. determine the prevalence of abdominal obesity based on abdominal fat indices (WC, WHtR, and WHR) in spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

II. determine the prevalence of elevated BP (hypertension) in spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

III. investigate seasonal association of abdominal fat indices and BP variables between spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

V. investigate the risk associated with the development of obesity and BP between autumn and spring variables among the Ellisras population aged 4−18 over time.

1.2.2 Hypothesis

I. The prevalence of abdominal obesity amongst Ellisras rural children and adolescents will be higher in autumn compared to spring.

II. The prevalence of elevated BP (hypertension) will be higher in spring compared to autumn amongst Ellisras rural children and adolescents.

III. The development of abdominal obesity in autumn (1999−2003) will be associated with the development of obesity in spring (1999−2003) amongst the Ellisras rural children and adolescents.

IV. The risk associated with the development of abdominal obesity and BP in autumn (1999−2003) will be associated with the risk for the development of abdominal obesity and BP in spring (1999−2003) amongst Ellisras rural children and adolescents.

1.3 SCIENTIFIC CONTRIBUTION

Currently, there is little scientific evidence that shows seasonal variation in the prevalence of hypertension and obesity in South Africa (SA). Furthermore, the literature on longitudinal studies is scanty. Therefore, the study aims to add more information on how seasonal variation contributes to the development of obesity and hypertension within a certain community. The findings of the study will help future researchers to have more information to build on when researching a similar topic. The study findings will be presented to the Ellisras community to educate them on the side effects of obesity and hypertension. This is aimed at decreasing the prevalence of obesity and hypertension. A decreased prevalence of obesity and hypertension will then lead to a decreased prevalence of other NCDs, thereby decreasing the health and economic burden that comes with these conditions. Furthermore, articles from this study will be published in journals to contribute to the scientific body of knowledge on obesity and hypertension.

1.4 STRUCTURE OF DISSERTATION

1. Chapter 1 Problems statement, rationale, and aim of the study
2. Chapter 2 Literature review
3. Chapter 3 Materials and methods
4. Chapter 4 Results and discussion
5. Chapter 5 Summary, conclusion, and recommendations
6. Articles accepted for publication in international peer-reviewed Journals

1.5 REFERENCES

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CHAPTER 2

2. LITERATURE REVIEW

2.1 INTRODUCTION

Obesity and hypertension have been declared a global pandemic (Perez *et al*., 2021). The WHO reported that more than 1 billion people worldwide are obese (WHO, 2022). Obesity prevalence in SA is reported to be one of the highest in Sub-Saharan Africa, while in Lephalale of the Limpopo province the prevalence of obesity by WC was reported to be 28.3% (Sebati *et al*., 2019; Boachie *et al*., 2022).

The prevalence of obesity causes an enormous financial burden on the South African healthcare system. Therefore, urgent interventions are needed to decrease the prevalence of obesity thereby decreasing the incidence, prevalence, and financial burden caused by NCDs (Boachie *et al*., 2022). A decrease in obesity prevalence will decrease the prevalence of NCDs since obesity was reported to be a risk factor for several NCDs such as several cancers, coronary heart disease, stroke, kidney disorder, type 2 diabetes, and hypertension (Nyberg *et al*., 2018; Dhawan and Sharma, 2020).

Hypertension is defined as increased BP in the blood vessels that is usually greater or equal to 140 and 90 mmHg for systolic and diastolic BP respectively among adults (WHO, 2023). The aetiology of obesity-related hypertension is said to be mainly due to the stimulation of the sympathetic nervous system, the amount of intra-vascular and intra-abdominal fat, activation of the renin-angiotensin-aldosterone system (RAAS), sodium retention which increases renal reabsorption, and hyperinsulinemia (Vaneckova *et al*., 2014; Jiang *et al*., 2016). Furthermore, it was reported that obesity and hypertension also develop because of environmental risk factors such as ethnicity, geographical areas, socio-economic status, and seasons (Jiang *et al*., 2016).

Seasonal variation was reported to result in changes in PA, types of food available, and individual feeding habits (Kanikowska *et al*., 2015). Ma *et al*., (2006) reported the highest fat intake in autumn and the highest PA level in spring. This then leads to seasonal variation in obesity prevalence. Van Anders *et al*., (2006) reported a high WHR in autumn and summer than spring and winter. According to our knowledge, none of the studies in the literature investigated seasonal variation in obesity based on WHtR.

Furthermore, seasonal variation was reported to result in changes in physiological factors such as increased sympathetic activity, arterial stiffness, endothelial dysfunction, and modification in coagulation profile, leading to seasonal differences in BP (Youn *et al*., 2007; Cuspidi, *et al*., 2012; Goyal *et al*., 2018). Cold temperatures result in vasoconstriction which then results in elevated BP (Narita *et al*., 2021). Furthermore, Goyal *et al*., (2018) reported seasonal variation in BP across four seasons in the Indian population. Their study reported a significantly higher systolic blood pressure (SBP) in winter compared to summer. Moreover, a significantly higher diastolic blood pressure (DBP) in spring compared to autumn.

Fewer studies investigated seasonal variations in obesity and BP. Those that are published are mostly cross-sectional while longitudinal studies are scanty. A preliminary cross-sectional study in the Ellisras Longitudinal Study investigated seasonal variation in fat patterning (Mulaudzi *et al*., 2023). However, seasonal variation in abdominal fat indices and BP over time was never investigated among the Ellisras population. Therefore, investigating seasonal variations in abdominal fat indices and BP remain a need.

2.2 ABDOMINAL OBESITY

Obesity is defined as an increased body weight resulting from increased fats stored in adipose tissue due to an energy imbalance between energy input and energy output (Pengbid and Peltzer, 2017). However, abdominal obesity is defined as an increased deposit of fat in the abdomen (Dhawan and Sharma, 2020). The prevalence of abdominal obesity has increased drastically in the past years leading to an increased prevalence of other lifestyle diseases associated with obesity (Karlsson *et al*., 2019). Obesity Prevalence is estimated to have affected approximately 1.12 billion people worldwide (Herrera *et al*., 2011).

The high prevalence of obesity then leads to a high prevalence of other conditions such as cardiovascular diseases, type 2 diabetes mellitus, some cancer, coronary artery disease, dyslipidaemia, stroke, and hypertension (Herrera *et al*., 2011; Rohde *et al*., 2019). This then results in an increased public health burden, leading to high mortality (Herrera *et al*., 2011). Strategic interventions are usually put in place to decrease the prevalence of obesity, but they usually fail to provide a long-term solution to this pandemic (Herrera *et al*., 2011). Understanding obesity risk factors and the mechanism by which the condition develops might help in providing solutions to this condition.

Obesity often occurs because of disorders in energy homeostasis, which include positive energy balance being favoured over negative energy balance (Mehta *et al.*, 2022). These disorders in homeostasis are influenced by genetics, epigenetics, behavioural, hormonal, developmental, and environmental factors (Mehta *et al.*, 2022). Common obesity risk factors include smoking, physical inactivity, alcohol intake, and unhealthy diet (Pengbid and Peltzer, 2017; Rohde *et al.*, 2019).

2.2.1 Obesity risk factors

2.2.1.1 Genetic factors

Genes like single-minded 1 (SIM1), proopiomelanocortin (POMC), preproconvertase 1 (PCSK1), brain-derived neurotrophic factor (BDNF), melanocortin-4 receptor (MC4R), leptin (LEP), and leptin receptor (LEPR) are associated with the development of obesity (Nieto, 2022). The MC4R gene is a gene that codes for the melanocortin 4 receptor, impairment of its function causes hyperphagia leading to overeating. Proopiomelanocortin causes obesity through hyperphagia. Mutations in PCSK1 result in the misprocessing of melanocortin peptides, which causes abnormalities in glucose homeostasis leading to obesity (Nieto, 2022). Single-minded 1 result in obesity through hyperphagia and reduced paraventricular nucleus of the hypothalamus. Expression of BDNF by the hypothalamus suppresses appetite, therefore deficiency in BDNF results in overeating (Nieto, 2022).

Mutation in the leptin profile is associated with obesity (Socol *et al.*, 2022). Leptin is produced by the adipose tissue and causes a satiety signal when it binds to the leptin receptor in the hypothalamus (Yarim *et al.*, 2022). Obesity happens when the body is resistant to leptin or there’s a functional disorder on the leptin receptor which both results in increased appetite (Yarim *et al.*, 2022). At the genetic level, hundreds of gene loci are associated with the development of obesity (Rohde *et al.*, 2019). These loci are associated with anthropometric obesity phenotype being BMI, WHR, WHtR, and WC (Herrera *et al.*, 2011). Therefore, mutation at the gene loci that are associated with obesity phenotype may result in obesity. Although a lot of studies were done by genome-wide association studies, the mechanism by which genetics results in obesity is still poorly understood (Rohde *et al.*, 2019).

2.2.1.2 Epigenetics factors

Genomic imprinting plays a major role in epigenetics. Imprinted genes are involved in growth, development, viability, differentiation, and metabolic functions. Failure in imprinting results in translocation, duplication, inversion, and hypo/hyper-methylation. These then result in obesity due to alteration in the expression of growth factors (Herrerra *et al*., 2011).

2.2.1.3 Hormonal factors

Alteration in the satiety and hunger hormones such as Ghrelin, leptin, and neuropeptide Y can result in the development of obesity (Van der Valk *et al*., 2019). Ghrelin is produced in the stomach when nutrient availability is low to increase appetite. It decreases with an increase in nutrient availability (Ciu *et al*., 2017). Therefore, a person is most likely to have increased appetite if Ghrelin levels remain high during satiety. This will result in a positive energy balance, resulting in obesity.

Leptin is a cytokine that is mostly produced by adipose tissue (Cui *et al*., 2017). Satiety or adipose tissue depots trigger the secretion of leptin so that it promotes negative energy balance (Rezai-Zadeh, *et al*., 2014). Conversely, a decreased level of leptin promotes hyperphagia and increased energy storage which results in obesity (Cui *et al*., 2017). Neuropeptide Y is associated with food intake and is stimulated during hunger (Zhang *et al*., 2011). Therefore, mutations in Neuropeptide Y result in hyperphagia, which then leads to obesity.

2.2.1.4 Behavioural factors

Obesity behavioural risk factors include smoking, physical inactivity, diet, and alcohol intake (Pengpid and Peltzer, 2017). Less PA is associated with an increased risk for obesity (Kim *et al*., 2017). A diet rich in fruits and vegetables is associated with a decreased prevalence of obesity (Ledoux *et al*., 2011; Rani and Sathiyasekaran, 2013; Schwingshackl *et al*., 2015). Furthermore, smoking is associated with a decreased risk for the development of obesity, while ex-smokers are at an increased risk for the development of obesity (Rupprecht *et al*., 2015; Pengpid and Peltzer, 2017).

2.2.1.5 Environmental factors

Environmental risk factors of obesity include transportation, work environment, food availability, seasonal variation and the geographical area one is situated (Buchowski *et al*., 2009; Lee *et al*., 2015). Availability of transport decreases PA since people do not walk as a form of PA (Creatore *et al*., 2016). People who work in an environment that does not promote PA are often obese than people who work in an environment that promotes PA (Church *et al*., 2011).

The type of food available in a certain geographical area influences a certain diet people in that area might consume. If people are in an environment that sells a lot of fast food, a lot of people are most likely to consume that. Fast food is associated with increased fat which can result in the prevalence of abdominal obesity (Lee *et al*., 2015). Furthermore, the type of food available in a certain geographical area is influenced by seasonal variation as an environmental factor (Ma *et al*., 2006).

The geographical area one is located also influences the development of obesity. In developed countries such as the United States of America, obesity prevalence was reported to be higher in rural areas than in urban areas (Trivedi *et al*., 2015; Wen *et al*., 2018). Conversely, it was reported that in African countries the prevalence of obesity is higher in urban areas than in rural areas (Agyemang *et al*., 2016; Price *et al*., 2018).

2.2.2 Prevalence of abdominal obesity

2.2.2.1 Global

The WHO reported that more than one billion people globally are obese (WHO, 2022). A national study in Korea reported an upward trend in the development of abdominal obesity from 2009−2018. The study reported an increased prevalence of abdominal obesity from 20.7% in 2009 to a 28.1% prevalence in 2018 (Nam *et al*., 2018). The prevalence of abdominal obesity among children and adolescents from the United States was reported to be 18.87% and 33.29% by WC and WHtR respectively (Xi *et al*., 2014). Furthermore, Ma *et al*., (2021) reported an increasing prevalence of abdominal obesity from 1993−2015 among Chinese children aged 6−17 years. They reported that the prevalence of abdominal obesity by WC increased from 5% to 19.3%, and from 6.4% to 14.5% by WHtR from 1993 to 2015. Longitudinal studies show that the prevalence of obesity continues to escalate despite the interventions put in place to minimise the prevalence.

2.2.2.2 South Africa

The prevalence of overweight and obesity is on the rise in SA, and it varies by population group, age, and gender (Rossouw *et al*., 2012). The prevalence of abdominal obesity by WC among children and adolescents in the Eastern Cape was reported to be 2.7% (Nomatshila *et al*., 2022). Furthermore, the prevalence of abdominal obesity in the Gauteng province (Tshwane city), was reported to be 5.14% and 2.28% by WC and WHR respectively among adolescents aged 13−19 years (Ngwenya and Ramukumba, 2017).

A study in SA analysed data among children aged 10−14 years from the Western Cape, Northwest, Limpopo, Kwazulu-Natal, and Mpumalanga. The study reported that abdominal obesity prevalence is higher in the Western Cape, with rural Limpopo (Ellisras) showing the lowest prevalence (Motswagole *et al*., 2019). The prevalence of abdominal obesity in the Limpopo province (Fetakgomo municipality) was reported to be 25% and 21% by WHR and WHtR respectively (Debeila *et al*., 2021). This proves that the prevalence of obesity in SA indeed differs by population and age groups.

2.2.3 Diagnosis of abdominal obesity

Several methods are used to measure abdominal obesity. These methods include WC, WHR, and WHtR (Huxley *et al*., 2010; Ali *et al*., 2022). Other various methods are used to measure the development of obesity such as BMI. However, BMI accounts for both fat and fat-free mass and is considered less effective in the diagnosis of obesity compared to abdominal fat indices. The BMI often fails to provide adequate information on fat distribution, making WC, WHR, and WHtR the best predictors of fat distribution (Huxley *et al*., 2010).

Abdominal obesity is linked to increased visceral abdominal fat (VAF) (Olinto *et al*., 2017). Therefore, abdominal obesity indices better predict the development of cardiovascular diseases than BMI, since VAF is associated with calcification of coronary arteries and higher cardiometabolic risk. This is because VAF is proinflammatory and metabolically active (Olinto *et al*., 2017). However, abdominal fat indices have limitations since they cannot distinguish between subcutaneous fat and visceral fat. Methods such as densitometry and dual-energy X-ray (DEXA) are used to distinguish subcutaneous fat and visceral fat (Olinto *et al*., 2017).

2.2.4 Complications associated with abdominal obesity

Obesity negatively affects most of the body's systems. It affects mainly the reproductive system, kidney, heart, liver, and joints (WHO, 2022). Furthermore, obese individuals are three times more prone to hospitalisation due to COVID-19 (WHO, 2022). Obesity is also a risk factor for mental health issues, endothelial dysfunction, insulin resistance, inflammation, and a range of NCDs such as hypercholesterolemia, cancer, metabolic syndrome, cardiovascular diseases, stroke, type 2 diabetes mellitus, and hypertension (Olinto *et al*., 2017; Rohde *et al*., 2019; WHO, 2022).

2.3 HYPERTENSION

Hypertension is one of the highly prevalent conditions worldwide and has emerged as a risk factor for morbidity and mortality globally (Daniels, 2019; Hsu and Tain, 2021). The condition is represented by two BP values. The first value shows the SBP, and the second value shows the DBP. Systolic BP represents the pressure in blood vessels during a heartbeat, while DBP represents the pressure when the heart is relaxed between the beats (WHO, 2023).

Hypertension is considered life-threatening because people tend not to feel the symptoms of the condition. Patients only know about the condition only when checked for it (WHO, 2023). Symptoms of the condition include dizziness, blurred vision, nosebleeds, nausea, chest pain, severe headache, and difficulty in breathing (WHO, 2023).

Hypertension is controlled by numerous factors, which include the sympathetic nervous system, RAAS, inflammation, endothelial function, and immune system (Hsu and Tain, 2021). Studies reported that the main pathogenesis of hypertension is the activation of the RAAS (Moon, 2013; Hsu and Tain, 2021). The first enzymatic activity of the RAAS is initiated by renin. Renin from the kidney acts on angiotensinogen to form angiotensin I (Ji *et al*., 2017). Angiotensin-converting enzyme (ACE) therefore cleaves angiotensin I to form angiotensin II.

Angiotensin II acts on the anterior pituitary to secrete vasopressin or antidiuretic hormone (ADH) which reduces water loss, thereby increasing BP (Patel *et al*., 2017). Furthermore, Angiotensin II causes vasoconstriction and secretion of aldosterone (Ji *et al*., 2017). Aldosterone from the adrenal cortex results in increased potassium excretion and sodium absorption, thereby increasing BP (Ji *et al*., 2017). Therefore, activation of the RAAS under pathophysiological conditions causes vasoconstriction and inflammation thereby increasing BP (Hsu and Tain, 2021).

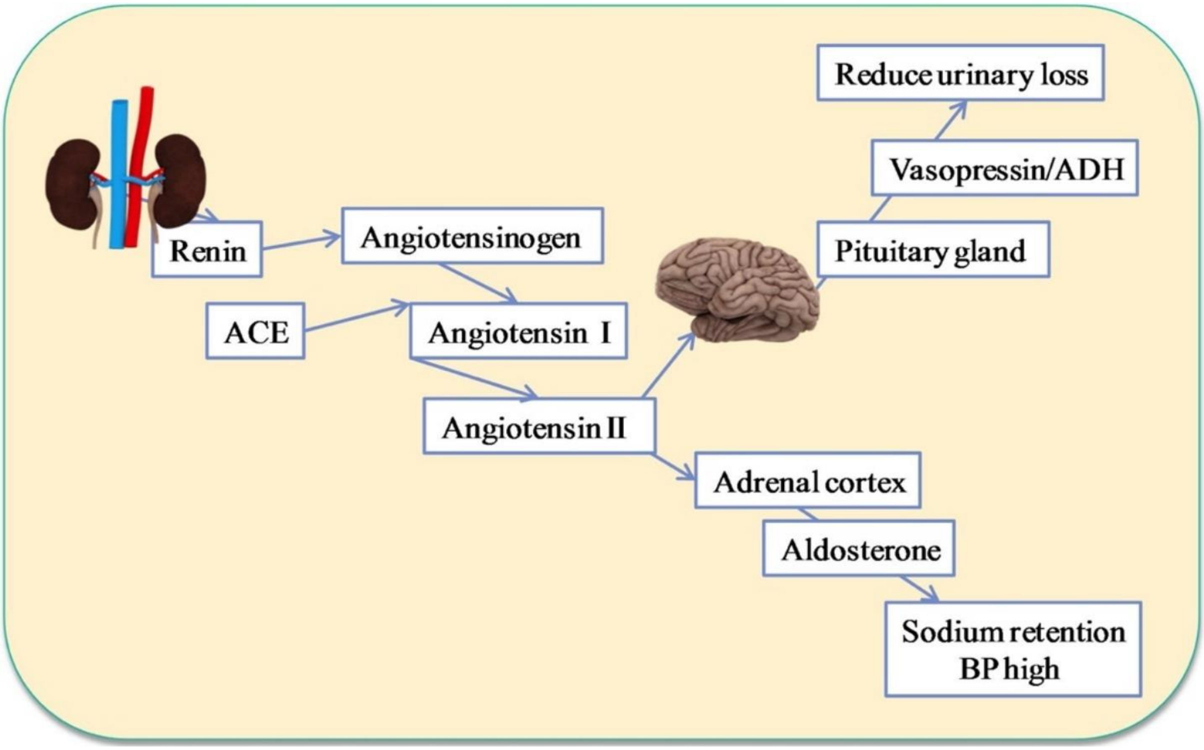

Figure 1: Control of BP by the renin-angiotensin-aldosterone system (Patel *et al*., 2017)

2.3.1 Risk factors of hypertension

Factors that increase the risk of high BP include air pollution, alcohol consumption, age, high salt intake, overweight or obesity, ethnicity, physical inactivity, low potassium intake, and genetics (Ji *et al*., 2013; Mills *et al*., 2020; Hardy and Urbina, 2021; WHO, 2023). Furthermore, hypertension risk factors include gender, socio-economic status, stress, smoking, education level, and dyslipidaemia (Pinto and Martins, 2017; Nawi *et al*., 2021).

2.3.2 Prevalence of hypertension

2.3.2.1 Global

The WHO reported that the prevalence of hypertension is higher in the African region (27%) than the Americans (18%). However, Zhou *et al*., (2021) reported an increased prevalence of hypertension in high and middle-income countries than in low-income countries. Al Kibria (2019) reported that 1.5% of children in the United States were hypertensive from 2013−2016 using the American Academy of Paediatrics guidelines. Moreover, the prevalence of hypertension among children (5−19 years) from India was reported to be 4.7% (Amritanshu *et al*., 2015).

A systematic literature review by Noubiap *et al*., (2017) reported that the prevalence of hypertension among African children (2−19 years) ranges from 0.2−24.8% from 1996−2017. Furthermore, a review by Crouch *et al*., (2022) reported that the prevalence of hypertension among African children (3−19 years) ranges from 0.2−38.9% from 2017 to 2020. This shows that the prevalence of hypertension continues to escalate in Africa despite interventions put in place to minimize the growing prevalence. The increasing prevalence in Africa may be due to urbanisation which results in dietary changes, physical inactivity, tobacco use, obesity, and exposure to air pollution (Crouch *et al*., 2022).

2.3.2.2 South Africa

The prevalence of pre-hypertension/hypertension among children (6−9 years) from the Eastern Cape province (Mthatha and East London) was reported to be 42.16% (Matjuda *et al*., 2020). Furthermore, a longitudinal study by Kagura *et al*., (2015) reported that the prevalence of hypertension among children from Johannesburg ranged from 8.4−24.4% over time. The prevalence of hypertension among children from Kwazulu-Natal was reported to be 13.7% (Bhimma *et al*., 2018).

Moreover, the prevalence of hypertension in the Limpopo province (Mankweng and Toronto) was reported to be 6.9% among children (10−16 years) (Moselakgomo *et al*., 2012). The prevalence of hypertension among the Ellisras population was reported to range between 2−5.5% among children aged 9−17 years (Mphahlele *et al*., 2020). Therefore, this shows that the prevalence of hypertension in SA remains low in rural areas than urban areas.

2.3.3 Diagnosis of hypertension

An individual is considered hypertensive if BP measurements are considered high for two days (WHO, 2023). High BP is defined as SBP and DBP ≥140 mmHg and ≥90 mmHg respectively (WHO, 2023). These cut-off points are mostly applicable to adults. According to the NHBPEP Working Group on High Blood Pressure in Children and Adolescents (2004), children are mostly considered hypertensive when both the SBP and DBP are greater or equal to the 95th percentile by age and gender. However, the diagnosis of paediatric hypertension remains complex because normal and elevated BP varies by gender, age, and height (Hansen *et al*., 2007).

2.3.4 Complications associated with hypertension

Hypertension has been reported to be one of the risk factors that may result in dementia, stroke, ischaemic heart diseases, chronic kidney diseases, heart failure, coronary heart diseases, kidney damage or failure, heart attack, and other cardiovascular diseases (Zhou *et al*., 2021, WHO, 2023). Furthermore, hypertension is associated with left ventricular hypertrophy, peripheral artery disease, atherosclerosis, and myocardial infarction (Falkner, 2010; Daniels, 2019).

2.3.5 The relationship between obesity and hypertension

The association between abdominal obesity and hypertension has been long reported by several studies in the literature (Silva *et al*., 2016; Sangrós *et al*., 2018). Furthermore, Ryu *et al*., (2019) reported that the relationship between obesity and hypertension can be maintained over time. Zhou *et al*., (2021) reported that BP is mostly raised in obese individuals. Both obesity and hypertension have been reported to result from imbalances in the RAAS. Angiotensin II drives insulin resistance, dyslipidemia, and hypertension, and promotes obesity. Furthermore, angiotensin II promotes adipocyte proliferation and differentiation which results in the development of obesity (Patel *et al*., 2017).

2.4 SEASONAL VARIATION

Seasonal variation is defined as the physiological, behavioural, and psychological changes in humans' response to seasonal changes (APA, 2022). Physiological changes that take place because of seasonal variation include changes in circadian rhythm, sympathetic nervous system, vasocontraction, sweating, triglycerides, cholesterol, glycemia, and weight (Bowden *et al*., 2007, Aubinière-Robb *et al*., 2013; Stergiou et al., 2022). Seasonal behavioural changes include PA, dietary habits, and sleep duration (Stergiou *et al*., 2022). Psychological factors that vary across seasons include depression, mood changes, and anxiety (Harmatz *et al*., 2000; Alpérovitch *et al*., 2009). Seasonal variation in physiological, behavioural, and psychological factors may therefore lead to variations in both obesity and BP.

Studies that investigated seasonal variation in abdominal obesity and BP are scanty. Most of the studies looked at the relationship between BP and temperature (Barnett *et al*., 2007; Alpérovitch *et al*., 2009, Kent *et al*., 2011; Hozawa *et al*., 2011; Miersch *et al*., 2013; Yang *et al*., 2015; Wang *et al*., 2017). Furthermore, Studies define season variation differently. Some studies define seasonal variation based on school years (Moreno *et al*., 2015), with some defining seasonal variation by months of the year (Hozawa *et al*., 2011). Furthermore, several studies define seasonal variation based on the seasons of the year (summer, autumn, winter, and spring) as done in this study (Kobayashi and Kobayashi, 2006; Alpérovitch *et al*., 2009; Nilles *et al*., 2023).

Although several studies defined seasonal variation similarly to this study, the weather conditions in different seasons vary significantly in countries in the northern hemisphere compared to those in the southern hemisphere (Means, 2019). In most of the provinces in SA, the summer season is the warmest, sunny, and rainy season, except for the Cape Peninsula in the Southwest which remain clear skied and sunny all summer. Summer is followed by autumn which is still warm during the day but gets chilly in the evening and early morning. Autumn marks the end of the rainy season, except for the Cape Peninsula region which marks the end of the dry season. Winter is the driest and coldest season which is followed by spring. Spring quickly warms up the country. The Limpopo Province gets too hot with the desert part of the Northwest and Northern Cape (Alexander, 2023).

Seasons influence plant growth and vegetation. Therefore, little vegetation grows in winter, while in spring they germinate. Summer is characterised by adequate growth of plants, while plants lose leaves in winter (National Geographic Society, 2023). The differences in plant growth have an impact on the development of obesity and hypertension. Studies reported that plants and vegetables have phytochemicals such as polyphenols that protect against obesity and hypertension (Willians *et al*., 2013; Kooshki and Hoseini, 2014, Godos *et al*., 2019).

Literature therefore provides evidence on how obesity and hypertension risk factors vary across seasons. This then shows that seasonal variations of obesity and hypertension risk factors may affect the prevalence of obesity and hypertension. However, studies that investigated seasonal variation in obesity and hypertension over time remain scanty. Most cross-sectional studies in the literature investigated seasonal variations in BP. However, little is done on seasonal variation in abdominal obesity. Therefore, investigating seasonal variation in obesity and BP remains a need.

2.4.1 Seasonal variation in obesity

Several studies conducted in the Netherlands, North America, France and Northern Greece reported seasonal variations in obesity. However, only a few studies from Netherlands and America reported seasonal variation in abdominal obesity (Visscher and Seidell, 2004; Van Anders *et al*., 2006), with some reporting seasonal variation in general obesity (Visscher and Seidell, 2004; Alpérovitch *et al*., 2009; Nika *et al*., 2019). Furthermore, some studies from Tokyo and United states of America investigated seasonal variations in body weight (Kobayashi and Kobayashi, 2006; Ma *et al*., 2006).

Visscher and Seidell, (2004) reported that the prevalence of obesity was lower in summer than winter among adults from Netherlands. Furthermore, they reported that seasonal variation is larger for abdominal obesity compared to general obesity. Furthermore, Van Anders *et al*., (2006) reported a higher WHR in autumn and summer compared to spring and winter. Kobayashi and Kobayashi (2006) reported that body weight among Japanese children usually decreases in summer and increases in autumn, winter, and early spring. Furthermore, Ma *et al*., (2006) reported an increase in body weight in winter compared to summer, spring, and autumn among adults from the United States of America.

Seasonal variation in abdominal obesity may be due to seasonal variation observed in obesity risk factors. Obesity risk factors such as blood lipids, low-density lipoprotein cholesterol, PA, and diet have been reported to vary by season (Ockene *et al*., 2004; Ma *et al*., 2006). However, the mechanism on how seasonal variation in obesity risk factors leads to the development of obesity is less know.

2.4.2 Seasonal variation in blood pressure

Seasonal variation in BP has been reported in the literature (Marti-Soler *et al*., 2014). Seasonal variation in BP is reported to increase in winter compared to summer in countries such as Australia, Belgium, Czech Republic, Denmark, France, Italy, Lithuania, New Zealand, Northern Ireland, Norway, Portugal, Principality of Liechtenstein, Russia, Spain and Switzerland (Marti-Soler *et al*., 2014; Stergiou *et al*., 2020; Narita *et al*., 2021;). Furthermore, Young *et al*., (2007) reported that BP is mostly lower in summer, spring, and autumn than winter among adults from Korea. Moreover, a study conducted in Northern Greece reported the prevalence of elevated BP to be lower in autumn and summer than spring and winter (Nika *et al*., 2019).

The increase in BP in winter is because there is a decrease in temperature which results in decreased sweating which causes increased salt retention. Winter also plays a role in the sympathetic nervous system by upregulating endothelin-A while down-regulating endothelin-B receptor causing vasoconstriction which then results in increased BP (Marti-Soler, 2014). Aubinière-Robb *et al*., (2013) reported that the effect of seasons in BP can be observed mostly in people who are temperature-sensitive.

2.5 TRACKING OF ABDOMINAL OBESITY AND BLOOD PRESSURE

Studies reported that childhood obesity mostly results in adulthood obesity (Van Lenthe *et al*., 1998; Monyeki *et al*., 2006; Simmonds *et al*., 2016). Since obesity is reported to be a risk factor for cardiovascular diseases such as hypertension, this may result in the development of these cardiovascular diseases to be maintained over time. Therefore, it is important to track and investigate the development of cardiovascular diseases from childhood.

However, few studies exist in the literature that investigated seasonal variations of abdominal obesity and BP over time. Seasonal variation in obesity by BMI was reported by Kobayashi and Kobayashi (2006) over time. However, most of the seasonal studies on obesity and hypertension reported the prevalence in different seasons and never reported the seasonal association of obesity and BP.

2.6 SUMMARY

Obesity and hypertension are a global concern. Their escalating prevalence is more concerning in Sub-Saharan Africa as it is still under rapid demographic transition. Therefore, NCDs are increasing morbidity and mortality because of this demographic transition (Price *et al*., 2018). To decrease the growing prevalence, improving the prevention, diagnosis, and treatment of NCDs should be a major goal of clinical medicine (Hunter and Reddy, 2013).

The WHO reported that approximately 39 million children, 340 million adolescents, and 650 million adults globally are obese (WHO, 2022). Furthermore, studies reported childhood obesity to be a predictor of adulthood obesity (Van Lenthe *et al*., 1998; Monyeki *et al*., 2006; Simmonds *et al*., 2016). Early intervention is therefore essential to prevent the development of obesity (WHO, 2022). Early prevention of obesity will therefore minimise the prevalence of other NCDs such as hypertension.

Obesity and hypertension are linked to increased cardiovascular mortality (Ali *et al*., 2022). Furthermore, higher obesity and hypertension prevalence was reported in cold seasons compared to warm seasons. These then result in increased cardiovascular mortality in cold seasons. Therefore, health professionals should take into consideration the impact of seasonal variation on cardiovascular morbidity and mortality. People should be encouraged to follow a healthy lifestyle at different seasons as it was reported that lifestyle factors such as diet and PA vary across seasons. This will therefore decrease the seasonal variability observed in cardiovascular morbidity and mortality.

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CHAPTER 3

3. MATERIALS AND METHODS

3.1 SAMPLING PROCEDURE

This study took place in Lephalale (formerly known as Ellisras until 2002 when the name was changed by the provincial government of the Limpopo province), SA. The Ellisras Longitudinal Study (ELS), a subset of which this study is a part, is described in more depth elsewhere (Monyeki *et al.* 2017). Data for this study was sourced from the Ellisras Longitudinal Study which was collected in the autumn (May) and Spring (November) of 1999, 2000, 2001, and 2003. The ELS data collection was previously carried out at two points, which were in autumn and spring. Therefore, investigation of all four seasons using the available data on the ELS was not possible.

The sample size for the current study was determined using the population size of 115 767, 95% confidence, 5% margin of error, and an estimated population proportion of 50%. This study started with 1 974 (1033 boys and 941 girls) participants in 1999 and ended with 1 701 (873 boys and 828 females) participants in 2003, aged 4−18 years. The baseline age of the population was 4−14 years, while the last follow−up age was 8−18 years.

These participants were measured repeatedly over the years. The current study (with ethical clearance no. TREC/360/2022: PG) was approved by the Turfloop research ethics committee before it was undertaken.

3.2 MEASUREMENTS

3.2.1 Blood pressure

Blood pressure measurements were taken following the procedure by the NHBPEP Working Group on Hypertension Control in Children and Adolescents (1996). After 5 minutes of relaxation in a well-ventilated room, BP was measured. BP used was the average of 3 measures at an interval of five minutes apart, from both the left and right arms. Measurements were done with an electronic Micronta monitoring kit while the individual was seated with their legs touching the ground but not crossed (NHBPEP Working Group on Hypertension Control in Children and Adolescents, 1996). An electronic infrasonic transducer on the device's bladder detects the BP and pulse rate and simultaneously displays them on the screen. This adaptable tool was created for both research and medical purposes. A prior pilot study found a high association (r=0.93) between the results obtained using the automated device and those obtained with a conventional mercury sphygmomanometer.

Figure 2: Picture showing measurement of BP in the ELS.

3.2.2 Anthropometry

Following the guidelines established by the International Society for the Advancement of Kinanthropometry (ISAK), anthropometric measurements were taken to the nearest 0.1 cm (Norton, 2018). Height was measured with a stadiometer, with the participant in a standing position. The participant was placed such that the heels, buttocks, and shoulders touched the stadiometer, with shoes and socks off. Feet were put flat on the ground, together. The stadiometer's headboard was then pressed against the participant's head, and height was measured. Participants were measured WC with a flexible steel tape, halfway between the lowest rib cage and the iliac crest while standing, following a typical expiration. Hip circumference (HC) was measured with a flexible steel tape on the broadest point above the buttocks (Norton, 2018).

Figure 3: Picture showing measurement of height in the ELS.

Figure 4: Picture showing measurement of WC in the ELS.

3.3 PREVALENCE OF OBESITY AND BP (HYPERTENSION)

To classify obesity, a WHtR ≥ 0.5 in both males and females was used, and a WHR ≥ 0.9 (males) and ≥ 0.8 (females) was also used (Goon et al. 2014). A WC ≥ 90th percentile was used in both males and females (Ribas and Santana da Silva, 2012). Hypertension was determined as the average of three different BP readings when either the SBP or the DBP is greater than the 95th percentile for age and gender using the NHBPEP Working Group on Hypertension Control in Children and Adolescents (1996) reference tables. High SBP and DBP was defined as the SBP or the DBP greater than the 95th percentile for age and gender using the NHBPEP Working Group on Hypertension Control in Children and Adolescents (1996) reference tables.

3.4 ATTRITION RATE

The overall attrition rate among the ELS ranges from 2.4%−70.3% because of urbanisation, illness, pregnancy, and death. Participants form part of the study when they are in the Lephalale Municipality. Those who are permanently lost due to death range from 0.71%−3.73% for boys and 0.75%−4.89% for girls (Monyeki *et al*., 2019).

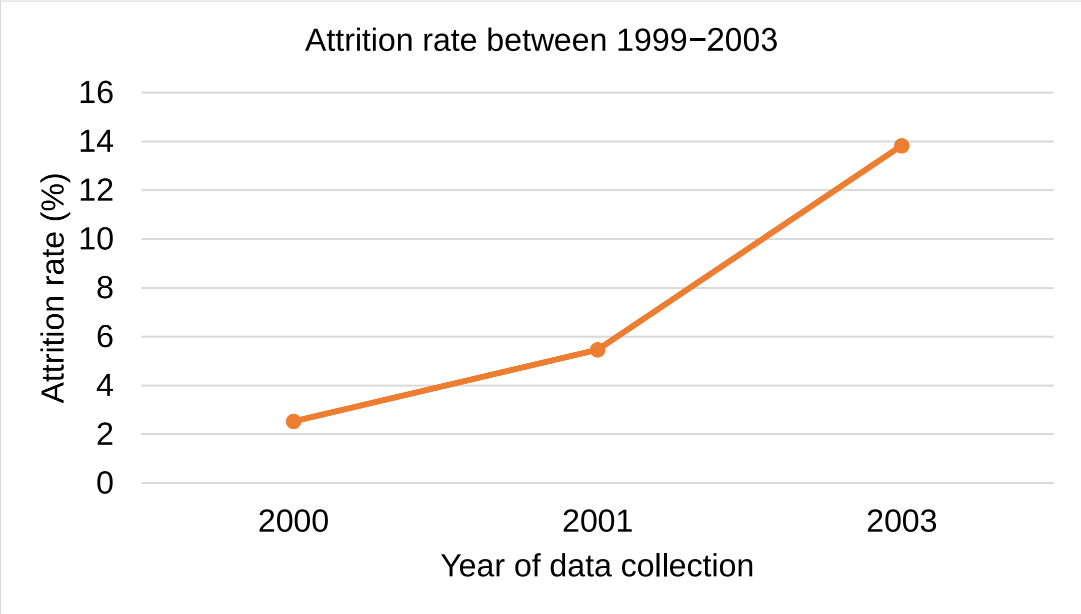

Figure 5: Attrition rate of the current study.

3.5 QUALITY ASSURANCE

The reliability and validity of the study are published elsewhere (Monyeki *et al.* 2008a; Sebati *et al.* 2019). In short, the inter- and intra-tester technical errors of WC, HC, and height measurements were considered, ranging from 0−3.4 cm (0–4%) for WC and HC, and from 0.22−0.43 cm (0.12−0.32%) for height.

3.6 STATISTICAL ANALYSIS

3.6.1 Descriptive statistics

The Shapiro-Wilk test was used to test the normality of the data. Participants' characteristics (BP, WC, WHtR, and WHR) were presented as median and interquartile. Participants were divided into age categories, looking at the critical stages of the development of obesity (Dietz, 1994). Frequency analysis was used to determine the prevalence of obesity, elevated BP and hypertension in percentage. Seasonal variation in absolute values were presented graphically in different years by age groups (4−7 years, 8−11 years, and above 12 years) in both boys and girls.

3.6.2 Generalised estimating equation (GEE)

The GEE technique which determines the relationship between an indicator at baseline and the same indicator at all other measurement periods was used. The GEE was used to investigate the seasonal association of abdominal fat indices and BP variables in autumn and spring among the Ellisras population. Furthermore, GEE was used to investigate the risk associated with the development of both abdominal obesity and BP in autumn and spring with age and gender being included in the model (Monyeki et al., 2008b).

3.6.3 Statistical package and significance

The statistical analyses were computed with the IBM Statistical Package for the Social Sciences (SPSS) (version 28), and the STATA programme (version 12) with a significance level of $p \leq 0.05$.

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CHAPTER 4

4 RESULTS

4.1 DESCRIPTIVE STATISTICS OF THE POPULATION

Table one shows the descriptive statistics among the Ellisras population aged 4−18 from 1999 and 2003. The results showed that girls were markedly (P≤0.05) taller (143.7 cm) than boys (142.0 cm). Girls had a substantially (P≤0.05) larger HC (68.0 cm) than boys (65.0 cm). Furthermore, girls had a significantly (P≤0.05) higher systolic and diastolic BP compared to boys.

Table 1: Clinical characteristics of participants from 1999−2003

	Boys	Girls	P value
Clinical characteristics [median (25^{th}−75^{th} percentile)]			
Age (years)	11.6 (9.9−13.1)	11.6 (10.0−13.1)	0.268
Height (cm)	142.0 (134−150)	143.7 (135.0−153.0)	<0.001*
WC (cm)	56.8 (54.0−59.0)	56.9 (53.8−60.0)	0.722
HC (cm)	65.0 (61.0−69.4)	68.0 (63.0−74.3)	<0.001*
WHtR	0.4 (0.38−0.42)	0.4 (0.38−0.42)	<0.001*
WHR	0.9 (0.8−0.9)	0.8 (0.8−0.9)	<0.001*
SBP (mmHg)	98.0 (91.5−106.0)	100 (93.0−109.0)	<0.001*
DBP (mmHg)	63.0 (58.0−68.5)	64.0 (59.0−70.0)	<0.001*
Number of participants in different age groups n (%)			
1999			

4-7 years	163 (8)	129 (7)
8-11 years	683 (35)	660 (33)
Above 12 years	187 (9)	152 (8)
Total number of participants (1974)	1033(52)	941 (48)
2000		
4-7 years	80 (4)	57 (3)
8-11 years	536 (28)	517 (27)
Above 12 years	390 (20)	344 (18)
Total number of participants (1924)	1006 (52)	918 (48)
2001		
4-7 years	24 (1)	15 (1)
8-11 years	382 (20)	373 (20)
Above 12 years	556 (30)	516 (28)
Total number of participants (1866)	962 (52)	904 (48)
2003		
4-7 years	0 (0)	0 (0)
8-11 years	122 (7)	110 (7)
Above 12 years	751 (44)	718 (42)
Total number of participants (1701)	873 (51)	828 (49)

WC-waist circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure, *P≤0.05

Table 2 shows the clinical characteristics of Ellisras population aged 4−18 years from 1999 to 2003 yearly. The results showed that girls (141.0− 155.0 cm) were substantially (P<0.001) taller than boys (140.0−152.0 cm) from 2000−2003. Moreover, girls (64.5−74.0 cm) had a significantly (P<0.001) larger HC than boys (62.5−68.1 cm) from 1999−2003. Girls (97.0−106.0 mmHg) also showed a substantially (P<0.001) higher SBP compared to boys (95.0−103.0 mmHg) from 1999−2003. Furthermore, girls (61.0−66.0 mmHg) had a significantly (P=0.002) higher DBP compared to boys (60.0−65.0 mmHg) from 1999−2003.

Table 2: Clinical characteristics of the Ellisras population aged 4−18 yearly.

	1999		P value	2000		P value	2001		P value	2003		P value
	Boys	Girls		Boys	Girls		Boys	Girls		Boys	Girls	
Clinical characteristics [median (25th − 75th percentile)]												
Age (years)	10.2 (8.6 − 11.4)	10.3 (8.9 − 11.3)	0.799	11.1 (9.5 − 12.3)	11.1 (9.7 − 12.2)	0.966	12.1 (10.4 − 13.2)	12.1 (10.6 − 13.2)	0.680	14.0 (12.3 − 15.1)	14.0 (12.5 − 15.2)	0.345
Height (cm)	136 (127.0 − 142.0)	136.0 (128.0 − 142.0)	0.117	140.0 (132.0 − 147.0)	141.0 (133.0 − 148.0)	<0.001*	144.0 (136.0 – 151.0)	146.0 (137.8 − 153.5)	<0.001 *	152.0 (144.0 − 160.0)	155.0 (147.0 − 161.0)	<0.001*
WC (cm)	55.0 (52.6 − 57.8)	55.0 (52.5 − 58.0)	0.760	56.5 (54.0 − 59.0)	56.0 (53.0 − 59.0)	<0.001*	57.5 (54.6 − 60.2)	57.5 (54.5 − 60.8)	0.241	59.0 (56.0 − 61.8)	59.0 (56.0 − 62.5)	0.010*
HC (cm)	62.5 (58.6 − 65.8)	64.5 (60.4 − 68.8)	<0.001*	64.3 (60.5 − 67.8)	67.4 (62.5 − 72.8	<0.001*	66.6 (62.5 − 70.9)	69.1 (63.9 − 74.5)	<0.001*	68.1 (64.0 − 73.0)	74.0 (68.0 − 80.0)	<0.001*
WHtR	0.40 (0.40 − 0.43)	0.41 (0.39 − 0.43)	0.182	0.40 (0.38 − 0.420	0.40 (0.38 − 0.42)	<0.001*	0.40 (0.38 − 0.42)	0.40 (0.37 − 0.42)	<0.001 *	0.39 (0.37 − 0.40)	0.39 (0.37 − 0.40)	0.147

WHR	0.9 (0.8 − 0.9)	0.9 (0.8 − 1.0)	<0.001*	0.9 (0.8 − 0.9)	0.8 (0.8 − 0.9)	<0.001*	0.9 (0.8 − 0.9)	0.8 (0.8 − 0.9)	<0.001*	0.9 (0.8 − 0.9)	0.8 (0.7 − 0.8)	<0.001*
SBP (mmHg)	98.0 (90.0 − 104.0)	98.0 (92.0 − 106.0)	<0.001*	99.0 (92.0 − 106.0)	100.0 (94.0 − 109.0)	<0.001*	95.0 (88.5 − 101.5)	97.0 (91.0 − 104.0)	<0.001*	103.0 (96.0 − 111.0)	106.0 (98.5 − 114.0)	<0.001*
DBP (mmHg)	60.0 (55.0 − 66.0)	61.0 (56.0 − 68.0)	<0.001*	65.0 (60.0 − 71.0)	66.0 (61.0 − 72.0)	0.002*	63.0 (58.0 − 68.0)	63.5 (59.0 − 69.0)	<0.001*	63.5 (58.0 − 69.0)	65.5 (59.5 − 71.5)	<0.001*

WC-waist circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure, *P≤0.05

4.2 SEASONAL VARIATION IN ABSOLUTE VALUES

4.2.1 Seasonal variation in abdominal fat indices

Figures 6 to 8 show seasonal variation in, WC, WHtR, and WHR in both boys and girls. All non-significant results were removed from all figures and only significant (P≤0.05) results were reported. Graphs with both significant and non-significant results are shown in appendix D. Waist circumference was mostly substantially (P≤0.05) higher in autumn (55−60 cm) than spring (52.5−59.7 cm) from 1999−2003 among Ellisras girls and boys aged 4−18 years. Furthermore, WHtR was substantially (P≤0.05) higher in autumn (0.5) than spring (0.4) among Ellisras boys and girls aged 4−7 years in 2001. Seasonal variation in WHR was substantially (P≤0.05) higher in autumn (0.9) than spring (0.8) only in girls aged 8−18 in 1999 and 2000.

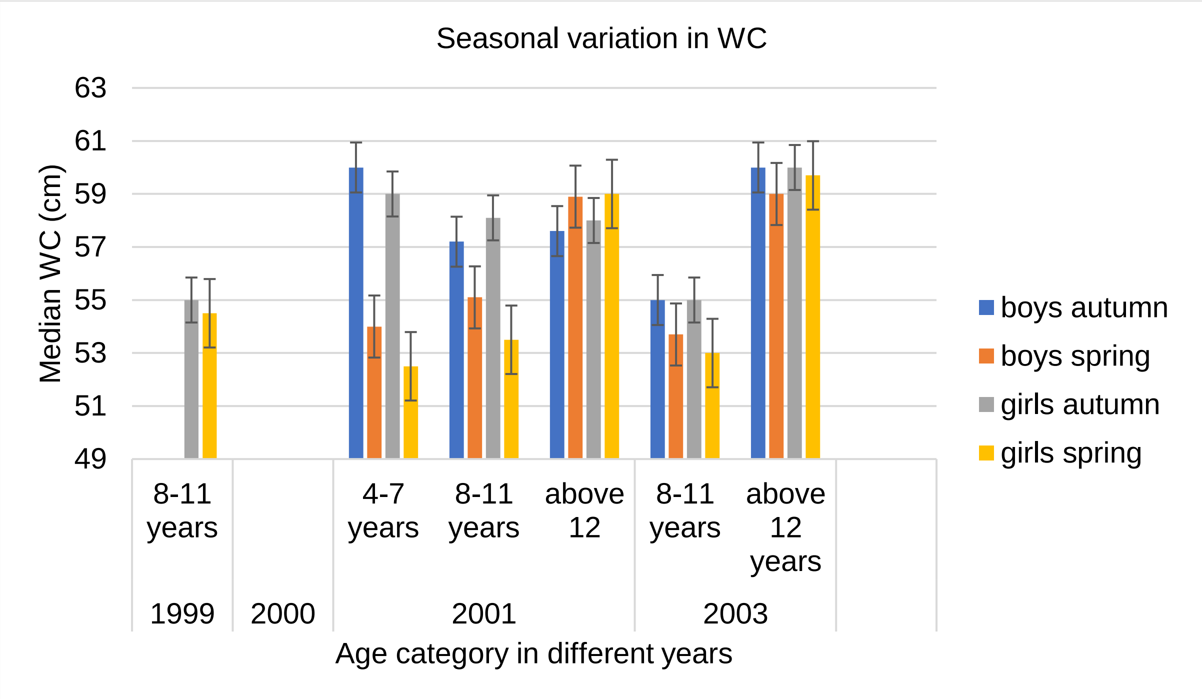

Figure 6: Seasonal variation in WC in boys and girls in spring and autumn.

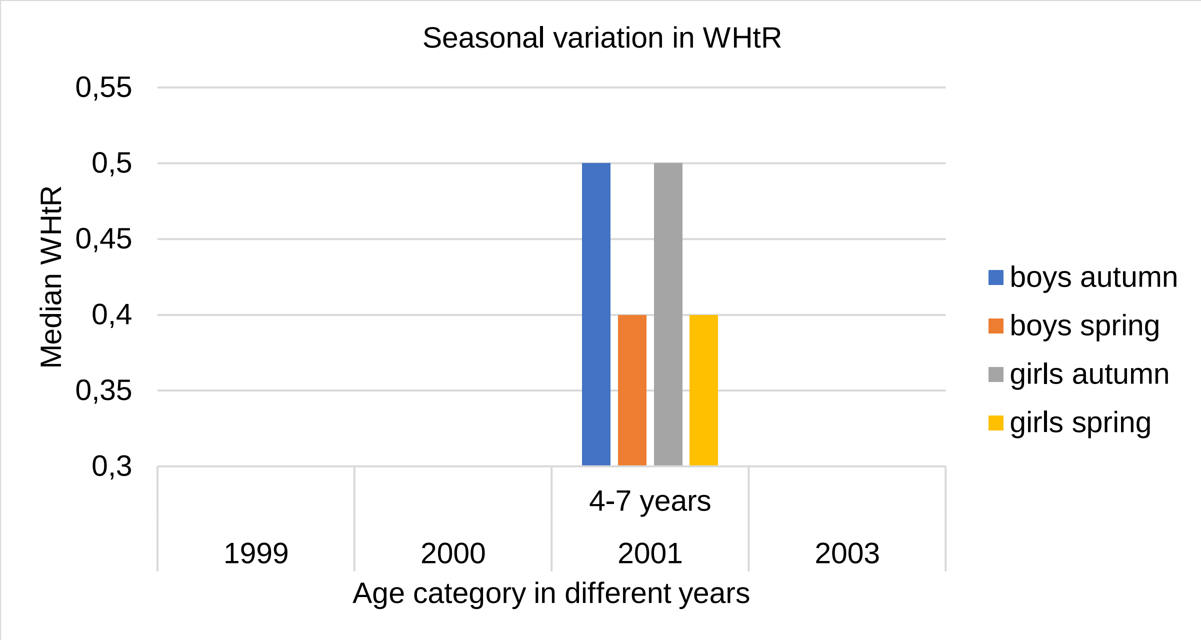

Figure 7: Seasonal variation in WHtR in boys and girls in spring and autumn.

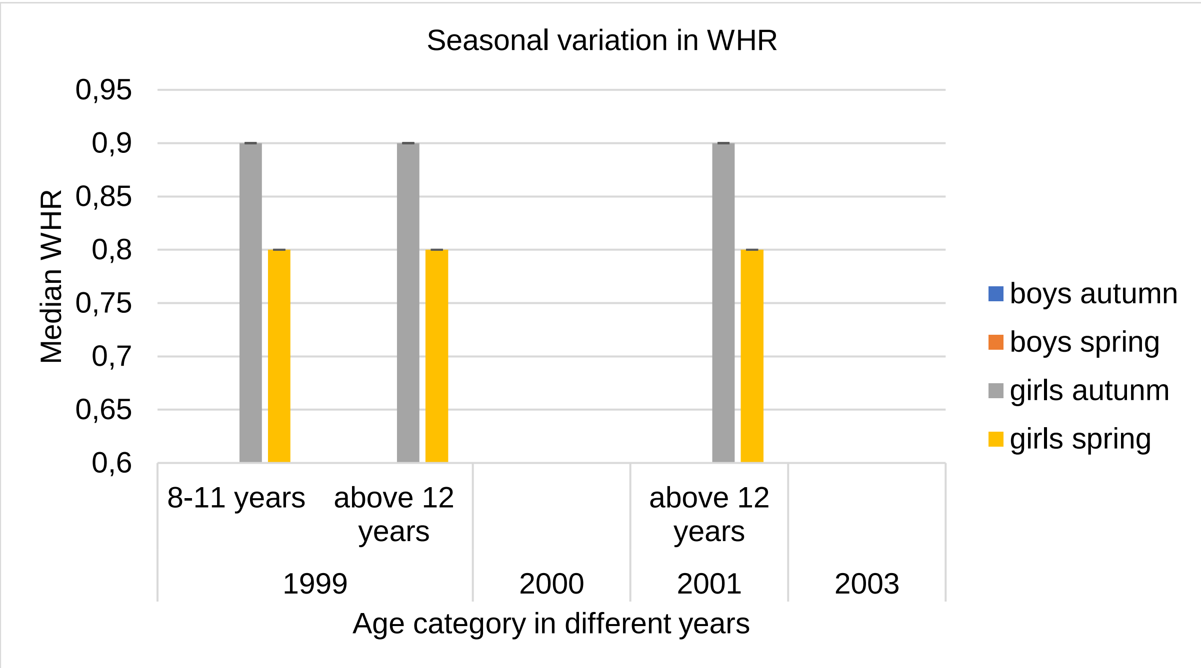

Figure 8: Seasonal variation in WHR in boys and girls in autumn and spring.

4.2.2 Seasonal variation in blood pressure

Figures 9 and 10 show seasonal variation in SBP, and DBP in both boys and girls. All non-significant results were removed from all figures and only significant ($P \leq 0.05$) results were reported. Systolic BP was significantly higher in autumn (96.5−109 mmHg) compared to spring (91.3−106 mmHg) among boys and girls aged 8−18 years in 2001 and 2003. Furthermore, DBP was significantly higher in autumn (64.7−69 mmHg) compared to spring (57.3−62 mmHg) among Ellisras boys and girls aged 8−18 years.

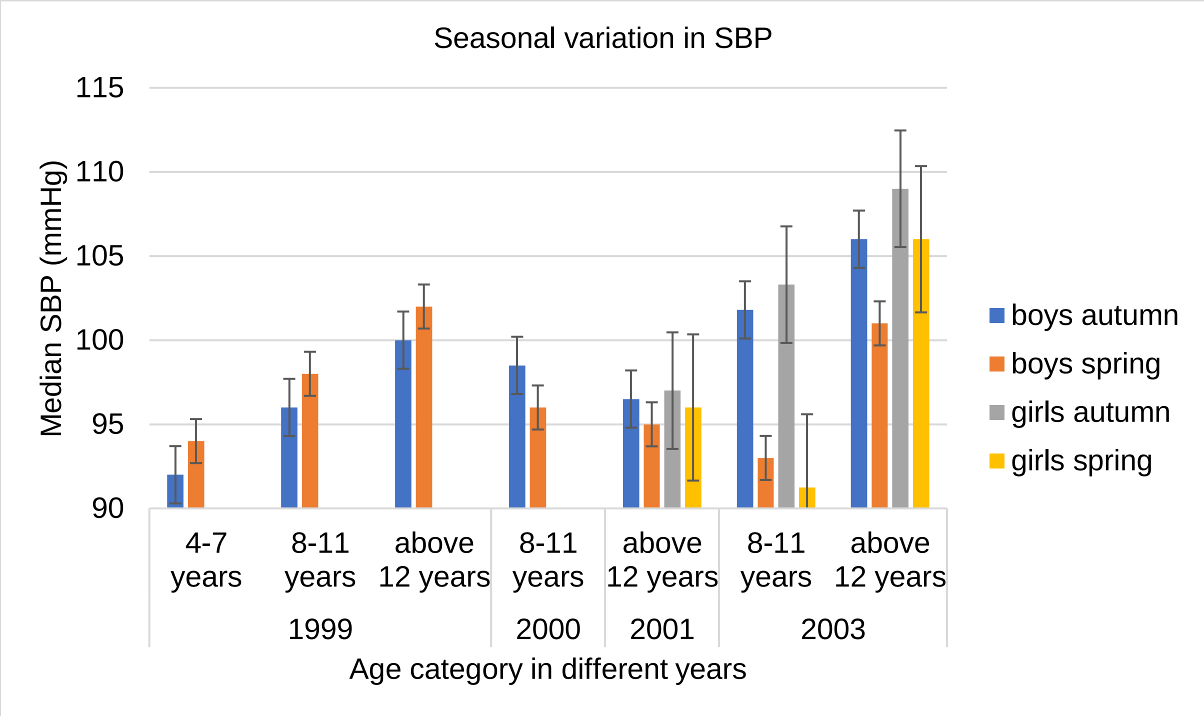

Figure 9: Seasonal variation in SBP in boys and girls in autumn and spring.

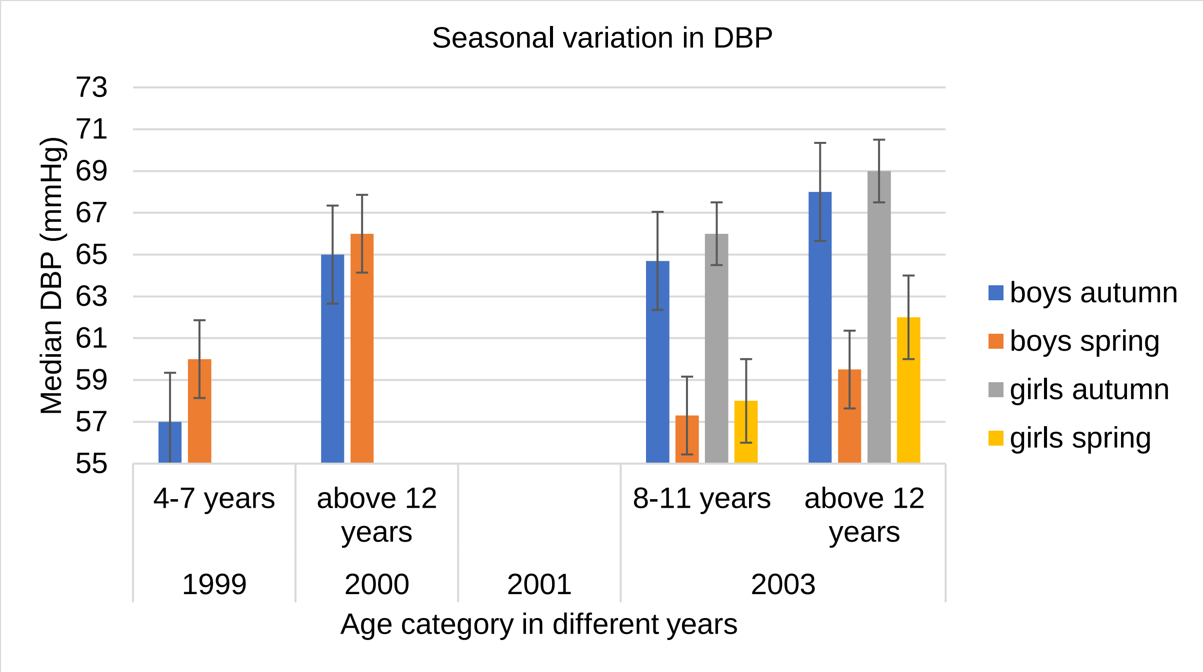

Figure 10: Seasonal variation in DBP in boys and girls in autumn and spring.

4.3 SEASONAL VARIATION IN OBESITY PREVALENCE AND ELEVATED BP (HYPERTENSION)

4.3.1 Seasonal variation in the prevalence of abdominal obesity

Figure 11 to 13 shows seasonal variation in obesity by WC, WHtR, and WHR. Only significant results are reported in all figures. The prevalence of obesity by WC was mostly substantially ($P \leq 0.05$) higher in autumn (0−30.4%) than spring (0−26.9%) among Ellisras boys and girls aged 4−18 from 1999−2003. Furthermore, the prevalence of obesity by WHtR was substantially ($P \leq 0.05$) higher in autumn (0−20.8%) than spring (0−1.3%) among Ellisras boys and girls from 2000−2002. Moreover, the prevalence of obesity by WHR was considerably ($P \leq 0.05$) higher in autumn (21.5−95.5%) compared to spring (13.1−88.9%) among Ellisras boys and girls from 1999−2003.

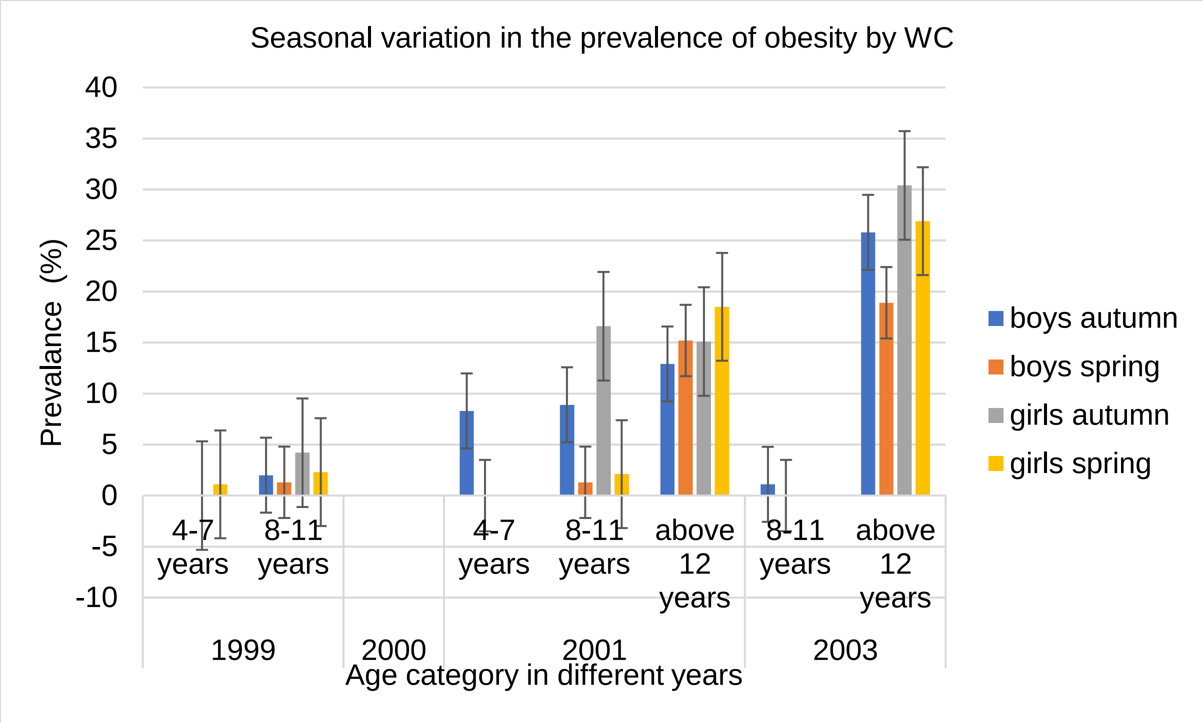

Figure 11: Seasonal variation in the prevalence of obesity by WC in boys and girls in autumn and spring.

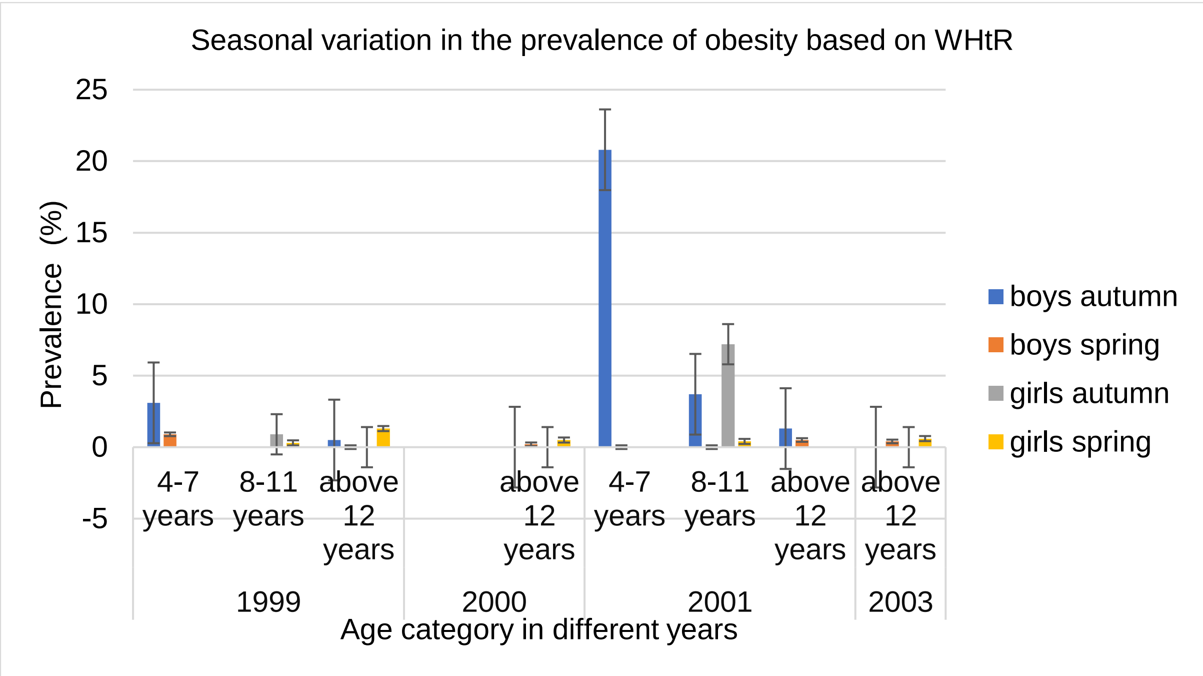

Figure 12: Seasonal variation in the prevalence of obesity by WHtR in boys and girls in autumn and spring.

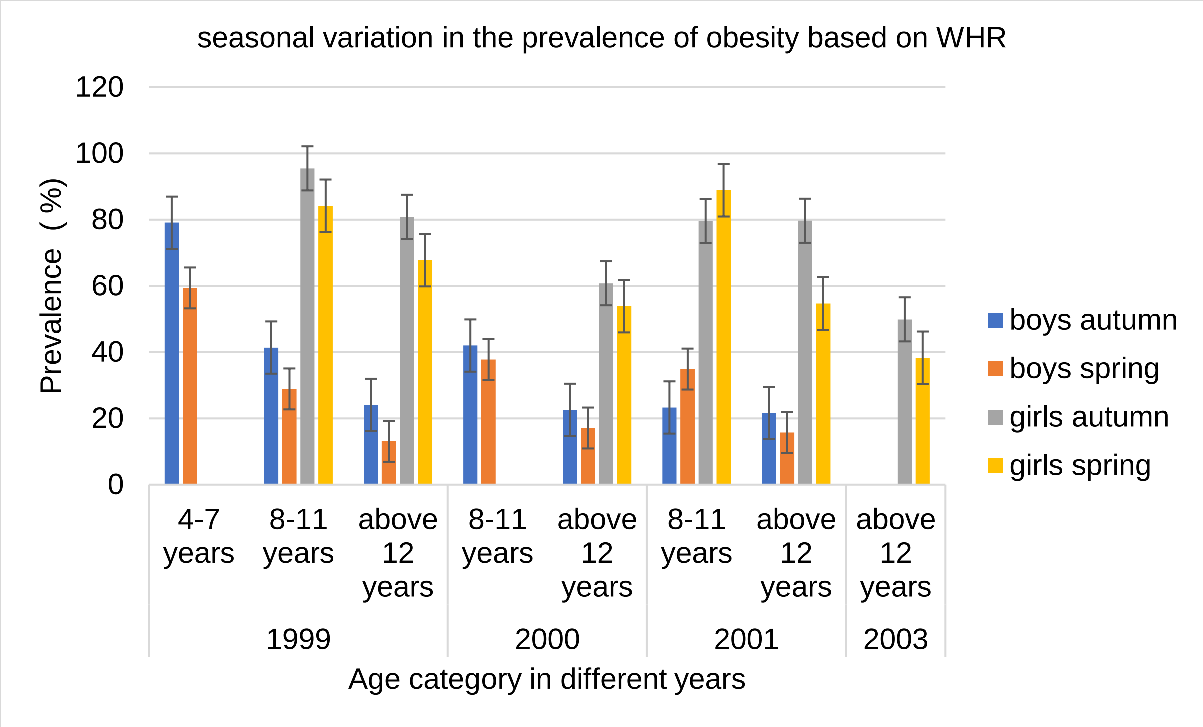

Figure 13: Seasonal variation in the prevalence of obesity by WHR in boys and girls in autumn and spring.

4.3.2 Seasonal variation in blood pressure and hypertension prevalence

Figure 14 to 16 shows seasonal variation in high SBP, high DBP, and hypertension. Only significant results are reported in all figures. The prevalence of high SBP was mostly markedly (P≤0.05) higher in spring (1.2−14.9%) compared to autumn (0.5−3.1%) among Ellisras boys and girls from 1999−2000. Moreover, the prevalence of high DBP was mostly substantially (P≤0.05) higher in spring (3.4−14.9%) compared to autumn (0.8−1.8%) among Ellisras boys and girls from 1999−2000. The prevalence of hypertension was mostly substantially (P≤0.05) higher in spring (0.7−12.8%) compared to autumn (0−1.8%) among Ellisras boys and girls from 1999−2000.

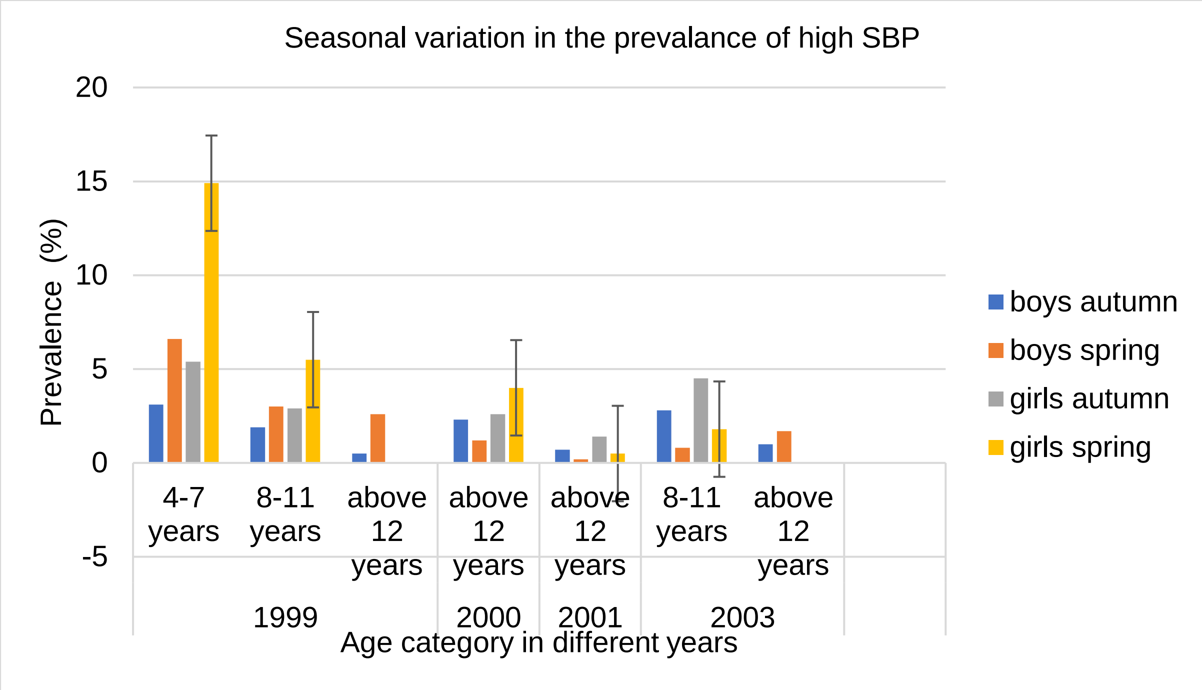

Figure 14: Seasonal variation in the prevalence of high SBP in boys and girls in autumn and spring.

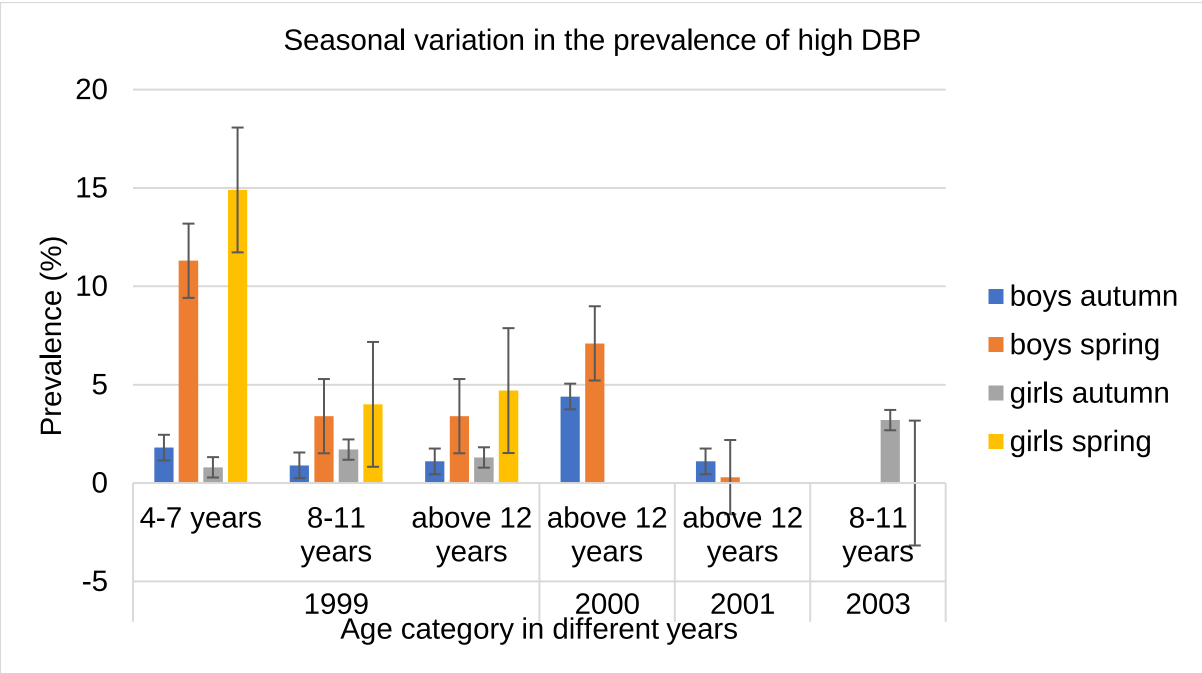

Figure 15: Seasonal variation in the prevalence of high DBP in boys and girls in autumn and spring.

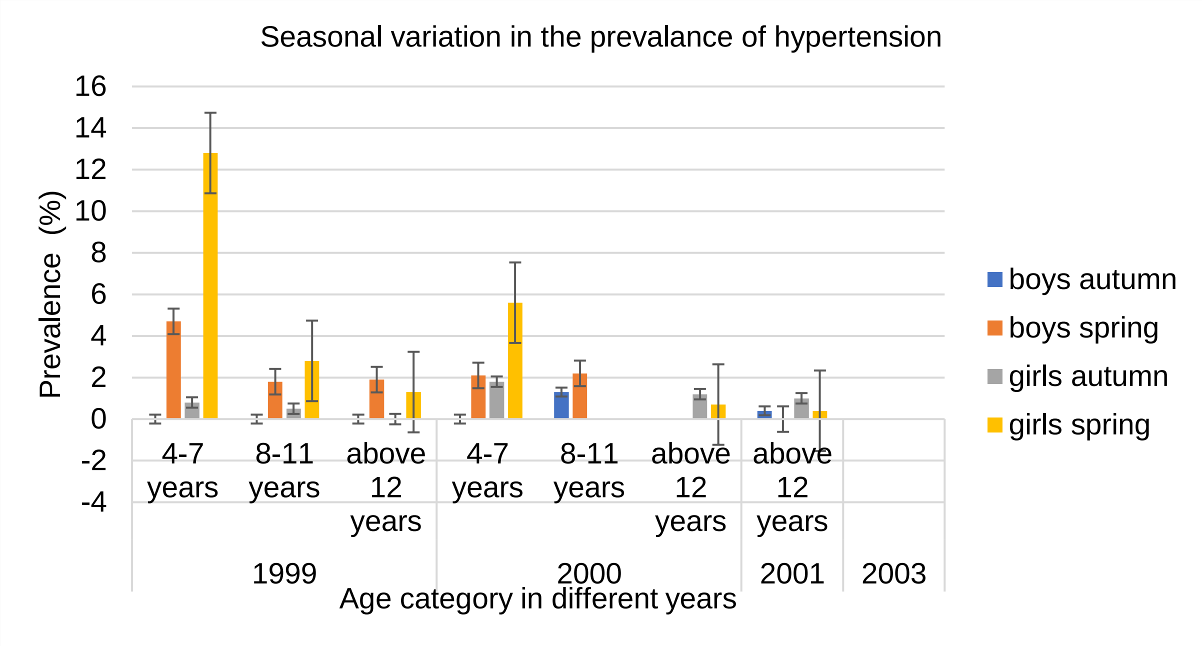

Figure 16: Seasonal variation in the prevalence of hypertension in boys and girls in autumn and spring.

4.4 SEASONAL TRACKING OF ABDOMINAL FAT AND BLOOD PRESSURE

Table 3 shows the association between autumn and spring obesity and BP variables among the Ellisras population aged 4−18 years. The results showed that DBP had the weakest significant (P≤0.05) association (B=0.007, 95% CI: 0.000−0.012) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements when adjusted for age and gender. The strongest significant (P≤0.05) association was observed in WHR (B=0.096, 95% CI: 0.077−0.116) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements. However, in autumn 2003 only WC (B=0.075, 95% CI: 0.056−0.094) and SBP B=0.009 (0.003−0.016) were still significantly (P≤0.05) associated with spring measurements (1999−2003) when adjusted for age and gender.

Table 3: Regression coefficient, P value, and 95% CI for the association of obesity and BP variables between autumn and spring among Ellisras population aged 4−18 years.

Year	Variables	Unadjusted			Adjusted for age and gender		
		B	P	95% CI	B	P	95% CI
	WC	0.006	0.000*	0.003−0.016	0.008	0.001*	0.003−0.012

Autumn 1999	WHtR	0.025	0.000*	0.167−0.337	0.016	0.000*	0.008−0.025
	WHR	0.588	0.000*	0.552−0.624	0.096	0.000*	0.077−0.116
	DBP	0.001	0.267	-0.001−0.003	0.007	0.028*	0.000−0.012
	SBP	0.003	0.055	0.000−0.007	0.007	0.009*	0.002−0.012
Autumn 2000	WC	0.010	0.000*	0.005−0.014	0.009	0.001*	0.004−0.014
	WHtR	-0.001	0.936	-0.267−0.246	-0.002	0.884	-0.028−0.024
	WHR	-	-	-	-	-	-
	DBP	0.000	0.975	-0.004−0.004	0.000	0.952	-0.004−0.004
	SBP	0.000	0.747	-0.002−0.002	0.000	0.666	-0.002−0.003
Autumn 2001	WC	0.000	0.873	-0.004−0.005	0.002	0.535	-0.004−0.008
	WHtR	0.011	0.499	-0.021−0.042	0.011	0.499	-0.207−0.042
	WHR	0.001	0.565	-0.003−0.005	0.001	0.646	0.003−0.005
	DBP	0.002	0.131	-0.001−0.005	0.003	0.136	-0.001−0.006
	SBP	0.005	0.027*	0.000−0.009	0.006	0.020*	0.001−0.010
Autumn 2003	WC	0.006	0.006*	0.002−0.011	0.075	0.000*	0.056−0.094
	WHtR	-	-	-	-	-	-
	WHR	-	-	-	-	-	-
	DBP	0.002	0.292	-0.001−0.005	0.002	0.291	-0.001−0.005
	SBP	0.010	0.002*	0.004−0.016	0.009	0.003*	0.003−0.016

WC-waist circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure, - collinearity, *P≤0.05

Table 4 shows the risk associated with the development of obesity and BP variables between autumn and spring among the Ellisras population aged 4−18 years. The results showed that WC had the weakest significant (P≤0.05) risk (OR=0.003, 95% CI: 0.002−0.011) between baseline measurements (autumn 1999) and subsequent spring measurements (1999−2003) when unadjusted for age and gender. The strongest significant (P≤0.05) risk was observed in obesity by WHtR (OR=0.619, 95% CI: 0.554−0.683) between baseline measurements and subsequent spring measurements when unadjusted for age and gender. In autumn 2003, only SBP showed a significant (P≤0.05) risk (OR=0.036, 95% CI: 0.016−0.057) and (OR=0.033 95% CI: 0.014−0.054) both unadjusted and adjusted for age and gender respectively.

Table 4: Regression coefficient, P value, and 95% CI for the risk associated with the development of obesity and BP between autumn and spring among the Ellisras population aged 4−18 years.

Year	Variables	Unadjusted			Adjusted for age and gender		
		OR	P	95% CI	OR	P	95% CI
Autumn 1999	Obesity by WC	0.003	0.001*	0.002−0.011	0.007	0.002*	0.002−0.011
	Obesity by WHtR	0.619	0.000*	0.556−0.683	0.617	0.000*	0.554−0.681
	Obesity by WHR	0.005	0.049*	0.000−0.010	-0.003	0.000*	-0.004− -0.002
	High DBP	0.006	0.019*	-0.001−0.012	0.006	0.020*	0.001−0.011
	High SBP	0.007	0.046*	0.000−0.014	0.007	0.050*	0.000−0014
	Hypertension	0.003	0.290	-0.002−0.008	0.003	0.306	-0.0023−0.008
Autumn 2000	Obesity by WC	0.012	0.000*	0.006−0.018	0.012	0.000*	0.006−0.020
	Obesity by WHtR	-0.001	0.936	-0.027−0.025	-0.002	0.884	-0.028−0.024
	Obesity by WHR	0.003	0.098	0.000−0.006	0.001	0.435	-0.002−0.004
	High DBP	0.000	0.971	-0.005−0.005	0.000	0.981	-0.005−0.005
	High SBP	0.000	0.097	-0.004−0.005	0.000	0.988	-0.005−0.005

	Hypertension	-0.001	0.947	-0.028−0.026	-0.002	0.904	-0.029−0.026
Autumn 2001	Obesity by WC	0.001	0.640	-0.006−0.009	0.003	0.525	-0.005−0.011
	Obesity by WHtR	0.011	0.499	-0.207−0.042	0.011	0.499	-0.207−0.424
	Obesity by WHR	0.000	0.947	-0.0003−0.0003	0.0002	0.852	-0.002−0.002
	High DBP	0.008	0.009*	0.002−0.131	0.008	0.008*	0.002−0.013
	High SBP	0.003	0.081	0.000−0.006	0.003	0.087	0.000−0.006
	Hypertension	0.013	0.006*	0.004−0.023	0.013	0.008*	0.003−0.023
Autumn 2003	Obesity by WC	0.017	0.080	-0.002−0.035	0.003	0.550	-0.008−0.015
	Obesity by WHtR	-	-	-	-	-	-
	Obesity by WHR	0.000	0.570	-0.001−0.002	0.006	0.142	-0.002−0.013
	High DBP	0.000	0.898	-0.004−0.004	0.000	0.976	-0.004−0.004
	High SBP	0.036	0.001*	0.016−0.057	0.033	0.001*	0.014−0.054
	Hypertension	0.003	0.384	-0.004−0.013	0.003	0.329	-0.005−0.013

WC-waist circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure, - collinearity, *P≤0.05

CHAPTER 5
5 DISSCUSSION

5.1 DESCRIPTIVE STATISTICS OF THE POPULATION

The results showed that girls were substantially ($P<0.001$) taller than boys from 2000−2003. Moreover, girls had a significantly ($P<0.001$) larger HC than boys from 1999−2003. Pinyerd and Zipf (2005) reported that girls reach puberty earlier than boy. Furthermore, it was also reported during puberty girls tend to gain more fat mass than boys, with faster growth in upper arm circumference, height, and increased body weight (Loomba-Albrecht and Styne, 2009; Thakur and Gautam, 2017).

Furthermore, girls had a significantly ($P\leq0.05$) higher systolic and diastolic BP compared to boys from 1999−2004. This result contradicts those reported on literature where DBP was significantly higher among boys 11 and 17 years compared to girls of same age, and SBP significantly higher among boys aged 12, 16 and 17 years old compared to girls (Landazuri *et al*., 2008). The differences in these studies may be due to differences in geographical location where these studies were conducted since their study was conducted in Colombia while this study was conducted in South Africa. Furthermore, the age differences in these two studies may be a contributing factor to the differences observed in both SBP and DBP. Furthermore, their study did not investigate the gender differences in BP seasonally.

5.2 SEASONAL VARIATION IN ABSOLUTE VALUES

5.2.1 Seasonal variation in abdominal fat indices

The results of the study further showed that WC was mostly substantially ($P \leq 0.05$) higher in autumn than spring from 1999−2003 among Ellisras girls and boys aged 4−18 years. Furthermore, WHtR was substantially ($P \leq 0.05$) higher in autumn than spring among Ellisras boys and girls aged 4−7 years in 2001. Seasonal variation in WHR was substantially ($P \leq 0.05$) higher in autumn than spring only in girls aged 8−18 in 1999 and 2000. Contrary to our results, Ockene *et al*., (2004) reported non-significant variation across all four seasons for WC and WHR. Furthermore, Visscher and Seidell, (2004) did not show a constant trend in WC among males and females from 1993−1997 in the Netherlands.

Moreover, the seasonal variation in WHR among girls may be explained by seasonal variation in testosterone levels, as it was reported to be higher in autumn compared to spring as well (Van Anders *et al*. 2006). However, the mechanism of how testosterone leads to a higher WHR was not clearly explained. Moreover, seasonal variation in WC, WHR, and WHtR may further be explained by seasonal variation in PA, since PA was reported to be low in autumn than spring (Visscher and Seidell, 2004).

5.2.2 Seasonal variation in blood pressure

Findings of the study further showed that SBP was significantly higher in autumn compared to spring among boys and girls aged 8−18 years in 2001 and 2003. Furthermore, DBP was significantly higher in autumn compared to spring among Ellisras boys and girls aged 8−18 years. Similar to our study findings, Nilles *et al*., (2023) reported a higher BP in autumn (quarter 1) compared to spring (quarter 2) among adults (18−85 years) from the United States of America from 2017−2020.

Contrary to our results, studies conducted among adults in France, and children from Northern Greece did not show any seasonal variation in the prevalence of obesity by BMI (Alpérovitch *et al*., 2009; Nika *et al*., 2019). Furthermore, studies conducted in

South Korea and India reported contradicting results to our findings (Youn *et al*., 2007; Goyal *et al*. 2018). The disparity observed in the studies may be due to geographical differences in the settings where they are conducted. Furthermore, the disparity observed in these studies may be due to the different anthropometric indices used since the other studies investigated seasonal variation in BMI. Moreover, the difference observed between Alpérovitch *et al*., (2009); Youn *et al*., (2007) and Goyal *et al*., (2018) and the current study may be due to the differences in age groups.

5.3 SEASONAL VARIATION IN OBESITY PREVALENCE AND ELEVATED BP (HYPERTENSION)

5.3.1 Seasonal variation in the prevalence of abdominal obesity

The prevalence of obesity by WC was mostly substantially ($P \leq 0.05$) higher in autumn than spring among Ellisras boys and girls aged 4−18 from 1999−2003. The results on WC are like those reported by Visscher and Seidell (2004) among women in the Netherlands from 1994−1997. According to our knowledge, none of the studies in the literature investigated seasonal variation on WHtR. The current study showed that the prevalence of obesity by WHtR was substantially higher in autumn than spring among Ellisras boys and girls from 2000−2002

Moreover, the prevalence of obesity by WHR was considerably ($P \leq 0.05$) higher in autumn compared to spring among Ellisras boys and girls from 1999−2003. The results in WHR are like those reported by Van Anders *et al*., (2006) among the American population. Contrary to our findings, studies conducted among French adults and children from Northern Greece did not show any seasonal variation in the prevalence of obesity by BMI (Alpérovitch *et al*.,2009; Nika *et al*., 2019). The disparity observed in the studies may be due to geographical differences in the settings where they are conducted since weather conditions vary significantly. Furthermore, Alpérovitch *et al*., (2009) and Nika *et al*., (2019) investigated season variation in general obesity, while the current study investigated seasonal variation in abdominal obesity.

The higher prevalence of obesity in autumn than spring observed in this study may be explained by seasonal variation in diet and PA since they have been reported to differ by season in literature (Van der Toorn *et al*., 2020). Ma *et al*., (2006) reported a high daily caloric intake with increased total fat and saturated fat in autumn, with increased PA levels in spring compared to other seasons.

5.3.2 Seasonal variation in blood pressure and hypertension prevalence

The prevalence of high SBP was mostly markedly (P≤0.05) higher in spring compared to autumn among Ellisras boys and girls from 1999−2000. Moreover, the prevalence of high DBP was mostly substantially (P≤0.05) higher in spring compared to autumn among Ellisras boys and girls from 1999−2000. The results on high BP are like what has been reported in studies conducted in China, and Europe (Wang *et al*., 2017; Nika *et al.*, 2019).

The prevalence of hypertension was mostly substantially (P≤0.05) higher in spring compared to autumn among Ellisras boys and girls from 1999−2000. Goyal *et al*., 2018 reported similar results on hypertension among the Indian population. Contrary to our findings, a longitudinal study by Alpérovitch *et al*., 2009 reported a high prevalence of BP and hypertension in autumn compared to spring in French adults (aged ≥65) at baseline measurements (1999). The disparity observed in the studies may be due to the differences in the study's geographical location and the differences in the age groups of the participants.

Factors such as temperature differences during the different seasons, sunshine, and humidity may result in seasonal differences in BP (Aubinière-Robb *et al*. 2013). Furthermore, a lot of physiological changes such as arteriolar vasoconstriction, arterial stiffness, aldosterone levels, and endothelial dysfunction take place at different seasons (Youn *et al*., 2007; Cuspidi, *et al*., 2012; Goyal *et al*. 2018). These seasonal changes in physiological factors then contribute to the seasonal changes in BP. Kent *et al*., (2011) reported variations in BP is mostly driven by temperature rather than factors that change seasonally such as cognitive function, stress level, mood, exercise, biological processes, and health behaviours. However, Goyal *et al*., (2018) reported that temperature is not an independent predictor of both SBP and DBP.

5.4 SEASONAL TRACKING OF ABDOMINAL FAT AND BLOOD PRESSURE

The results of the study showed that all obesity indices and BP measurements in autumn 1999 were significantly (P≤0.05) associated with subsequent spring (1999−2003) measurements when adjusted for age and gender. The results on the risk associated with the development of both obesity and BP showed similar results. Stanojevic *et al*., (2008) reported that the odds (OR 1.28, 95% CI 1.27–1.31, P<0.001) for the development of obesity increased by 30% each year from 1999−2004 among Chilean children. Furthermore, they reported that the odds of obesity were considerably (P≤0.05) higher in November than March. According to the South America specialist (2023), November falls under spring while March falls under autumn. Therefore, this study is one of the few studies in the literature that investigated the development of obesity over time and across seasons.

A cross-sectional study by Kent *et al*., (2011) reported a substantially univariate relationship between systolic and DBP with seasons among Americans. Furthermore, Barnett *et al*., (2007) reported a substantial (P≤0.05) correlation between BP and seasons (summer and winter) using the data from the World Health Association MONICA project. Moreover, Nika *et al*., (2019) reported a marked univariate association between autumn and spring BP z scores variables.

A longitudinal study by Alpérovitch *et al*., (2009) reported an association between BP and seasons among French adults. However, most of the studies that tracked the development of obesity and BP over time did not track seasonally. These studies reported that childhood obesity and BP are associated with adulthood obesity and BP (Herman *et al*., 2009; Sarganas *et al*., 2018; Rundle *et al*., 2020; Azegami *et al*., 2021). Studies that tracked seasonally remain scanty in literature to allow direct comparison of the results. Most of the studies on literature mostly investigated seasonal association in BP (Barnett *et al*., 2007; Alpérovitch *et al*., 2009; Kent *et al*., 2011; Nika *et al*., 2019). However, studies that investigated the risk associated with the development of obesity and BP in different seasons remain scanty in the literature.

5.5 STREGHTH AND LIMITATIONS OF THE STUDY.

The strength of this investigation is that it forms part of a longitudinal study which makes it possible to evaluate the impact of seasonal variation on BP and abdominal obesity in childhood and adolescence. An important limitation of this study is that it was based on data from the ELS conducted over two decades ago, the fact of which, implicates the need to determine the current trends of seasonal variation in BP and abdominal fat indices in diverse populations group over time. As the present study did not investigate the plausible causes of seasonal differences in BP and visceral fat indices in the studied sample, the physiological and environmental bases for the observed findings require further investigation. Furthermore, the attrition rate resulted in a decrease in the number of participants every year, leading to a different number of participants yearly.

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CHAPTER 6

6 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

Obesity and hypertension have been declared a global pandemic (Perez *et al*., 2021). Studies reported that the escalating hypertension prevalence is caused by the growing obesity epidemic (Peymani *et al*., 2017; Mohajan and Mohajan, 2023). Furthermore, obesity and hypertension have been reported to have similar risk factors such as poor diet, alcohol intake, PA, and seasonal variation (Sherpard and Aoyagi, 2009; Mills *et al*., 2020; Stergiou *et al*., 2020). Studies reported that the prevalence of abdominal obesity and elevated BP differs by season (Visscher and Seidell, 2004; Van Anders *et al*., 2006; Wang *et al*., 2017; Nika *et al*., 2019).

Ockene *et al*., (2004) reported that seasonal variation results in changes in PA, blood lipids, and low-density lipoprotein cholesterol. Furthermore, seasonal variation results in arterial stiffness, changes in sympathetic activity, and the RAAS (Youn *et al*., 2007; Cuspidi, *et al*., 2012; Goyal *et al*., 2018). This then results in seasonal variation in obesity and elevated BP prevalence. Barnett *et al*., (2007) reported that blood vessels constrict with a decrease in temperature in cold seasons which also results in increased BP.

Studies reported that childhood obesity mostly results in adulthood obesity (Van Lenthe *et al*., 1998; Monyeki *et al*., 2006; Simmonds *et al*., 2016). Therefore, it is crucial to investigate and track the development of obesity from childhood and in different seasons for better management of obesity later in life. This will then lead to better management of obesity-related diseases such as hypertension since obesity is associated with the development of most cardiovascular diseases.

6.2 SUMMARY

Chapter 1 addressed the need to investigate seasonal variation in abdominal fat indices and BP amongst the Ellisras population aged 4−18 years over time. The need to investigate the prevalence of abdominal obesity, elevated BP and hypertension among the Ellisras population was addressed. Furthermore, the need to investigate the seasonal association of abdominal fat indices and BP variables and the risk associated with the development of obesity and BP at different seasons was addressed. To answer the aforementioned needs among the Ellisras population, chapter 1 addressed the following objectives:

I. determine the prevalence of abdominal obesity based on abdominal fat indices (WC, WHtR, and WHR) in spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

II. determine the prevalence of elevated BP (hypertension) in spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

III. investigate seasonal association of abdominal fat indices and BP variables between spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

V. investigate the risk associated with the development of obesity and BP between autumn and spring variables among the Ellisras population aged 4−18 over time.

Chapter 2 reviewed literature on the topic. Studies that investigated seasonal variation in obesity and BP were reviewed (Visscher and Seidell, 2004; Van Anders *et al*., 2006; Miersch *et al*., 2013; Goyal *et al*., 2018; Nika *et al*., 2019). However, most of the seasonal studies in the literature investigated the impact of temperature on BP (Barnett *et al*., 2007; Alpérovitch *et al*., 2009, Kent *et al*., 2011; Hozawa *et al*., 2011; Miersch *et al*., 2013; Yang *et al*., 2015; Wang *et al*., 2017). Furthermore, studies argued about the impact of seasonal variation on BP.

Kent *et al*., (2011) reported that seasonal variation in BP is mostly driven by temperature rather than factors that change seasonally such as cognitive function, stress level, mood, exercise, biological processes, and health behaviours. While Goyal *et al*., (2018) reported that temperature is not an independent predictor of both SBP and DBP. Studies also reported seasonal variations in obesity risk factors such as blood lipids, low-density lipoprotein cholesterol, diet, and PA (Ockene *et al*., 2004; Van der Toorn *et al*., 2020). Seasonal variation in obesity risk factors may be a contributing factor to the seasonal variation observed in obesity prevalence. The mechanism of how seasons lead to the development of abdominal obesity and BP is not clearly explained in the literature. Therefore, seasonal variation in obesity and BP is a complex phenomenon that still needs to be investigated.

Chapter 3 outlined the methodological procedures and statistical analysis computed. Frequency analysis was used to determine the prevalence of obesity, elevated BP, and hypertension in percentage. The GEE technique which determines the relationship between an indicator at baseline and the same indicator at all other measurement periods was used. The GEE was used to investigate the seasonal association of abdominal fat indices and BP variables in autumn and spring among the Ellisras population. Furthermore, GEE was used to investigate the risk associated with the development of both abdominal obesity and BP in autumn and spring with age and gender being included in the model.

Chapter 4 reported the results and discussions of the study. The prevalence of obesity by WC, WHtR, and WHR was mostly markedly ($P \leq 0.05$) higher in autumn than spring. The prevalence of obesity by WC and WHR concurs with previous studies in the literature (Visscher and Seidell, 2004; Van Anders *et al*., 2006). The prevalence of high SBP, high DBP, and hypertension was mostly substantially ($P \leq 0.05$) higher in spring than autumn. The results in BP agree with those reported in the literature (Wang *et al*., 2017; Nika *et al*., 2019). however, Alpérovitch *et al*., (2009) reported contradicting findings. All obesity indices and BP measurements at baseline (autumn 1999) were considerably ($P \leq 0.05$) associated with subsequent spring (1999−2003) measurements when adjusted for age and gender. The development of abdominal obesity and BP is associated with seasons. Furthermore, the development of abdominal obesity and BP in autumn may result in the development of abdominal obesity and BP in spring, and the relationship may be maintained over time.

Chapter 6 summarised the dissertation and provided conclusions and recommendations that arose from the study. This will raise awareness of the impact of seasonal variation on the development of abdominal obesity and BP.

6.3 CONCLUSIONS

The conclusions of the study were made based on the objectives and hypothesis made in Chapter 1.

Objective 1: determine the prevalence of abdominal obesity based on abdominal fat indices (WC, WHtR, and WHR) in spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

Hypothesis 1: The prevalence of abdominal obesity amongst Ellisras rural children and adolescents will be higher in autumn compared to spring.

The prevalence of obesity by WC was mostly substantially ($P \leq 0.05$) higher in autumn (0−30.4%) than spring (0−26.9%) among Ellisras boys and girls aged 4−18 years from 1999−2003. Furthermore, the prevalence of obesity by WHtR was mostly markedly ($P \leq 0.05$) higher in autumn (0−20.8%) than spring (0−1.3%) among Ellisras boys and girls from 2000−2002. Moreover, the prevalence of obesity by WHR was considerably higher in autumn (21.5−95.5%) compared to spring (13.1−88.9%) among Ellisras boys and girls from 1999−2003. The results on WC are similar to those reported by Visscher and Seidell (2004) among women in the Netherlands. Moreover, the results in WHR are similar to those reported by Van Anders *et al*., (2006) among the American population from 1994−1997. According to our knowledge, none of the studies in the literature investigated seasonal variation on WHtR. Contrary to our results, studies conducted among French adults, and children from Northern Greece did not report seasonal variation in the prevalence of obesity by BMI (Alpérovitch *et al*., 2009; Nika *et al*., 2019).

Hypothesis 1 was therefore partially accepted based on the findings.

Objective 2: determine the prevalence of BP (hypertension) in spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

Hypothesis 2: The prevalence of elevated BP (hypertension) will be higher in spring compared to autumn amongst Ellisras rural children and adolescents.

The prevalence of high SBP was mostly significantly (P≤0.05) higher in spring (1.2−14.9%) compared to autumn (0.5−3.1%) among Ellisras boys and girls from 1999−2000. Moreover, the prevalence of high DBP was mostly markedly (P≤0.05) higher in spring (3.4−14.9%) compared to autumn (0.8−1.8%) among Ellisras boys and girls from 1999−2000. The prevalence of hypertension was mostly considerably (P≤0.05) higher in spring (0.7−12.8%) compared to autumn (0−1.8%) among Ellisras boys and girls from 1999−2000. The results on BP are like that reported in studies conducted in China, and Europe (Wang *et al*., 2017; Nika *et al*., 2019). Furthermore, Goyal *et al*., 2018 reported similar results on hypertension among the Indian population. Contrary to our findings, a longitudinal study by Alpérovitch *et al*., (2009) reported a high prevalence of BP and hypertension in autumn compared to spring among French adults.

Hypothesis 2 was therefore accepted based on the results.

Objective 3: investigate seasonal association of abdominal fat indices and BP variables between spring and autumn among the Ellisras population (age 4−18) from 1999−2003.

Hypothesis 3: The development of abdominal obesity in autumn (1999−2003) will be associated with the development of obesity in spring (1999−2003) amongst the Ellisras rural children and adolescents.

Diastolic BP showed the weakest substantial (P≤0.05) association B=0.007 (95% CI, 0.000−0.012) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements when adjusted for age and gender. The strongest substantial (P≤0.05) association was observed in WHR (B=0.096, 95% CI: 0.077−0.116) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements. However, in autumn 2003 only WC (B=0.075, 95% CI: 0.056−0.094) and SBP B=0.009 (0.003−0.016) were still considerably (P≤0.05) associated with spring measurements (1999−2003) when adjusted for age and gender. Stanojevic *et al*., (2008) reported that the odds (OR 1.28, 95% CI 1.27–1.31, P<0.001) for the development of obesity increased by 30% each year from 1999−2004 among Chilean children. Furthermore, they reported that the odds of obesity were considerably (P≤0.05) higher in November (spring) than March (autumn). Most of the studies that tracked the development of obesity and BP reported that childhood obesity and BP are associated with adulthood obesity and BP (Herman *et al*., 2009; Sarganas *et al*., 2018; Rundle *et al*., 2020; Azegami *et al*., 2021).

Furthermore, cross-sectional and longitudinal studies reported a correlation between seasons and BP (Barnett *et al*., 2007; Alpérovitch *et al*., 2009; Kent *et al*., 2011). However, these studies only investigated the association between each season and BP. They did not investigate how the development of BP in one season may be associated with another season as accomplished in this study. Only a cross-sectional study by Nika *et al*., (2019) investigated a similar seasonal association as in this study using BP z scores. Studies that reported findings on seasonal variation in obesity only reported the prevalence in different seasons (Visscher and Seidell, 2004; Van Anders *et al*., 2006; Alpérovitch *et al*., 2009; Nika *et al*., 2019). However, these studies did not investigate the longitudinal association between obesity and seasons.

Hypothesis 3 was therefore partially accepted based on the results.

Objective 4: Investigate whether there is a risk associated with the development of obesity and BP between autumn and spring variables among the Ellisras population aged 4−18 over time.

hypothesis 4: The risk associated with the development of abdominal obesity and BP in autumn (1999−2003) will be associated with the risk for the development of

abdominal obesity and BP in spring (1999−2003) amongst Ellisras rural children and adolescents.

Waist circumference showed the weakest significant (P≤0.05) risk (OR=0.003, 95% CI: 0.002−0.011) between baseline measurements (autumn 1999) and subsequent spring measurements (1999−2003) when unadjusted for age and gender. The strongest significant (P≤0.05) risk was observed in obesity by WHtR (OR=0.619, 95% CI: 0.554−0.683) between baseline measurements and subsequent spring measurements when unadjusted for age and gender. In autumn 2003, only SBP showed a significant (P≤0.05) risk (OR=0.036, 95% CI: 0.016−0.057) and (OR=0.033 (95% CI: 0.014−0.054) both unadjusted and adjusted for age and gender respectively. Studies on literature mostly investigated seasonal association in BP (Barnett *et al*., 2007; Alpérovitch *et al*., 2009; Kent *et al*., 2011; Nika *et al*., 2019). However, studies that investigated the risk associated with the development of obesity and BP in different seasons remain scanty in the literature.

Hypothesis 4 was therefore partially accepted based on the results.

Inconclusion, Seasonal variation in abdominal fat indices and BP was evident in this population of boys and girls and it differs by age group. A significant association between autumn and spring measurements for obesity and BP variables was evident in this study for that period. Furthermore, the development of obesity and BP is associated with seasons, and the development of obesity and BP in autumn may lead in the development of obesity and BP in spring and this relationship may be maintained overtime.

6.4 RECOMMENDATION

We recommend that:

I. Healthcare workers take into consideration the impact of seasonal variation on abdominal obesity and BP before diagnosis of the conditions.

II. People maintain a healthy lifestyle across seasons such that the development of obesity and BP is not maintained across seasons and over time.

III. Investigation of seasonal variation in obesity and BP is done using recent data among the Ellisras population to demonstrate the impact of climate change on obesity and BP.

IV. Investigation of seasonal variation in environmental factors (e.g. temperature) and lifestyle factors (e.g. diet and PA) that are associated with obesity and BP among the Ellisras population.

V. Seasonal variation in obesity and BP is investigated in four seasons among the Ellisras population.

VI. Future studies on seasonal variation control for confounding effects such as access to air conditioners as they maintain a relatively constant temperature across seasons.

VII. Studies on obesity and BP control for temperature or seasons as a confounding factor.

VIII. Studies investigate the seasonal effect of phytochemicals on obesity and hypertension.

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APPENDICES

Appendix A: Ellisras Longitudinal Study data form

Anthropometry and blood pressure data form

Subject number: | | | | | | | Date of birth (DD MM YY): | | | | | | | Observation date (DD MM YY): | | | | | | |

Height (cm)			
Waist circumference (cm)			
Hip circumference (cm)			
Systolic blood pressure (mmHg)			
Diastolic blood pressure (mmHg)			

Appendix B: Ellisras Longitudinal Study consent form

Project leader: **Prof KD Monyeki**

I hereby voluntarily consent to participate in the Ellisras longitudinal study.

I understand that:

1. The study deals with anthropometric measurements of height, hip and waist circumference, and blood pressure.
2. The procedure may hold some risks for me that cannot be foreseen at this stage.

Anthropometric measurements will be done according to the procedures of the International Society for the Advancement of Kinanthropometry (ISAK) (Norton & Olds, 1996). Blood pressure measurements will be taken following the procedure by the National High Blood Pressure Education Programme (NHBPEP) Working Group on Hypertension Control in Children and Adolescents (NHBPEP, 2004). Waist circumference will be taken in a standing position using a flexible steel, midway between the lowest rib cage and the iliac crest after a normal expiration. Height will be measured with a stadiometer in a standing position such that the heels, buttocks, and shoulders of the participants touch the stadiometer, with shoes and socks off. Feet will be put flat on the ground, together. The stadiometer's headboard will then be pressed against the participant's head, and the height will be measured. Hip circumference will be measured with a flexible steel tape on the broadest point above the buttocks (Norton, 2018). Blood pressure will be measured using an electronic Micronta monitoring kit, after 5 minutes of relaxation. The measurements will be taken in the Ellisras rural area.

3. The Ethics Committee has approved that individuals may be approached to participate in the study.
4. The research project, aims, and methods of the research, have been explained to me.
5. I will be informed of any new information that may become available during the research that may influence my willingness to continue my participation.
6. Access to the records that pertain to my participation in the study will be restricted to persons directly involved in the research.

7. Any questions that I may have regarding the research or related matters, will be answered by the researcher/s.

8. Participation in this research is voluntary and I can withdraw my participation at any stage.

9. If any medical problem is identified at any stage during the research, or when I am vetted for participation, such condition will be discussed with me in confidence by a qualified person, and/or I will be referred to my doctor.

10. I indemnify the University of Limpopo and all persons involved with the above project from any liability that may arise from my participation in the above project or that may be related to it, for whatever reasons, including negligence on the part of the mentioned persons.

Signature of interviewee **Signature of witness**

--------------------------------------- -----------------------------------

Signature of interviewer---------------------------------------

Appendix C: Ethical approval

University of Limpopo
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TURFLOOP RESEARCH ETHICS COMMITTEE

ETHICS CLEARANCE CERTIFICATE

MEETING: **22 August 2022**

PROJECT NUMBER: **TREC/360/2022: PG**

PROJECT:

Title:	Investigating Seasonal Variation in Abdominal Fat Indices and Hypertension amongst Ellisras Population from Childhood into Adulthood: Ellisras Longitudinal Study.
Researcher:	TN Mkhatshwa
Supervisor:	Prof KD Monyeki
Co-Supervisor/s:	Ms M Matshipi
School:	Molecular and Life Science
Degree:	Master of Science in Physiology

PROF D MAPOSA
CHAIRPERSON: TURFLOOP RESEARCH ETHICS COMMITTEE

The Turfloop Research Ethics Committee (TREC) is registered with the National Health Research Ethics Council, Registration Number: **REC-0310111-031**

Note:

i) **This Ethics Clearance Certificate will be valid for one (1) year, as from the abovementioned date. Application for annual renewal (or annual review) need to be received by TREC one month before lapse of this period.**

ii) **Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee, together with the Application for Amendment form.**

iii) **PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.**

Finding solutions for Africa

Appendix D: Graphs showing both significant and non-significant results

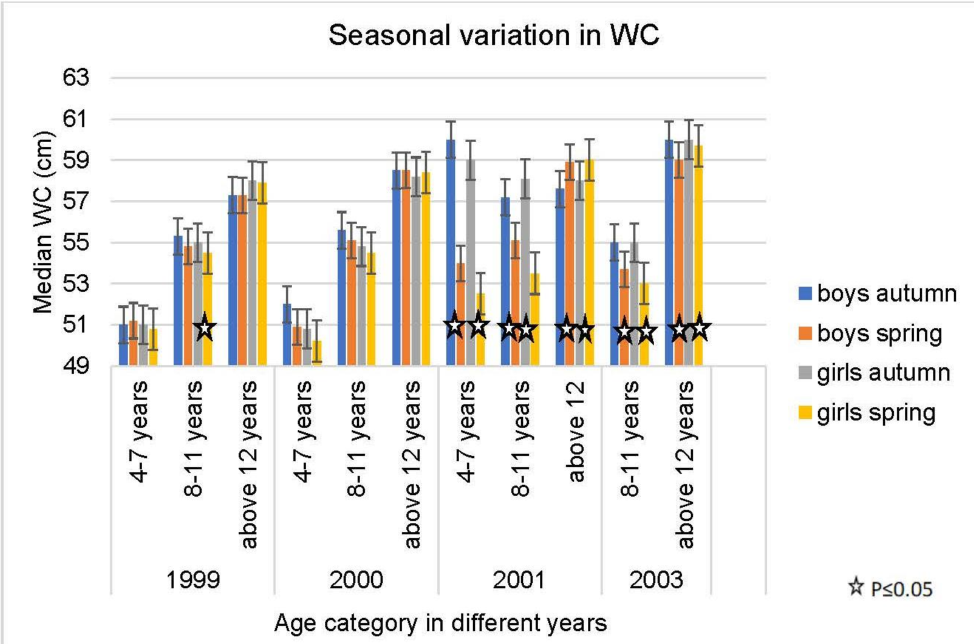

Figure 1: Seasonal variation in WC in boys and girls in spring and autumn.

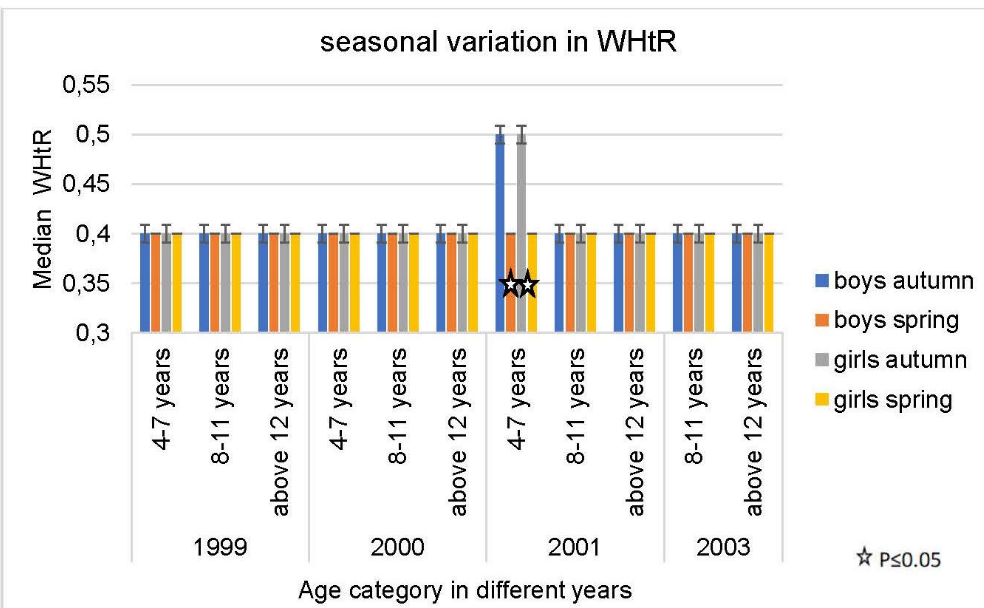

Figure 2: Seasonal variation in WHtR in boys and girls in spring and autumn.

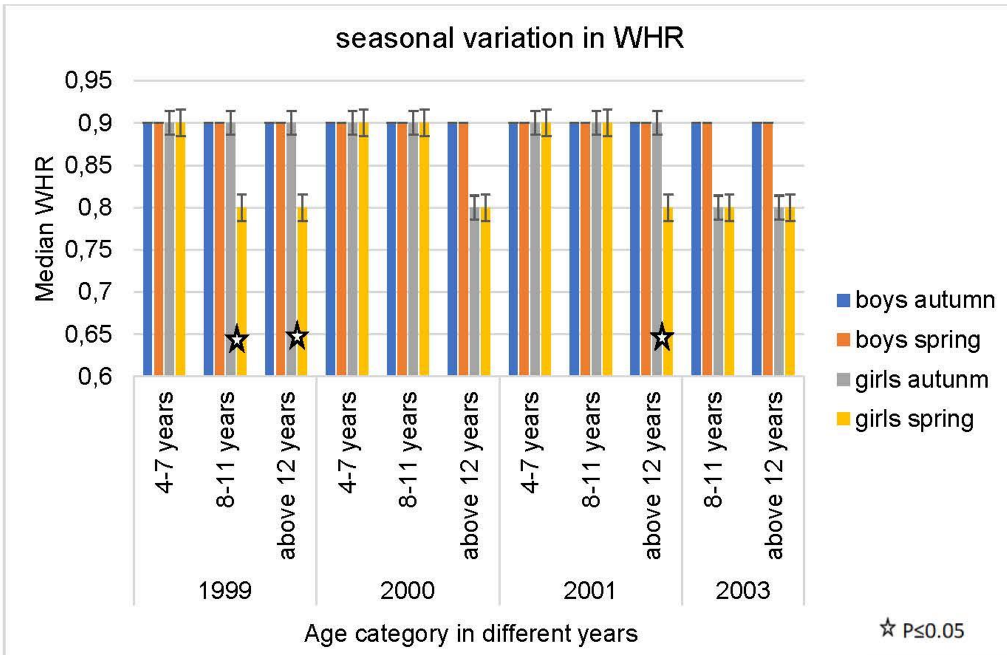

Figure 3: Seasonal variation in WHR in boys and girls in autumn and spring.

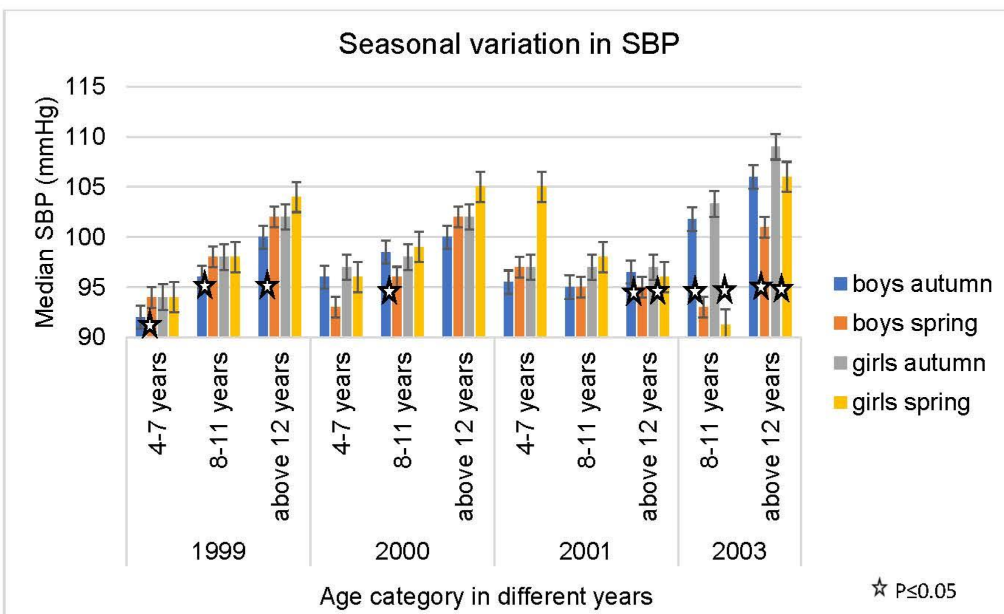

Figure 4: Seasonal variation in SBP in boys and girls in autumn and spring.

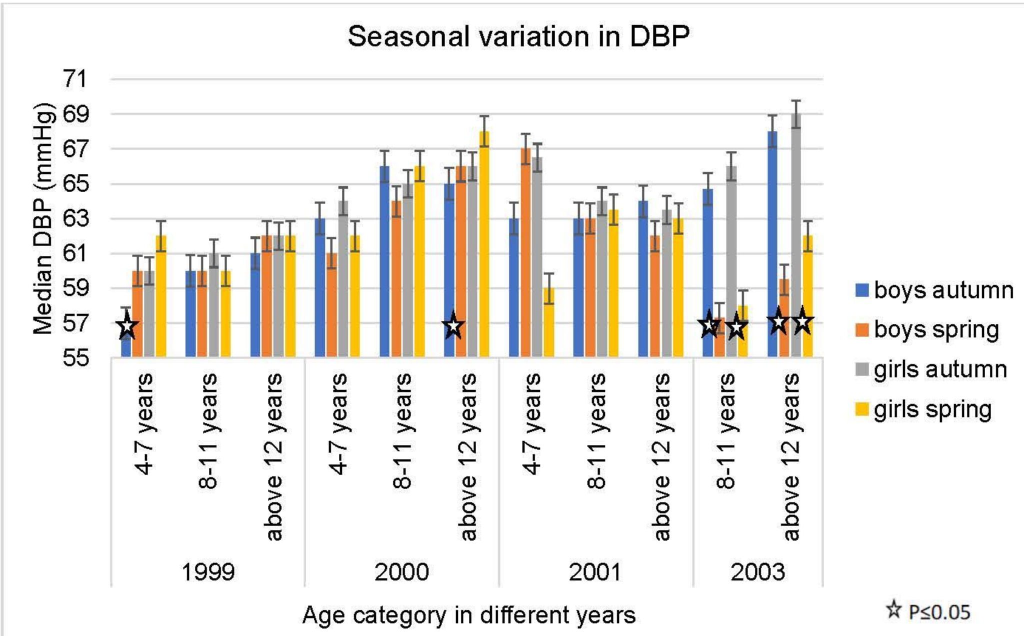

Figure 5: Seasonal variation in DBP in boys and girls in autumn and spring.

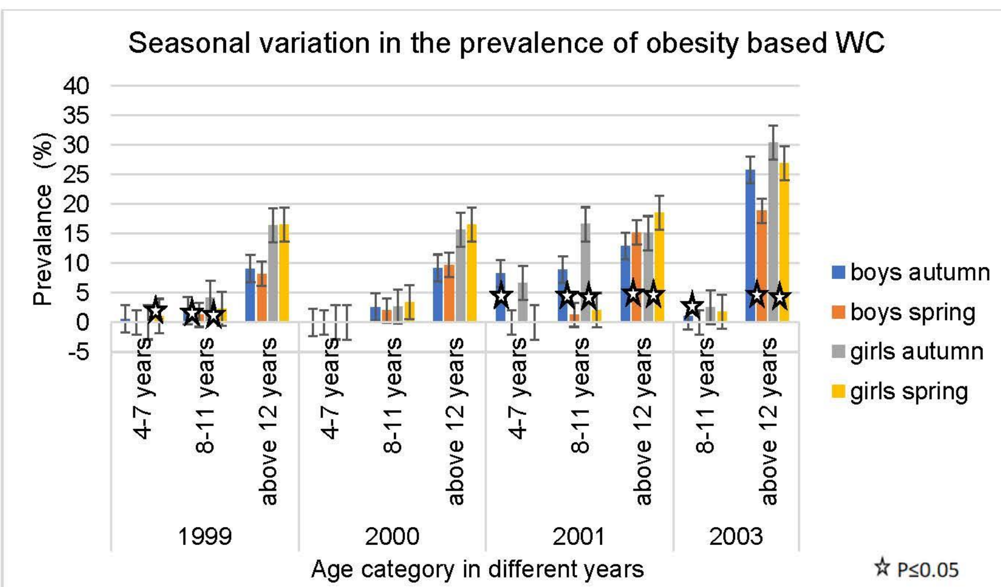

Figure 6: Seasonal variation in the prevalence of obesity by WC in boys and girls in autumn and spring.

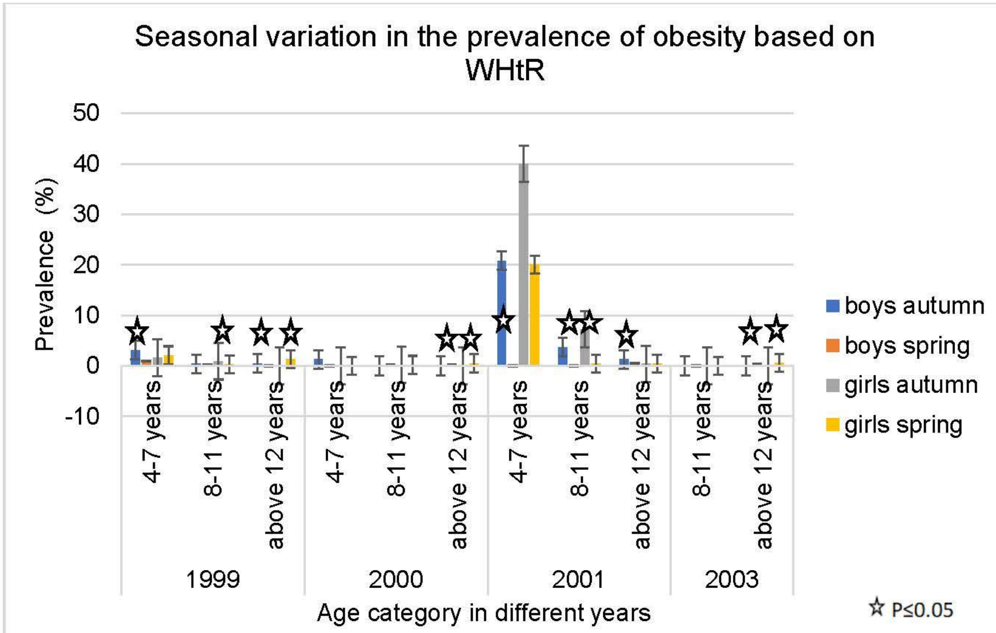

Figure 7: Seasonal variation in the prevalence of obesity by WHtR in boys and girls in autumn and spring.

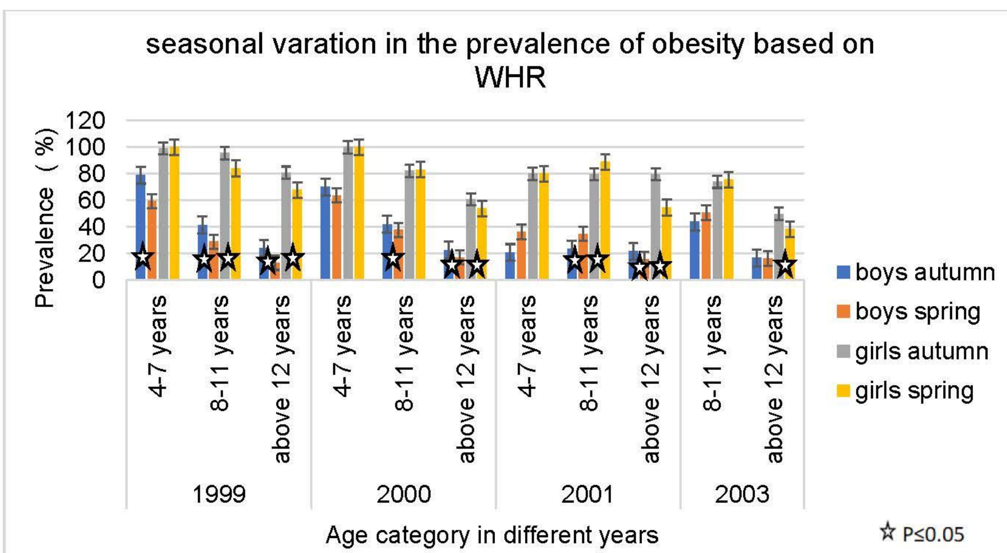

Figure 8: Seasonal variation in the prevalence of obesity by WHR in boys and girls in autumn and spring.

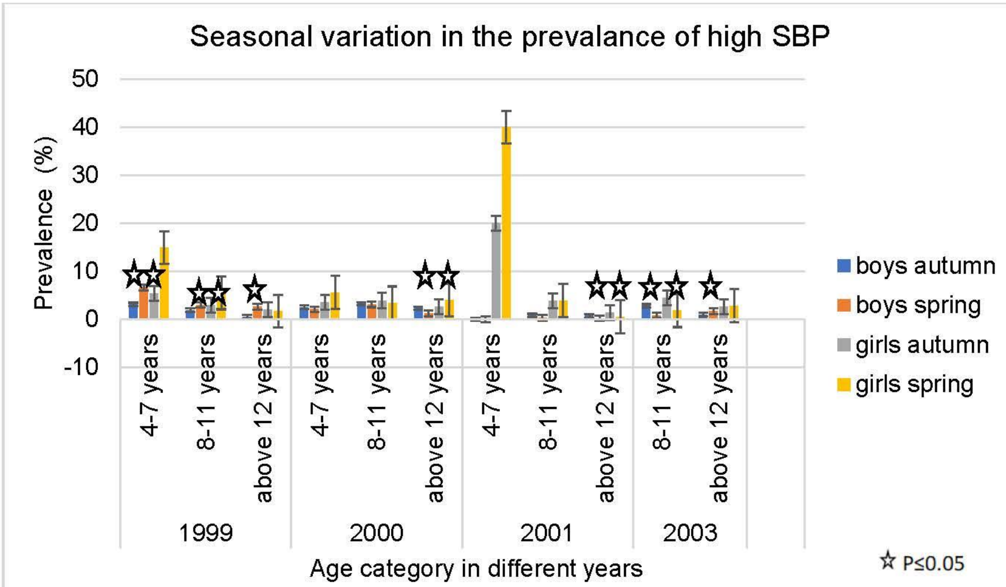

Figure 9: Seasonal variation in the prevalence of high SBP in boys and girls in autumn and spring.

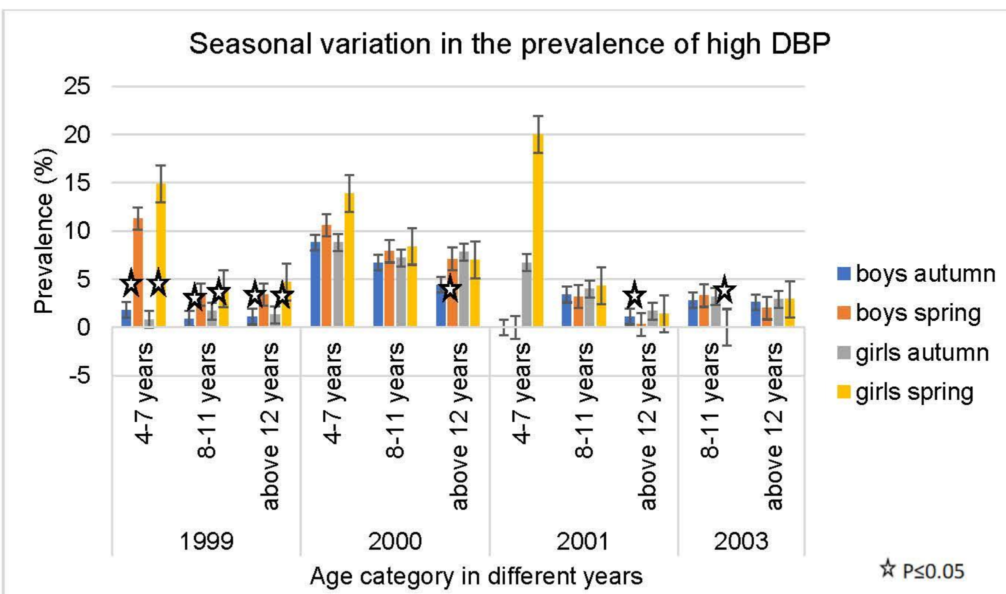

Figure 10: Seasonal variation in the prevalence of high DBP in boys and girls in autumn and spring

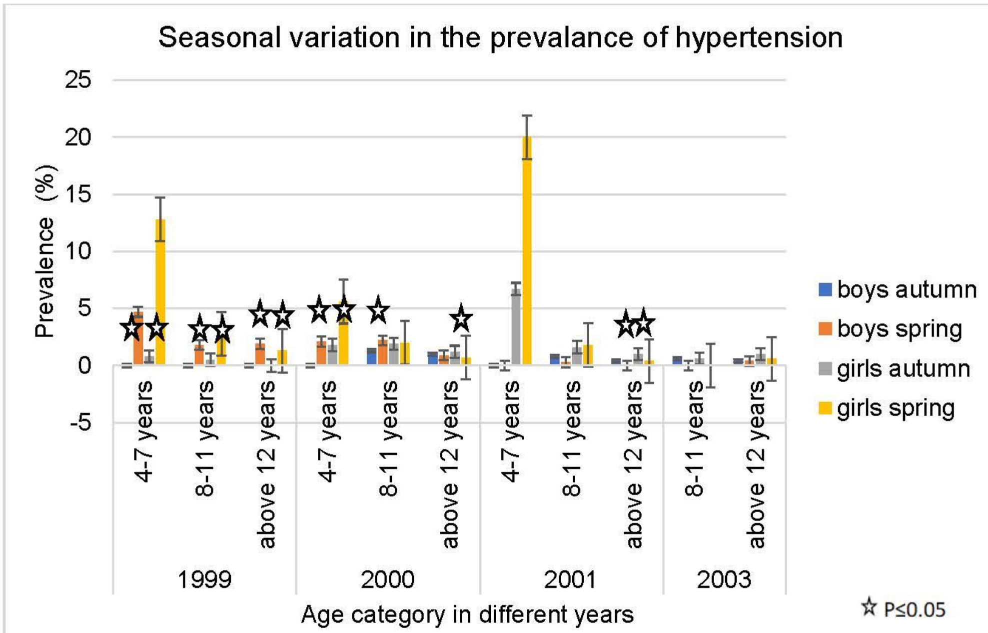

Figure 11: Seasonal variation in the prevalence of hypertension in boys and girls in autumn and spring.

7 PEER-REVIEWED ARTICLES EMANATING FROM THE DISSERTATION

Mkhatshwa, T.N., Matshipi, M., Monyeki, K.D., Monyeki, M.S., Kemper, H.C.G., & Moselakgomo, V.K. (2023). Seasonal variation in blood pressure and visceral fat indices among Lephalale rural children overtime: Ellisras Longitudinal Study (ELS). *African Journal for Physical Activity and Health Sciences*, 29, Supplement (December), pp. DOI: https://doi.org/10.37597/ajphes.2022.29.4.2.xx

Seasonal variation in blood pressure and visceral fat indices among Lephalale rural children: Ellisras Longitudinal Study (ELS)

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Abstract

Hypertension and obesity have been a growing concern globally. Their prevalence continues to escalate, affecting a lot of people, especially in cold seasons. This leads to high mortality in cold seasons due to the increased prevalence of non-communicable diseases. This study investigated seasonal variation in blood pressure and visceral fat indices among the Ellisras (now known as Lephalale) population. The longitudinal study took place in Ellisras, Limpopo Province of South Africa. A total of 1 974 (1033 boys and 941 girls) participants aged 4−18 years enrolled in this study. The protocol of the International Society for the Advancement of Kinanthropometry (ISAK) was followed for all anthropometric measurements. Blood pressure was taken following the procedure of the National High Blood Pressure Education Program's (NHBPEP) Working Group on Hypertension Control in Children and Adolescents. Obesity and hypertension prevalence was determined using frequency analysis. Cases of elevated systolic blood pressure (BP) were significantly higher in spring (6.6%) than in autumn (3.1%) among boys aged 4−7 years in 1999. Hypertension was substantially ($p \leq 0.01$) more prevalent in spring (12.8%) than autumn (0.8%) among girls aged 4−7 years in 1999. Among boys aged 8−11 years in 2001, obesity (estimated by waist circumference), was markedly ($p \leq 0.01$) higher in autumn (8.9%) than spring (1.3%). Obesity measured by waist-to-hip ratio, was significantly ($p \leq 0.01$) more preponderant in autumn (95.5%) than spring (84.2%) among girls aged 8−11 in 1999. Seasonal variation in blood pressure and visceral fat indices was evident in Lephalale rural population of boys and girls and it differed by age group.

Keywords: Seasonal variation, hypertension, obesity, Lephalale rural children

How to cite this article:
Mkhatshwa, T.N., Matshipi, M., Monyeki, K.D., Monyeki, M.S., Kemper, H.C.G., & Moselakgomo, V.K. (2023). Seasonal variation in blood pressure and visceral fat indices among Lephalale rural children: Ellisras Longitudinal

Study (ELS). *African Journal for Physical Activity and Health Sciences*, 29, Supplement (December), pp. DOI: https://doi.org/10.37597/ajphes.2022.29.4.2.xx

Introduction

Hypertension is defined as increased blood pressure (BP) above a threshold of 140 mmHg systolic and 90 mmHg for diastolic BP (World Health Organisation, 2021). According to Ataklte *et al*. (2015) and Guwatudde *et al*. (2015), hypertension has become a widespread public health problem affecting approximately 38% of the total population in Sub-Saharan Africa. This is a serious health concern especially in developing countries, and rural areas. The prevalence of hypertension stage 1 and 2 is estimated to be 2.7% and 2%, respectively among Lephalale (formerly known as Ellisras until 2002) children aged 6−17 years (Sekgala *et al.*, 2017). The leading risk factors of hypertension include alcohol intake, poor diet, physical inactivity, and obesity (Mills *et al*., 2020).

Obesity and hypertension have long been linked to all age groups (Jiang *et al.*, 2016). Obesity indices such as waist-to-height ratio (WHtR), waist circumference (WC), and waist-to-hip ratio (WHR), were reported to be effective in predicting hypertension (Wu *et al.*, 2019). However, most of these studies were conducted on children and adults, and none were carried out longitudinally and across seasons (Nafiu *et al.*, 2014; Sebati *et al.*, 2019). Both hypertension and obesity prevalence have been reported to be higher in winter in countries such as Japan, London, and Italy (Kobayashi & Kobayashi, 2006; Cuspidi *et al.*, 2012; Modesti *et al.*, 2013).

Nika *et al.* (2019) reported a higher hypertension prevalence in spring (5.5%) and winter (5%) compared to summer (4%) and autumn (2.5%) in Europe. Furthermore, Visscher and Seidell (2004) noted a high prevalence of obesity, determined by WC in winter (19.6%) and spring (19.2%) compared to autumn (17.6%) and summer (16.2%) among men. They further showed that WC was higher in winter (25.7%) and autumn (24.5%) compared to spring (23.3%) and summer (22.0%) among women. These findings are probably due to seasonal variations in behavioural factors such as diet, duration of sleep, and physical activity (Modesti *et al.*, 2018). Seasonal variation also results in changes in blood lipid, body weight, bone mass, and bone density (Ma *et al*., 2006; Stergiou *et al.*, 2020).

Seasonal variation also results in many physiological markers such as changes in coagulation profile, increased sympathetic activity, and endothelial dysfunction leading to increased blood pressure (Goyal *et al.*, 2018). Although hypertension is a growing concern in South African cities, little is known regarding its incidence and risk factors in the country's rural areas (Alberts *et al.*, 2015). Moreover, few studies exist in the literature that investigated seasonal variation as a risk factor for non-communicable diseases. Therefore, this study was carried out to investigate seasonal variation in blood pressure and abdominal fat indices among children in Lephalale rural area of Limpopo province, South Africa.

Methodology

Study setting and sampling procedure

This descriptive survey took place in Lephalale (formerly known as Ellisras until 2002 when the name was changed by the provincial government of the Limpopo province), South Africa. The study is part of the Ellisras Longitudinal Study (ELS), the procedure of which is described in detail elsewhere (Monyeki *et al.*, 2017). Data for this study were sourced from the Ellisras Longitudinal study conducted in autumn (May) and Spring (November) of 1999, 2000, 2001, and 2003. The sample size was calculated using the population size of 115 767 (95% confidence, 5% margin of error), and an estimated population proportion of 50%. The study started with 1 974 (1033 boys and 941 girls) participants in 1999 and ended with 1 701 (873 boys and 828 females) participants in 2003, aged 4−18 years. The participants were measured repeatedly over the years. The Turfloop research ethics committee of the University of the North (now known as the University of Limpopo) approved this study before it was undertaken.

Blood pressure

Blood pressure (BP) measurements were taken following the procedure of the National High Blood Pressure Education Program's (NHBPEP) Working Group on Hypertension Control in Children and Adolescents (NHBPEP's Working Group on Hypertension Control in Children and Adolescents, 1996). After 5 minutes of relaxation in a well-ventilated room, BP was measured. Measurements were done with an electronic Micronta monitoring kit while the individual was seated with her legs touching the ground but not crossed.

Anthropometry

Following the guidelines of the International Society for the Advancement of Kinanthropometry (ISAK), anthropometric measurements were taken to the nearest 0.1 cm (Norton, 2018). Height was measured with a stadiometer, with the subject in a standing position. The participant stood barefoot such that the feet were placed together flat on the ground with the heels, buttocks, and shoulders touching the stadiometer. The stadiometer's headboard was then pressed against the participant's head, and height was measured. Participants' WC were measured while standing with a flexible steel tape, halfway between the lowest rib cage and the iliac crest, following a typical expiration. Hip circumference was measured with a flexible steel tape on the broadest point above the buttocks (Norton, 2018).

Quality assurance

The reliability and validity of the study have been published elsewhere (Monyeki *et al.*, 2008; Sebati *et al.*, 2019). In short, the inter- and intra-tester technical errors of measurements for WC, HC, and height were taken into consideration. The instruments were calibrated before data collection. Fieldworkers were trained on achieving technical errors within acceptable limits.

Statistical analysis

A diastolic and systolic BP greater than the 95th percentile was used to classify hypertension using NHBPEP's data. To classify obesity, a WHtR ≥ 0.5 in both males and females was used, and a WHR ≥ 0.9 (males) and ≥ 0.8 (females) were also used (Goon *et al*., 2014). A WC $\geq 90^{th}$ percentile was used as cut-off point for obesity in both males and females (Ribas & Santana da Silva, 2012). Seasonal variation in absolute values and the prevalence of both obesity and hypertension, were presented graphically in different years by age categories (4−7 years, 8−11 years, and above 12 years) in both boys and girls. Normality of data distribution was evaluated using the Shapiro-Wilk test. Participants' dependent variables (blood pressure, WC, WHtR, and WHR) were presented as median values and interquartile ranges. Frequency analysis was used to examine the prevalence of high BP and excessive body fat among the participants. The data were analysed with the IBM's

Statistical Package for the Social Sciences (SPSS) version 28. For all analyses, a probability level of $p \leq 0.05$ was used to indicate significance.

Results

Table 1 presents the participants' physical characteristics. The results showed that girls were significantly ($p \leq 0.05$) taller (143.7cm) than boys (142.0cm). furthermore, girls showed a significantly ($p \leq 0.05$) larger hip circumference (68.0 cm) than boys (65.0 cm). Moreover, girls had a significantly ($p \leq 0.05$) higher systolic and diastolic BP than boys.

Table 1: Physical and physiological characteristics of participants

	Boys	**Girls**
Clinical characteristics [median (25:75 interquartile)]		
Age (years)	11.6 (9.9:13.1)	11.6 (10.0:13.1)
Height (cm)	142.0 * (134:150)	143.7 * (135.0:153.0)
WC (cm)	56.8 (54.0:59.0)	56.9 (53.8:60.0)
HC (cm)	65.0 * (61.0:69.4)	68.0 * (63.0:74.3)
WHtR	0.4 (0.38:0.42)	0.4 (0.38:0.42)
WHR	0.9 (0.8:0.9)	0.8 (0.8:0.9)
Systolic blood pressure (mmHg)	98.0 * (91.5:106.0)	100 * (93.0:109.0)
Diastolic blood pressure (mmHg)	63.0 * (58.0:68.5)	64.0 * (59.0:70.0)
Number of participants in different age groups (n)		
1999		
4-7 years	163	129
8-11 years	683	660
Above 12 years	187	152
2000		
4-7 years	80	57
8-11 years	536	517
Above 12 years	390	344
2001		
4-7 years	24	15
8-11 years	382	373
Above 12 years	556	516
2003		
4-7 years	0	0
8-11 years	122	110
Above 12 years	751	718

*p≤0.05, cm- centimetre, mmHg- millimetres of mercury, WC-waist circumference, HC- hip circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure,

Seasonal variation in absolute values

Figures 1 to 5 show seasonal variation in systolic blood pressure (SBP), diastolic blood pressure (DBP), WC, WHtR, and WHR in both boys and girls. The non-significant results were removed from all figures and only significant results were reported. Systolic BP showed a significant variation ($p \leq 0.01$) in both boys and girls aged 8−11 years in 2003. Systolic BP was also higher in autumn (median=101.8 mmHg) than in spring (median=93.0 mmHg) among boys, 103.3 mmHg in autumn and 91.3 mmHg in spring among girls. Diastolic BP showed a significant ($p \leq 0.01$) disparity in both genders above 12 years in 2003. The median was 68.0 mmHg (autumn) and 59.5 mmHg (spring) among the boys, while corresponding data for the girls were 69.0 mmHg (autumn) and 62.0 mmHg (spring).

A significant ($p \leq 0.01$) variation in WC was evident among boys aged 4−7 years in autumn (median=60.0 cm) and spring (median=54.0 cm) of 2001. Girls of the same age group in the same year also showed a significant ($p \leq 0.01$) variation in autumn (median=59.0 cm) and spring (median=52.5 cm). Waist-to-height ratio showed a substantial ($p \leq 0.01$) variation in both sexes aged 4−7 years in 2001. The WHtR in this group of children was higher in autumn (median=0.5) than in spring (median=0.4). Only girls showed a significant ($p \leq 0.01$) variation in WHR, and it was higher in autumn (median=0.9) than spring (median=0.8) in 2001 among those older than 12 years of age.

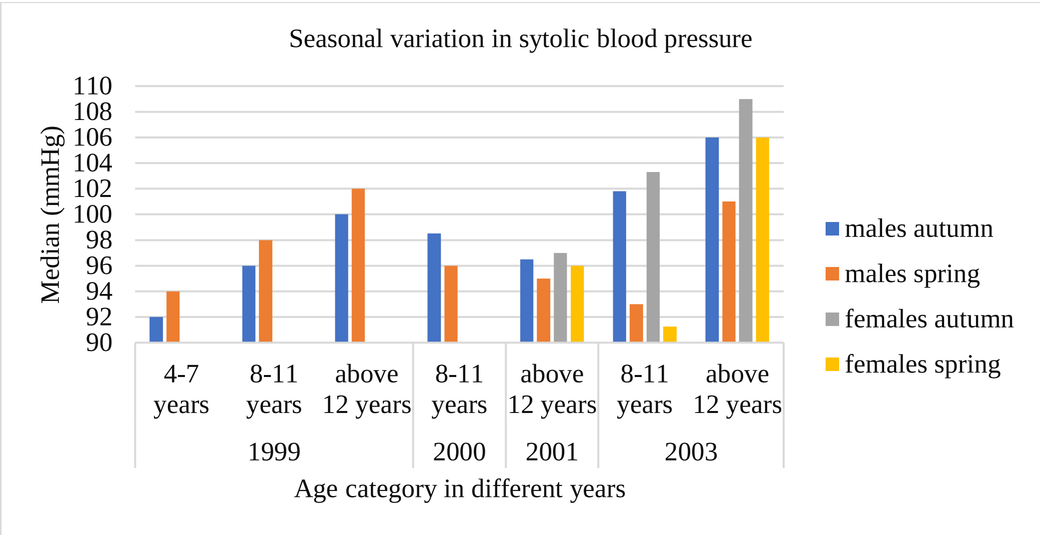

Figure 1: Seasonal variation in SBP in boys and girls in autumn and spring.

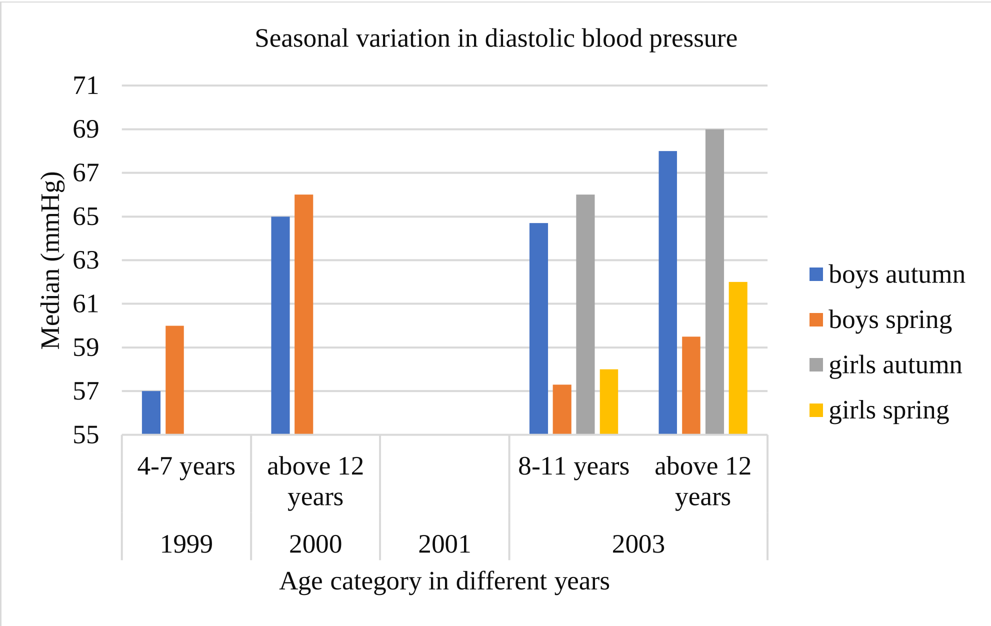

Figure 2: Seasonal variation in DBP in boys and girls in autumn and spring.

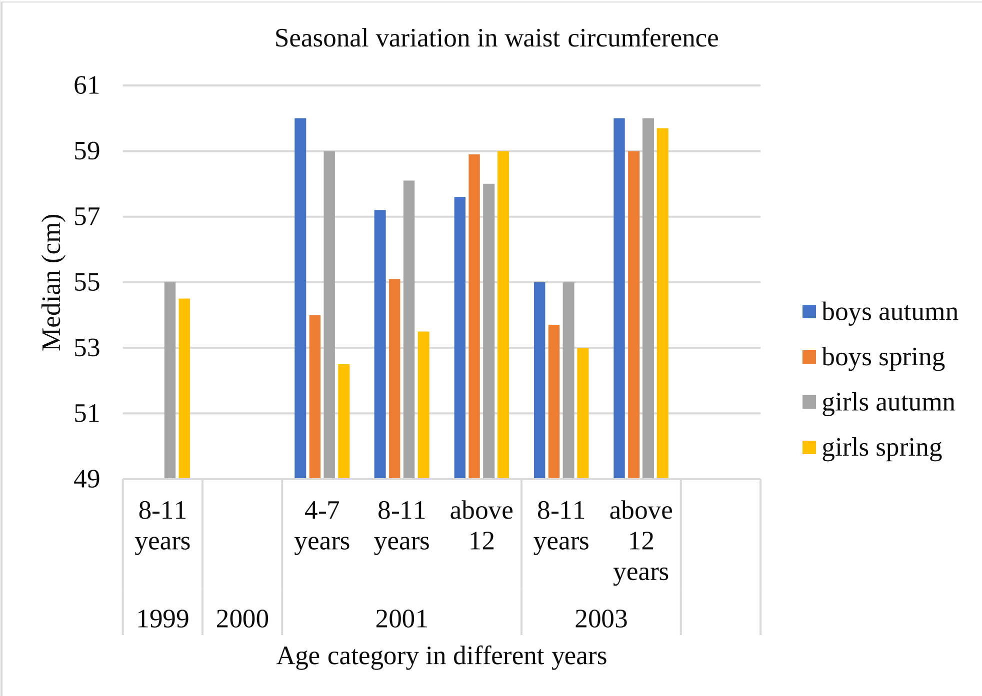

Figure 3: Seasonal variation in WC in boys and girls in spring and autumn.

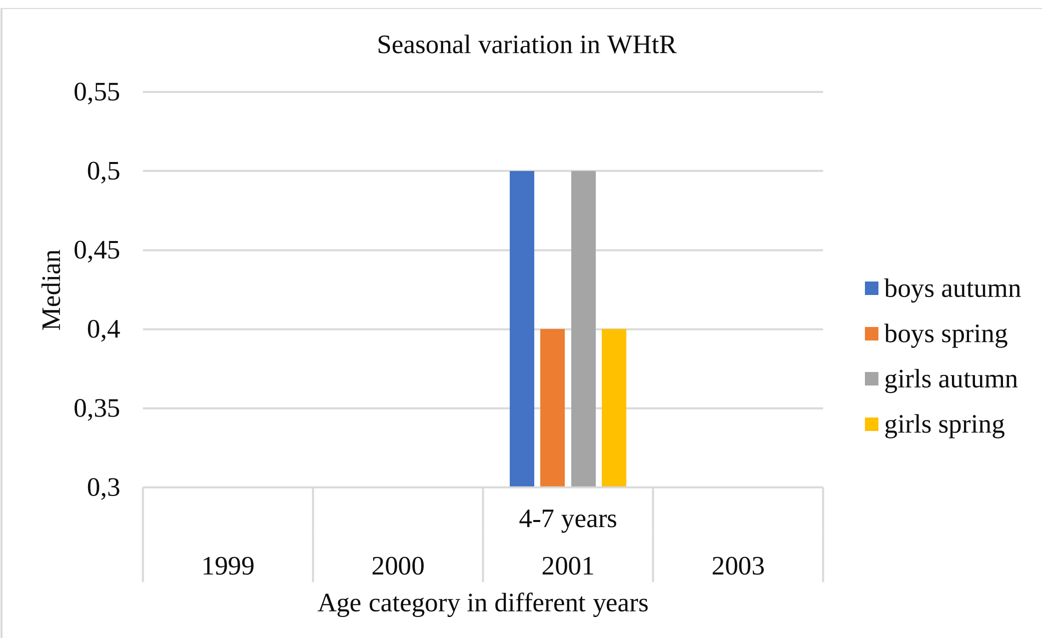

Figure 4: Seasonal variation in WHtR in boys and girls in spring and autumn.

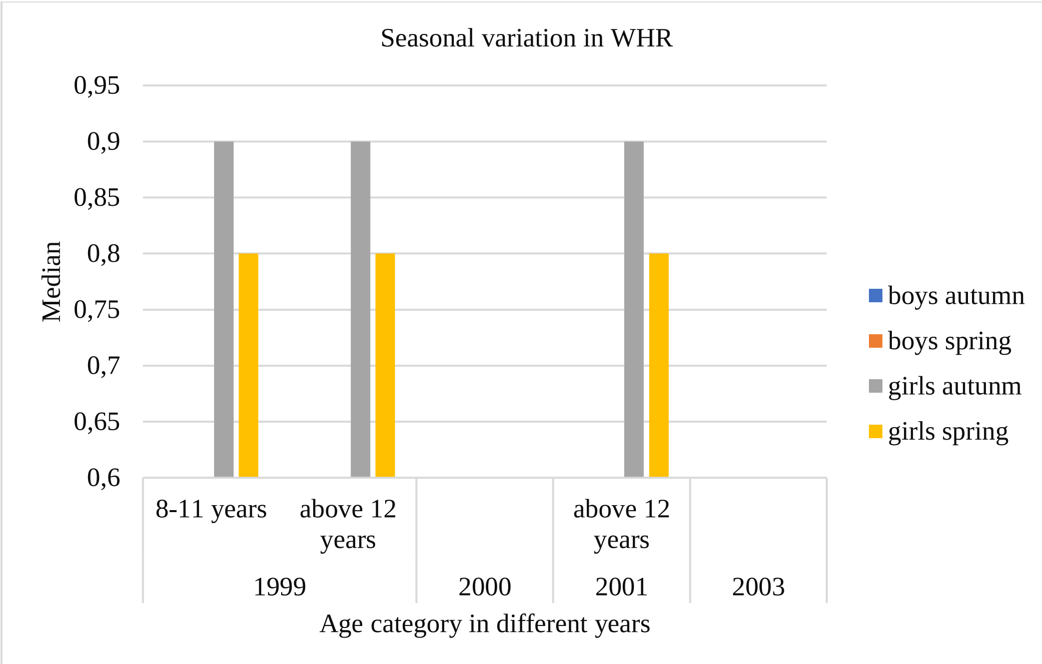

Figure 5: Seasonal variation in WHR in boys and girls in autumn and spring.

Seasonal variation in blood pressure and obesity prevalence

Figures 8 to 11 show the prevalence of hypertension and obesity among the participants. Only significant results are reported in all Figures. Figures 6 and 7 show seasonal variation in high SBP and high DBP. A significant ($p \leq 0.01$) variation in both high SBP and high DBP among boys and girls aged 4−7 years in 1999 was evident. The prevalence of high SBP was 3.1% in autumn and 6.6% in spring for boys; and 5.4% (autumn) and 14.9% (spring) in girls. High DBP was 1.8% in autumn and 11.3% in spring among the boys, whereas 0.8% (autumn) and 14.9% (spring) were found for girls. Figure 8 shows seasonal variation in hypertension. A significant ($p \leq 0.01$) variation was evident in both girls and boys aged 4−7 years in 1999. Data on hypertension were 0% and 4.7% (autumn and spring) as well as 0.8% and 12.8% (autumn and spring) for the boys and girls, respectively.

Figures 9 to 11 illustrate seasonal variation in obesity by WC, WHtR, and WHR. A significant ($p \leq 0.01$) disparity in obesity based on WC was evident in both the boys and girls aged 8−11 years in 2001. The prevalence was 8.9% (autumn) and 1.3% (spring) for boys, 16.6% (autumn) and 2.1% (spring) among the girls. Data on obesity estimated from WHtR also yielded significant ($p \leq 0.01$) variation among boys and girls 8−11 years in 2001. The prevalence was 3.7% and 0% in autumn and spring, respectively among boys, and 7.2% (autumn) and 0.4% (spring) for the girls. Seasonal variation estimated from WHR was also evident among boys and girls aged 8−11 in 1999. Specific data were 41.4% in autumn and 28.9% in spring among boys, whereas corresponding findings for the girls were 95.5% and 84.2%.

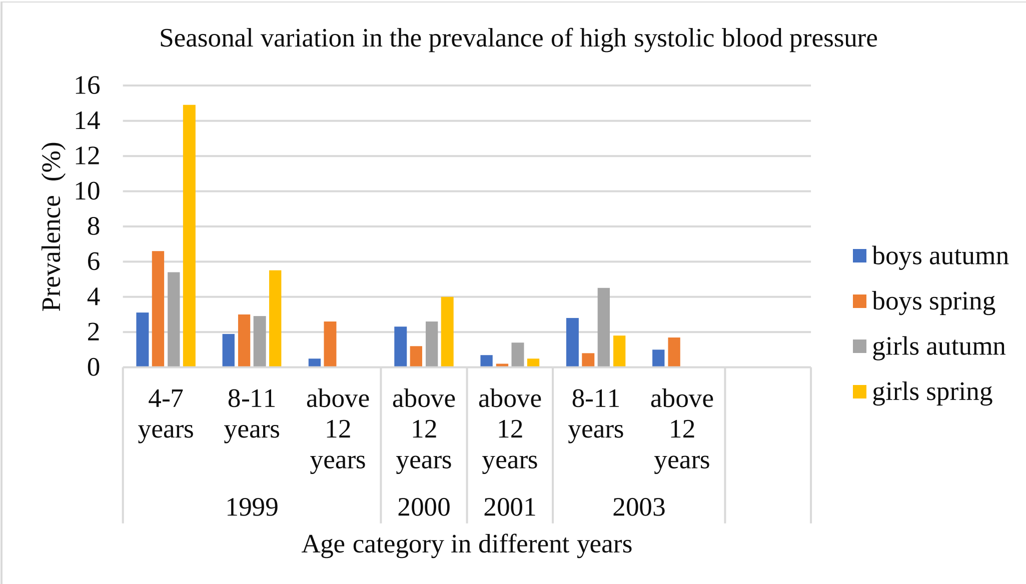

Figure 6: Seasonal variation in the prevalence of high SBP pressure in boys and girls in autumn and spring.

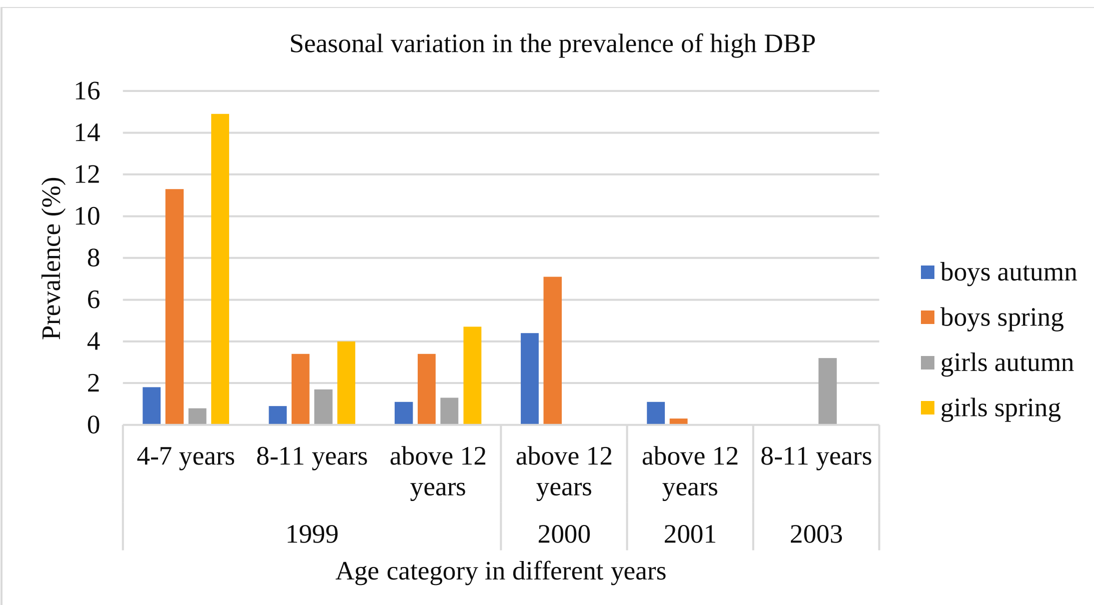

Figure 7: Seasonal variation in the prevalence of high DBP in boys and girls in autumn and spring.

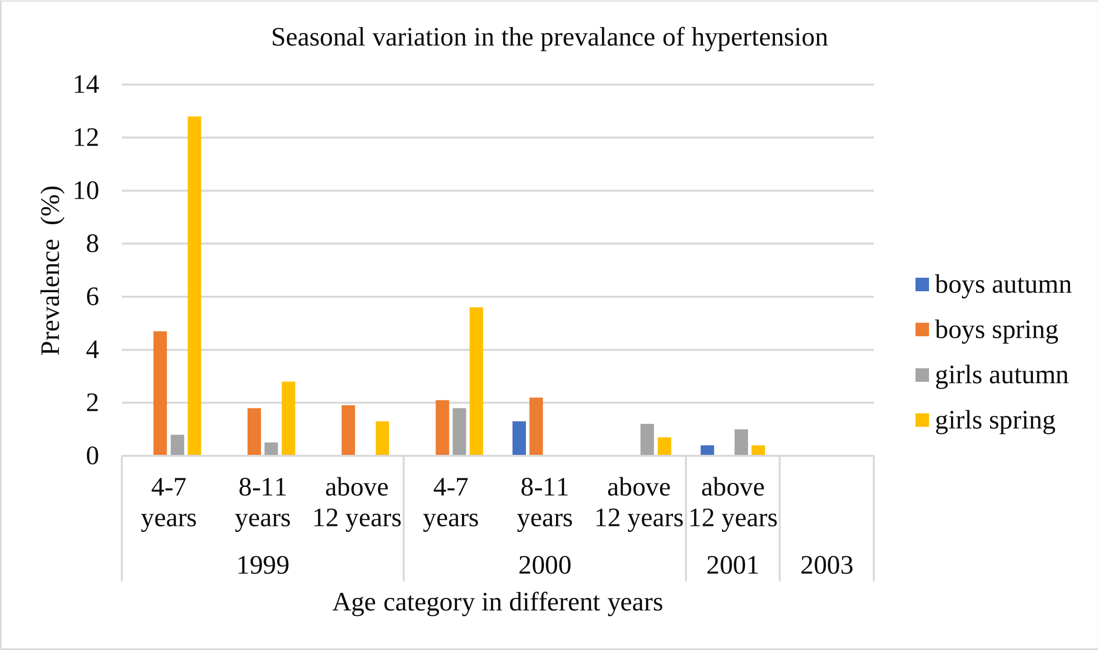

Figure 8: Seasonal variation in the prevalence of hypertension in boys and girls in autumn and spring.

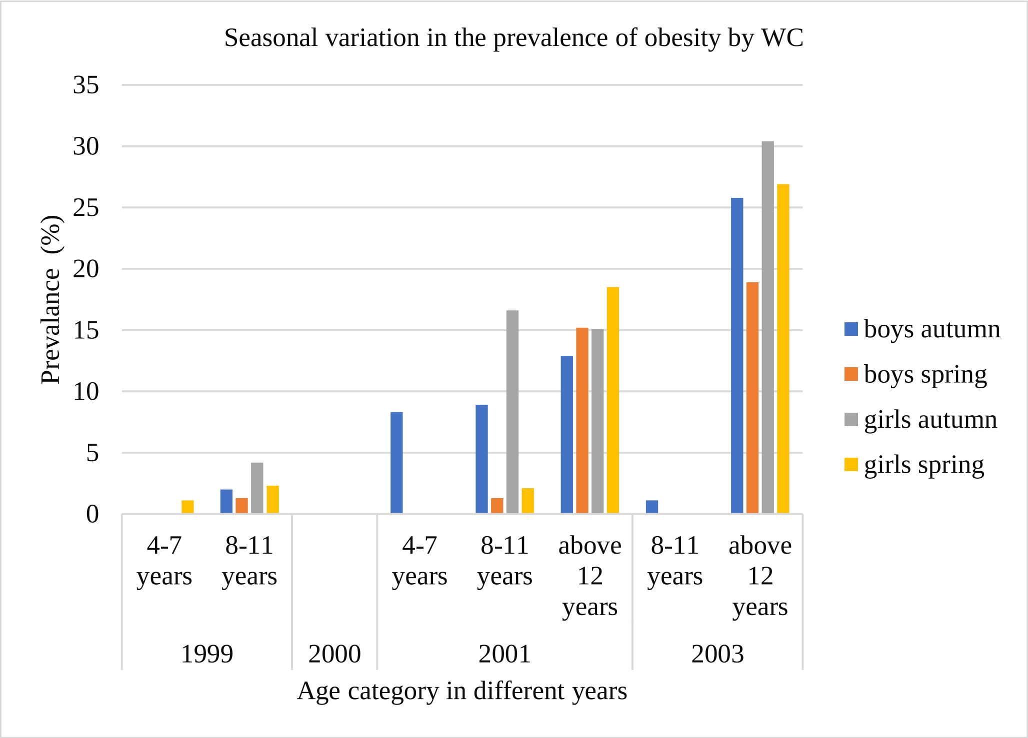

Figure 9: Seasonal variation in the prevalence of obesity by WC in boys and girls in autumn and spring.

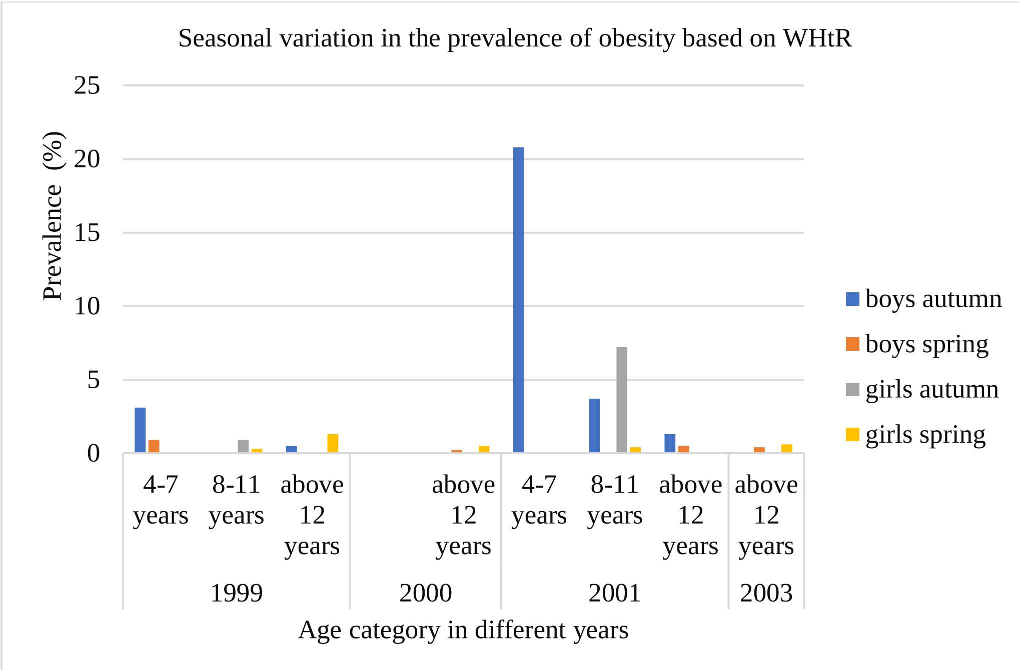

Figure 10: Seasonal variation in the prevalence of obesity by WHtR in boys and girls in autumn and spring.

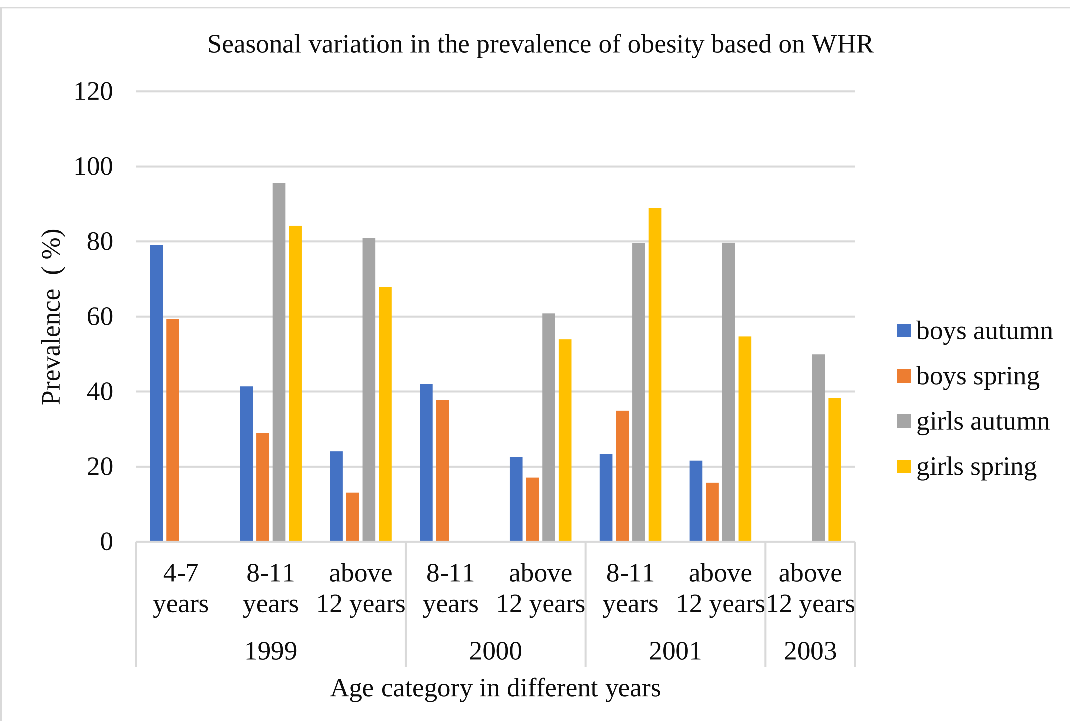

Figure 11: Seasonal variation in the prevalence of obesity by WHR in boys and girls in autumn and spring.

Discussion

This study investigated the existence of seasonal variation in blood pressure and abdominal fat indices among children in Lephalale (formerly called Ellisras), South Africa. The results of the study showed a significantly (p≤0.01) higher SBP in autumn compared to spring in both boys and girls aged 8−11 years in 2003. Diastolic blood pressure also indicated a significant (p≤0.01) variation in both boys and girls older than 12 years in 2003, where the median was also higher in autumn than spring. Conversely, Goyal *et al*. (2018) reported significantly higher SBP and DBP in spring in contrast to autumn among an Indian sample. The disparity observed in these studies may be due to geographical differences in the settings where they were conducted, and the participants' age differences since Goyal *et al.*'s study was conducted in Indians who were 18 years and older.

A significant (p≤0.01) variation in the prevalence of high SBP and high DBP among boys and girls aged 4−7 years in 1999 was observed, with the prevalence being higher in spring compared to autumn. Wang *et al*. (2017) had earlier reported similar findings. A substantial variation in the prevalence of hypertension was also evident in both girls and boys aged 4−7 years in 1999. The prevalence was higher in spring than autumn. These results are similar to what Nika *et al.* (2019) reported for European children and adolescents, who also had a higher rate of hypertension in spring than autumn.
Factors such as temperature differences during the various seasons, sunshine, and humidity may result in seasonal variation in blood pressure (Aubinière-Robb *et al*., 2013). Furthermore, a lot of physiological changes such as increased sympathetic activity, endothelial dysfunction, arteriolar vasoconstriction, and aldosterone levels take place at different seasons (Goyal *et al*., 2018). These seasonal changes in physiological factors could contribute to the variation in BP observed in the present study.

A significant difference in WC and WHtR in both boys and girls aged 4−7 in 2001 was observed, where the median score was higher in autumn than spring. Seasonal variation in WHR was only observed among girls and it was also higher in autumn than spring. The seasonal variation in WHR among the girls in our study may be explained in the light of seasonal variation in testosterone (Van Anders *et al*., 2006). Furthermore, seasonal changes in WC, WHR, and WHtR may further be explained by the variation in physical activity, since physical activity was reported to be low in autumn compared to spring (Visscher & Seidell, 2004).

Further results showed a significant (p≤0.01) variation in the prevalence of obesity (determined by WC and WHtR) in both boys and girls aged 8−11 years in 2001, and a marked (p≤0.01) difference in obesity based on WHR was also noted among boys and girls older than 12 years in 2001. The obesity prevalence observed based on WC, WHtR and WHR was substantially higher in autumn than spring in both boys and girls. The higher prevalence of obesity in autumn than spring may be partly attributed to winter and autumn being associated with high fat intake than summer and spring (Visscher & Seidell, 2004). The strength of this investigation is that it forms part of a longitudinal study which makes it possible to evaluate the impact of seasonal variation on blood pressure and visceral fat indices in childhood and adolescence.

An important limitation of this study is that it was based on data from the ELS conducted over two decades ago, the fact of which however, implicates the need to determine the current trends of seasonal variation in BP and abdominal fat indices among boys and girls in the Lephalale population over time. As the present study did not investigate the plausible causes of seasonal differences in BP and visceral fat indices in the children, the physiological and environmental bases for the observed findings require further investigation.

Conclusions

Seasonal variation in SBP and abdominal fat indices among Lephalale rural population was found, which differed by age group. Prevalence of SBP and DBP was significantly higher in spring compared to autumn, while obesity was substantially more prevalent in in autumn than spring. More studies are needed to clarify the observed findings.

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Article

SEASONAL ASSOCIATION OF ABDOMINAL FAT INDICES AND BLOOD PRESSURE VARIABLES AMONG THE ELLISRAS POPULATION AGED 4−18 OVERTIME: DATA FROM ELLISRAS LONGITUDINAL STUDY

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Abstract: Obesity and hypertension have been declared a global pandemic, and both have been reported to be affected by seasonal variation as a risk factor. However, the association of obesity and blood pressure (BP) variables at different seasons received little to no attention on literature. Therefore, this study investigated whether there is an association between autumn and spring obesity and BP variables, and whether there is a risk associated with the development of obesity and BP between autumn and spring variables among the Ellisras population aged 4−18 over time. At baseline, measurements were collected in autumn 1999 with 1 974 (1033 boys and 941 girls) participants. The same participants were followed repeatedly overtime (autumn and spring 2000, 2001, 2003). In spring 2003, a total of 1 701 (873 boys and 828 girls) participants were still presence in the study. Anthropometric and BP variables were measured following standard procedures throughout the period of survey. The prevalence of obesity by WC was significantly ($P \leq 0.05$) higher among girls (17−27%) compared to boys (8−19%) above 12 years in spring from 1999−2003. Diastolic BP showed the lowest significant ($P \leq 0.05$) association B=0.007 (95% CI, 0.000−0.012) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements when adjusted for age and gender. Furthermore, the highest significant ($P \leq 0.05$) risk was observed in obesity by WHtR B=0.619 (95% CI, 0.554−0.683) between baseline measurements (autumn 1999) and subsequent spring (1999−2003) measurements when unadjusted for age and gender. An association between autumn and spring measurements for obesity and BP variables was evident in this study overtime. Furthermore, the development of obesity and BP is associated with seasons.

Keywords: obesity; hypertension; seasonal variation

1. Introduction

Obesity and hypertension have been declared a global pandemic [1]. The World Health Organisation (WHO) reported that more than 1 billion people worldwide are obese [2]. The prevalence of obesity in South Africa is reported to be one of the highest in Sub-Saharan Africa, while in Lephalale (formerly known as Ellisras) of the Limpopo province the prevalence of obesity by waist circumference (WC) was reported to be 28.3% [3,4].

The Prevalence of obesity imposes a huge financial burden on the South African healthcare system. Therefore, urgent interventions are needed to decrease the prevalence of obesity thereby decreasing the incidence, prevalence, and financial burden caused by noncommunicable diseases [4]. A decrease in obesity prevalence will decrease the prevalence of noncommunicable diseases since obesity was reported to be a risk factor for several non-communicable diseases such as stroke, type 2 diabetes, coronary heart disease, several cancers, kidney disorder, and hypertension [5,6].

Hypertension is defined as increased blood pressure (BP) in the blood vessels that is usually greater or equal to 90 and 140 mmHg for systolic and diastolic BP respectively [7]. The pathogenesis of obesity-related hypertension is said to be mainly due to the stimulation of the sympathetic nervous system, the amount of intra-vascular and intra-abdominal fat, activation of the renin-angiotensin-aldosterone system, sodium retention which increases renal reabsorption, and hyperinsulinemia [8,9]. Furthermore, it was reported that obesity and hypertension also develop because of environmental risk factors such as ethnicity, geographical areas, socio-economic status, and seasons [9].

Seasonal variation was reported to result in changes in physical activity, types of food available, and individual feeding habits [10]. It was reported that the highest fat intake is mostly observed in autumn and the highest physical activity level is observed in spring [11]. This then leads to seasonal variation in obesity prevalence. One study [12] reported the highest waist-to-hip ratio (WHR) in autumn and summer compared to spring and winter. According to our knowledge, none of the studies in the literature investigated seasonal variation in obesity based on waist-to-height ratio (WHtR).

Furthermore, seasonal variation was reported to result in changes in physiological factors such as increased sympathetic activity, endothelial dysfunction, and modification in coagulation profile, leading to seasonal differences in BP [13]. Cold temperatures result in vasoconstriction which then results in elevated BP [14]. Furthermore, seasonal variation in BP was reported across all four seasons. Systolic blood pressure (SBP) was reported to be significantly higher in winter compared to summer. Moreover, a significantly higher diastolic blood pressure (DBP) in spring compared to autumn was reported [13].

Fewer studies investigated seasonal variations in obesity and blood pressure. Those that are published are mostly cross-sectional while longitudinal studies are in scanty. A preliminary cross-sectional study in the Ellisras Longitudinal Study investigated seasonal variation in fat patterning [15]. However, seasonal variation in abdominal fat indices and blood pressure overtime was never investigated among the Ellisras population. Therefore, this study was aimed at investigating whether there is an association between autumn and spring variables, and whether there is a risk associated with the development of obesity and BP between autumn and spring variables among the Ellisras population aged 4−18 over time.

2. Materials and Methods

2.1 Sampling procedure

This study took place in Lephalale, South Africa (previously known as Ellisras until 2002, when the Limpopo provincial government changed the name). This study is a component of the Ellisras Longitudinal Study (ELS), which is explained in detail elsewhere [16,17]. The ELS data used in this study were obtained in the autumn (May) and spring (November) of 1999, 2000, 2001, and 2003. The sample size was determined using a population size of 115 767, a confidence level of 95%, a margin of error of 5%, and an estimated population percentage of 50%. At baseline, measurements were collected in autumn 1999 with 1 974 (1033 boys and 941 girls) participants. The same participants were followed repeatedly overtime (autumn and spring 2000, 2001, 2003). In spring 2003, a total of 1 701 (873 boys and 828 girls) participants were still presence in the study. This study was approved by the Turfloop Research Ethics Committee (ethical clearance number: TREC/360/2022: PG).

2.2 Blood pressure

Standard procedures were followed to measure BP as documented by the National High Blood Pressure Education Program (NHBPEP) Working Group on Hypertension Control in Children and Adolescents [18]. Briefly, at least three BP measurement were taken after 5 or more minutes of relaxation in a well-ventilated room using an electronic Micronta monitoring kit, while the individual was seated with their legs touching the ground but not crossed. An electronic infrasonic transducer on the device's bladder, detects BP and pulse rate and simultaneously displays them on the screen. This adaptable tool was created for both research and medical purpose. A high correlation (r=0.93) was found between the results obtained using the automated device and those obtained with a conventional mercury sphygmomanometer on a pilot study conducted before the survey.

2.3 Anthropometry

Anthropometric measurements to the nearest 0.1 cm were taken following the guidelines established by the International Society for the Advancement of Kinanthropometry (ISAK) [19]. Height was measured in a standing position with a stadiometer. Feet were put flat on the ground together, with the participant placed such that the heels, buttocks, and shoulders touched the stadiometer, with shoes and socks off. The headboard of the stadiometer was then lowered against the participant's head, and height was recorded. A flexible steel tape was used to measure the participants' WC and hip circumference. Following a normal expiration, WC was measured while standing midway between the lowest rib cage and the iliac crest. Hip circumference was measured on the widest point above the buttocks [19].

2.4 Quality assurance

The reliability and validity of the study's measurements are reported elsewhere [3,20]. In short, the inter- and intra-tester technical errors of WC, HC, and height measurements were considered, ranging from 0–3.4 cm (0–4%) for WC and HC, and from 0.22–0.43 cm (0.12–0.32%) for height.

2.5 Statistical analysis

2.5.1 Descriptive statistics

The participants' characteristics (BP, WC, WHtR, and WHR) were presented as a mean and standard deviation. Participants were divided into age groups, looking at the critical stages for the development of obesity [21]. An independent sample T-test was used to test the significant level among gender across seasons.

2.5.2 Prevalence of obesity and hypertension

Frequency analysis was used to determine the prevalence of both obesity and hypertension in percentage. Obesity was defined as a WHtR ≥ 0.5 in both males and females, and a WHR ≥ 0.9 (males) and ≥ 0.8 (females) [22]. A WC $\geq$ 90th percentile was used in both males and females [23]. Hypertension was determined as the average of three different BP readings when either the SBP or the DBP is greater than the 95th percentile for age and sex [18].

2.5.3 Generalized estimating equation

Generalized estimating equation (GEE) technique which determines the association between an indicator at the first measurement period and the same indicator at all other measurement period was used with age and gender being included in the model [24].

2.5.4 Statistical package and significance

The statistical analysis was computed with the IBM Statistical Package for the Social Sciences (SPSS) version 28, and STATA (12) with a significance level set at $p \leq 0.05$.

3. Results

Table one shows the descriptive statistics for WC, WHtR, WHR, SBP and DBP among Ellisras boys and girls. The results showed a significantly ($P \leq 0.05$) higher WC among boys (54.06−55.47 cm) compared to girls (53.51−54.87 cm) aged 8−11 in spring from 2000−2003. The results did not show a specific trend in WHtR from 1999−2003, however WHtR was significantly ($P \leq 0.05$) higher among boys (0.41) compared to girls (0.40) aged 8−11 years in autumn 2003. Waist-to-hip ratio was significantly ($P \leq 0.05$) higher among boys (0.85−0.87) compared to girls (0.79−0.85) above 12 years in both autumn and spring from 1999−2003. The results did not show any significant trends in both SBP and DBP from 1999−2003. However, DBP was significantly higher ($P \leq 0.05$) among girls (70.80 mmHg) compared to boys (65.91 mmHg) 4–7 years in spring 2001 while SBP was significantly ($P \leq 0.05$) higher among girls (97.74 mmHg) compared to boys (96.52 mmHg) aged 4–7 years in spring of 1999.

Table 1: Descriptive Statistics among Ellisras population aged 4–18 years.

		1999				2000				2001				2003			
		Autumn		Spring		Autumn		Spring		Autumn		Spring		Autumn		Spring	
	Age	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	boys	girls	boys	Girls	Boys	girls
Number of participants (n)	4–7 years	163	129	106	95	80	57	47	36	24	15	11	5				
	8–11 years	683	660	610	577	536	517	455	440	382	373	315	280	178	154	122	110
	Above 12	187	152	267	236	390	344	434	401	556	516	586	567	764	724	751	718
Mean age (years)	4–7 years	6.38	6.40	6.59	6.66	6.77	6.75	6.92	6.89	7.02	7.09	7.16	7.16				
	8–11 years	9.91	9.83	9.89	9.95	8.87	9.93	9.86	9.92	9.86	9.94	9.95	9.96	10.38	10.42	10.57	10.65
	Above 12	12.05	12.04	12.26	12.23	12.47	12.41	12.65	12.61	12.89	12.90	13.19	13.12	14.12	14.13	14.44	14.49
Mean (SD)																	
WC (cm)	4–7 years	51.23 (3.23)	51.13 (3.28)	51.20 (2.89)	51.06 (3.71)	52.23 (3.06)	50.81 (2.67)	51.51 (2.56)	50.80 (3.33)	56.61 (4.31)	57.73 (4.88)	53.30 (3.78)	51.82 (4.14)				
	8–11 years	55.42 (3.46)	55.61 (4.07)	55.09 (3.29)	54.91 (3.86)	55.69* (3.16)	55.00 * (3.89)	55.38* (3.28)	54.87* (3.85)	57.36 (4.69)	58.53 (4.53)	55.26* (3.16)	54.07* (3.78)	55.47* (3.01)	55.34* (3.73)	54.06* (2.90)	53.51* (3.72)
	Above 12	57.74 (4.33)	58.56 (4.38)	57.63** (3.53)	58.77** (4.77)	58.71 (3.42)	58.77 (4.41)	58.71** (3.54)	59.05 ** (4.47)	57.84 (4.75)	58.32 (4.45)	59.20 ** (4.09)	59.05 ** (4.86)	59.99 ** (3.93)	55.34 ** (3.72)	59.41 ** (4.49)	60.02 ** (5.40)
WHtR	4–7 years	0.44 (0.03)	0.44 (0.02)	0.43 (0.02)	0.43 (0.38)	0.43 (0.02)	0.43 (0.02)	0.42 (0.02)	0.42 (0.02)	0.46 (0.04)	0.48 (0.04)	0.41 (0.03)	0.44 (0.04)				

	8–11 years	0.41 (0.02)	0.41 (0.02)	0.41 (0.02)	0.41 (0.02)	0.41 (0.02)	0.40 (0.02)	0.42 (0.02)	0.40 (0.02)	0.43 (0.04)	0.43 (0.04)	0.41 (0.02)	0.40 (0.02)	0.41* (0.02)	0.40* (0.03)	0.39 (0.02)	0.39 (0.02)
	Above 12	0.40 (0.03)	0.41 (0.03)	0.40 (0.02)	0.40 (0.03)	0.40 (0.02)	0.40 (0.03)	0.40 (0.02)	0.40 (0.03)	0.39 (0.04)	0.39 (0.03)	0.39 (0.03)	0.39 (0.03)	0.39 (0.02)	0.39 (0.03)	0.38 ** (0.02)	0.39 ** (0.02)
WHR	4–7 years	0.93 (0.05)	0.91 (0.04)	0.92 (0.05)	0.89 (0.05)	0.93 (0.06)	0.90 (0.04)	0.92 (0.05)	0.89 (0.05)	0.86 (0.49)	0.85 (0.07)	0.87 (0.07)	0.92 (0.08)				
	8–11 years	0.90* (0.04)	0.87* (0.05)	0.88 (0.05)	0.85 (0.05)	0.89* (0.05)	0.85* (0.05)	0.89* (0.04)	0.85* (0.05)	0.86 (0.05)	0.84 (0.05)	0.89 (0.05)	0.85 (0.05)	0.88 (0.05)	0.84 (0.05)	0.90 (0.05)	0.84 (0.06)
	Above 12	0.87* (0.03)	0.85* (0.04)	0.86* (0.04)	0.82* (0.05)	0.87* (0.04)	0.81* (0.05)	0.86** (0.04)	0.81** (0.06)	0.86 (0.06)	0.85 (0.06)	0.86 (0.05)	0.81 (0.05)	0.85 ** (0.06)	0.80** (0.07)	0.86** (0.05)	0.79 ** (0.05)
DBP mmHg	4–7 years	57.50 (7.87)	60.02 (7.26)	61.12 (10.85)	62.95 (10.54)	65.15 (9.56)	66.09 (9.32)	62.66 (10.85)	62.94 (10.52)	63.10 (7.22)	67.47 (12.26)	65.91*(6.74)	70.80* (20.49)				
	8–11 years	60.33 (7.90)	61.39 (7.62)	61.76 (9.29)	61.74 (9.24)	66.33 (8.67)	66.15 (8.80)	65.65 (9.15)	66.69 (8.77)	63.48 (7.84)	64.48 (7.75)	63.52 (7.74)	64.52 (7.740	65.14 (8.37)	66.13 (7.02)	58.62 (10.48)	58.32 (8.10)
	Above 12	61.36 (7.71)	63.22 (7.78)	62.44 (9.03)	63.64 (9.40)	65.93 (8.49)	67.44 (9.15)	67.21 (9.42)	68.06 (8.84)	63.32 (7.72)	63.98 (7.99)	62.52 (7.74)	63.71 (7.57)	67.51 (7.64)	69.11 (7.59)	60.66 (9.27)	63.27 (9.48)
SBP mmHg	4–7 years	91.73 (10.85)	94.40 (10.28)	96.52* (11.45)	97.74* (13.50)	96.49 (9.41)	97.53 (10.17)	93.40 (10.15)	94.53 (12.53)	97.44 (10.60)	102.00 (17.45)	100.14 * (9.42)	110.70* (27.22)				
	8–11 years	96.88 (10.35)	98.58 (10.52)	99.62 (11.48)	99.77 (11.42)	99.99 (10.98)	99.60 910.92)	97.63 (10.73)	100.02 (10.73)	95.55 (9.79)	98.17 (11.15)	95.04 (9.22)	98.38 (11.14)	101.17 (11.44)	102.74 (10.96)	94.45 (13.52)	93.11 (11.31)
	Above 12	99.05* (9.18)	102.27* (11.34)	102.27 (10.35)	104.32 (11.27)	101.59 (11.32)	103.42 (11.38)	102.0* (10.97)	105.6* (12.51)	96.77 (10.02)	98.41 (10.97)	95.19 (9.55)	96.88 (10.30)	106.07 (9.98)	109.01 (10.49)	102.56 (13.19)	106.03 (12.97)

WC-waist circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure, *P≤0.05, **P≤0.001

Table 2 shows the prevalence of obesity and hypertension among Ellisras boys and girls. The prevalence of obesity by WC was significantly (P≤0.05) higher among girls (17−27%) compared to boys (8−19%) above 12 years in spring from 1999−2003. The prevalence of obesity by WHtR was not evident among boys and girls 8−11 in spring from 1999−2003. The prevalence of obesity by WHR was significantly (P≤0.05) higher among girls (38−81%) compared to boys (13−24%) above 12 years both in spring and autumn from 1999−2003. High DBP was significantly (P≤0.05) higher among girls (14−20%) compared to boys (0−11%) 4−7 years in spring from 1999−2001. High SBP was significantly (P≤0.05) higher among girls (3−5%) compared to boys (1−3%) 8−11 years in spring from 1999−2003. The prevalence of hypertension was higher among girls (1−7%) compared to boys (0%) aged 4−7 in autumn from 1999−2000.

Table 2: Gender comparison of the prevalence of obesity and blood pressure among the Ellisras population aged 4–18 years.

		1999				2000				2001				2003			
		Autumn		Spring		Autumn		Spring		Autumn		Spring		Autumn		Spring	
		Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	girls
		N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Obesity by WC	4–7 years	1 (1)	0 (0)	0 (0) *	1 (1) *	0 (0)	0 (0)	0 (0)	0 (0)	2 (8) *	1 (7) *	0 (0)	0 (0)				
	8–11 years	14 (2) **	28 (4) **	8 (1) *	13 (2) *	14 (3)	14 (3)	9 (2) *	15 (3) *	34 (9) **	62 (17) **	4 (1)	6 (2)	2 (1) *	4 (3) *	0 (0) *	2 (2) *
	Above 12	17 (9)	25 (16)	22 (8) **	39 (17) **	36 (9) **	54 (16) **	42 (10) **	66 (17) **	72 (13) *	78 (15) *	89 (15) *	105 (19) *	197 (26) **	220 (30) **	142 (19) **	193 (27) **
Obesity by WHtR	4–7 years	5 (3)	2 (2)	1 (0)	2 (2)	1 (1)	0 (0)	0 (0)	0 (0)	5 (21)	6 (40)	0 (0) *	1 (20) *				
	8–11 years	3 (0) *	6 (1) *	1 (0)	2 (0)	0 (0) *	1 (0) *	1 (0)	1 (0)	14(4) **	27 (7) **	0 (0) *	1 (0) *	0 (0)	0 (0)	0 (0)	0(0)
	Above 12	1 (0)	0 (0)	0 (0) **	3 (1) **	0 (0)	0 (0)	1 (0)	2 (1)	7 (1) *	2 (0) *	3 (1)	2 (0)	0 (0	0 (0)	3 (0)	4 (1)
Obesity by WHR	4–7 years	129 (79) **	128 (99) **	63 (59) **	95 (100) **	56 (70) **	57 (100) **	30 (64) **	36 (100) **	5 (21)	12 (80)	4 (36)	4 (80)				
	8–11 years	283 (41) *	630 (96) *	176 (29) *	486 (84) *	226 (42) **	425 (82) **	172 (38) **	266 (83) **	89 (23)	297 (80)	110 (35) **	249 (89) **	78 (44) **	114 (74) **	62 (51) **	83 (76) **
	Above 12	45 (24) *	123 (81) *	35 (13) **	160 (68) **	88 (23) **	209 (61) **	74 (17) **	216 (54) **	129 (22)	411 (80)	92 (16) **	310 (55) **	127 (17) **	361 (50) **	123 (16) **	275 (38) **
High DBP	4–7 years	3 (1.8)	1 (1)	12 (11)	14 (15)	7 (9)	5 (9)	5 (11)	5 (14)	0 (0) *	1 (7) *	0 (0) *	1 (20) *				
	8–11 years	6 (1) *	11 (2) *	21 (3)	23 (4)	36 (7)	37 (7)	36 (8)	37 (8)	13 (3)	15 (4)	10 (3)	12 (4)	5 (3)	5 (3)	4 (3) **	0 (0) **
	Above 12	2 (1)	2 (1)	9 (3)	11 (5)	17 (4) **	27 (8) **	31 (7)	28 (7)	6 (1)	9 (2)	2 (0) **	8 (1) **	20 (3)	21 (3)	15 (2) *	21 (3) *
High SBP	4–7 years	5 (3) *	7 (5) *	7 (7) **	14 (15) **	2 (3)	2 (4)	1 (2)	2 (6)	0 (0) *	3 (20) *	0 (0) *	2 (40) *				
	8–11 years	13 (2) *	19 (3) *	18 (3) **	32 (6) **	17 (3)	20 (4)	14 (3)	15 (3)	3 (1) **	14 (4) **	1 (0) **	11 (4) **	5 (3)	7 (5)	1 (1)	2 (2)
	Above 12	1 (1) *	3 (2) *	7 (3)	4 (2)	9 (2)	9 (3)	5 (1) **	16 (4) **	4 (1) *	7 (1) *	1 (0) *	3 (1) *	8 (1) **	19 (3) **	13 (2) *	20 (3) *

Hypertension	4–7 years	0 (0) *	1 (1) *	5 (5) **	12 (13) **	0 (0) *	1 (2) *	1 (2)	2 (6)	0 (0) *	1 (7) *	0 (0) *	1 (20) *				
	8–11 years	0 (0) **	3 (1) **	11 (2) *	16 (3) *	7 (1)	10 (2)	10 (2)	9 (2)	3 (1) *	6 (2) *	1 (0) **	5 (2) **	1 (1)	1 (1)	0 (0)	0 (0)
	Above 12	0 (0)	0 (0)	5 (2)	3 (1)	4 (1)	4 (1)	4 (1)	3 (1)	2 (0) *	5 (1) *	0 (0) *	2 (0) *	3 (0) *	7 (1) *	3 (0)	4 (1)

WC-waist circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure, *P≤0.05, **P≤0.001

Table 3 shows the association between autumn and spring obesity and BP variables among the Ellisras population aged 4–18 years. The results showed that diastolic BP had the lowest significant (P≤0.05) association B=0.007 (95% CI, 0.000–0.012) between baseline measurements (autumn 1999) and subsequent spring (1999–2003) measurements when adjusted for age and gender. The highest significant (P≤0.05) association was observed in waist-to-hip ratio B=0.096 (95% CI, 0.077–0.116) between baseline measurements (autumn 1999) and subsequent spring (1999–2003) measurements. However, in autumn 2003 only waist circumference B=0.075 (95% CI, 0.056–0.094) and systolic BP B=0.009 (0.003–0.016) were still significantly (P≤0.05) associated with spring measurements (1999–2003) when adjusted for age and gender.

Table 3: Regression coefficient, P value, and 95% CI for the association of obesity and blood pressure variables between autumn and spring among Ellisras population aged 4–18 years.

Year	Variables	Unadjusted			Adjusted for age and gender		
		B	P	95% CI	B	P	95% CI
Autumn 1999	WC	0.006	0.000*	0.003–0.016	0.008	0.001*	0.003–0.012
	WHtR	0.025	0.000*	0.167–0.337	0.016	0.000*	0.008–0.025
	WHR	0.588	0.000*	0.552–0.624	0.096	0.000*	0.077–0.116
	DBP	0.001	0.267	-0.001–0.003	0.007	0.028*	0.000–0.012
	SBP	0.003	0.055	0.000–0.007	0.007	0.009*	0.002–0.012
Autumn 2000	WC	0.010	0.000*	0.005–0.014	0.009	0.001*	0.004–0.014
	WHtR	-0.001	0.936	-0.267–0.246	-0.002	0.884	-0.028–0.024
	WHR	-	-	-	-	-	-
	DBP	0.000	0.975	-0.004–0.004	0.000	0.952	-0.004–0.004
	SBP	0.000	0.747	-0.002–0.002	0.000	0.666	-0.002–0.003
Autumn 2001	WC	0.000	0.873	-0.004–0.005	0.002	0.535	-0.004–0.008
	WHtR	0.011	0.499	-0.021–0.042	0.011	0.499	-0.207–0.042

	WHR	0.001	0.565	-0.003–0.005	0.001	0.646	0.003–0.005
	DBP	0.002	0.131	-0.001–0.005	0.003	0.136	-0.001–0.006
	SBP	0.005	0.027*	0.000–0.009	0.006	0.020*	0.001–0.010
Autumn 2003	WC	0.006	0.006*	0.002–0.011	0.075	0.000*	0.056–0.094
	WHtR	-	-	-	-	-	-
	WHR	-	-	-	-	-	-
	DBP	0.002	0.292	-0.001–0.005	0.002	0.291	-0.001–0.005
	SBP	0.010	0.002*	0.004–0.016	0.009	0.003*	0.003–0.016

WC-waist circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure, - collinearity, *P≤0.05

Table 4 shows the risk associated with the development of obesity and BP variables between autumn and spring among the Ellisras population aged 4–18 years. The results showed that waist circumference had the lowest significant (P≤0.05) risk B=0.003 (95% CI, 0.002–0.011) between baseline measurements (autumn 1999) and subsequent spring measurements (1999–2003) when unadjusted for age and gender. The highest significant (P≤0.05) risk was observed in obesity by WHtR B=0.619 (95% CI, 0.554–0.683) between baseline measurements and subsequent spring measurements when unadjusted for age and gender. In autumn 2003, only SBP showed a significant (P≤0.05) risk B=0.036 (95% CI, 0.016–0.057) and B=0.033 (95% CI, 0.014–0.054) both unadjusted and adjusted for age and gender respectively.

Table 4: Regression coefficient, P value and 95% CI for the risk associated with the development of obesity and blood pressure between autumn and spring among Ellisras population aged 4–18 years.

Year	Variables	Unadjusted			Adjusted for age and gender		
		B	P	95% CI	B	P	95% CI
Autumn 1999	Obesity by WC	0.003	0.001*	0.002–0.011	0.007	0.002*	0.002–0.011
	Obesity by WHtR	0.619	0.000*	0.556–0.683	0.617	0.000*	0.554–0.681
	Obesity by WHR	0.005	0.049*	0.000–0.010	-0.003	0.000*	-0.004– -0.002
	High DBP	0.006	0.019*	-0.001–0.012	0.006	0.020*	0.001–0.011
	High SBP	0.007	0.046*	0.000–0.014	0.007	0.050*	0.000–0014
	Hypertension	0.003	0.290	-0.002–0.008	0.003	0.306	-0.0023–0.008
Autumn 2000	Obesity by WC	0.012	0.000*	0.006–0.018	0.012	0.000*	0.006–0.020
	Obesity by WHtR	-0.001	0.936	-0.027–0.025	-0.002	0.884	-0.028–0.024
	Obesity by WHR	0.003	0.098	0.000–0.006	0.001	0.435	-0.002–0.004
	High DBP	0.000	0.971	-0.005–0.005	0.000	0.981	-0.005–0.005
	High SBP	0.000	0.097	-0.004–0.005	0.000	0.988	-0.005–0.005
	Hypertension	-0.001	0.947	-0.028–0.026	-0.002	0.904	-0.029–0.026
Autumn 2001	Obesity by WC	0.001	0.640	-0.006–0.009	0.003	0.525	-0.005–0.011
	Obesity by WHtR	0.011	0.499	-0.207–0.042	0.011	0.499	-0.207–0.424
	Obesity by WHR	0.000	0.947	- 0.0003–0.0003	0.0002	0.852	-0.002–0.002
	High DBP	0.008	0.009*	0.002–0.131	0.008	0.008*	0.002–0.013
	High SBP	0.003	0.081	0.000–0.006	0.003	0.087	0.000–0.006
	Hypertension	0.013	0.006*	0.004–0.023	0.013	0.008*	0.003–0.023
Autumn 2003	Obesity by WC	0.017	0.080	-0.002–0.035	0.003	0.550	-0.008–0.015
	Obesity by WHtR	-	-	-	-	-	-

	Obesity by WHR	0.000	0.570	-0.001–0.002	0.006	0.142	-0.002–0.013
	High DBP	0.000	0.898	-0.004–0.004	0.000	0.976	-0.004–0.004
	High SBP	0.036	0.001*	0.016–0.057	0.033	0.001*	0.014–0.054
	Hypertension	0.003	0.384	-0.004–0.013	0.003	0.329	-0.005–0.013

WC-waist circumference, WHtR-waist-to-height ratio, WHR-waist-to-hip ratio, DBP-Diastolic blood pressure, SBP-systolic blood pressure, -collinearity, *P≤0.05

4. Discussion

This study was aimed at investigating whether there is an association between autumn and spring obesity and BP variables, and whether there is a risk associated with the development of obesity and BP between autumn and spring variables among the Ellisras population aged 4–18 over time. The results of the study showed a significantly (P≤0.05) higher WC among boys compared to girls in spring 2000–2003. These results are similar to those reported in literature whereby mean WC was significantly higher among boys compared to girls in spring [25]. The results of the study did not show any seasonal trends in WC from 1999–2003. Similarly, a longitudinal study among adults in the Netherlands did not show a constant trend in WC from 1993 to 1997 in spring and autumn [26].

Mean WHtR was significantly higher among boys compared to girls aged 8–11 years in autumn 2003. These results are similar to those reported on literature [27]. Furthermore, the prevalence of obesity by WHtR was not evident among boys and girls 8–11 in spring from 1999–2003 which contradicts the results reported on literature whereby an overall prevalence of obesity of 21.8% among children and adolescents in China was reported [27]. However, the study was cross sectional in nature and not seasonal.

Obesity by WHR was significantly (P≤0.001) higher among girls compared to boys above 12 years in spring of 2000. These results agree with those reported on literature, where a higher WHR was reported among girls in spring and summer compared to autumn and winter [12]. These results may be due to less level of testosterone among girls compared to boys since an inverse relationship between testosterone and WHR was reported [28]. Furthermore, girls were reported to show a higher testosterone in autumn as compared to spring [12]. Therefore, the seasonal gender differences in WHR may be explained by the seasonal differences in testosterone by gender.

It is important to investigate obesity indices and BP variables together. This is because an association between BP and WC, WHR, and WHtR was reported [27,29]. The association between obesity and BP is mostly because obesity leads to metabolic changes such as increased low-high-density lipoprotein, cholesterol levels, insulin resistance, and hypertriglyceridemia which in turn increases BP [29].

In this study, mean DBP was significantly higher among girls compared to boys 4–7 years in spring 2001 with mean SBP also significantly higher among girls compared to boys aged 4–7 years in spring 1999. This result contradicts those reported on literature where DBP was significantly higher among boys 11 and 17 years compared to girls of same age, and SBP significantly higher among boys aged 12, 16 and 17 years old compared to girls [30]. The differences in these studies may be due to differences in geographical location where these studies were conducted since their study was conducted in Colombia while this study was conducted in South Africa. Furthermore, the age differences in these two studies may be a contributing factor to the differences observed in both SBP and DBP. Furthermore, their study did not investigate the gender differences in blood pressure seasonally.

High SBP was significantly ($P \leq 0.05$) higher among girls compared to boys 8–11 years in spring from 1999–2003. High DBP was significantly ($P \leq 0.05$) higher among girls compared to boys 4–7 years in spring from 1999–2001. The prevalence of hypertension was higher among girls compared to boys 4–7 in autumn from 1999–2000. The results on high SBP and DBP, and hypertension are similar to those reported among Seychelles girls and boys from 2002–2004 [31]. Their study reported a higher elevated SBP, DBP and BP among girls compared boys of mean age 9.1 for SBP and mean age 5.4 for DBP and elevated BP.

Blood pressure was mostly higher in spring as compared to autumn from 1999–2001. The higher BP in spring compared to autumn may be due to seasonal variation in physical activity since a lower physical activity was reported in spring than autumn [32]. Lower physical activity has been associated with a high BP and risk for hypertension [33]. Therefore, the lower prevalence of BP in autumn may be due to an increased level of physical activity in autumn as compared to spring. Physical activity decreases cardiovascular risk factors such as reduced platelets activity, decreased BMI, improved glucose tolerance, and decreased risk of other comorbid diseases such as Type 2 diabetes mellitus [34]. Furthermore, it was suggested that physical activity decreases vascular resistance through the sympathetic nervous system and renin–angiotensin system [35]. Moreover, physical activity is said to improve endothelial function which then results in a positive impact on BP [34].

The results of the study showed that all obesity indices and BP measurements in autumn 1999 were significantly ($P \leq 0.05$) associated with subsequent spring (1999–2003) measurements when adjusted for age and gender. The results on the risk associated with the development of both obesity and blood pressure showed similar results. Furthermore, less association was observed on the variables from autumn 2000 when tested against all spring measurements. A preliminary cross-sectional study in the ELS reported a significant negative association between skinfolds ratios and seasons (autumn and spring) [15]. Furthermore, one study reported that the odds (OR 1.28, 95% CI 1.27–1.31, P<0.001) for the development of obesity increased by 30% each year from 1999–2004 among Chilean children [36]. Furthermore, they reported that the odds of obesity were significantly greater in November (spring) than March (autumn).

Most of the studies that tracked the development of obesity and BP reported that childhood obesity and BP are associated with adulthood obesity and BP [37-40]. Furthermore, longitudinal and cross-sectional studies reported an association between seasons and BP [41-43]. However, these studies only investigated the association between each season and blood pressure. They did not investigate how the development of blood pressure in one season may be associated with another season as accomplished in this study. Only a cross-sectional study investigated a similar seasonal association as in this study using BP z scores [44]. Studies that reported findings on seasonal variation in obesity only reported the prevalence in different seasons [12,26,42,44]. However, these studies did not investigate the longitudinal association between obesity and seasons.

This study was done in the presence of certain limitations such as the fact that the attrition rate resulted in a decrease in the number of participants every year, leading to a different number of participants yearly. Seasonal variation in environmental factors and lifestyle factors that are associated with obesity and BP were not investigated in this study, therefore the reasons that might have resulted in seasonal variation in the study variables are given based on existing literature. However, the study managed to show the seasonal variation in blood pressure and obesity variables over time which will add more information to the existing body of literature on seasonal variation in BP and obesity variables over time since literature in longitudinal studies is scanty.

5. Conclusions

Seasonal variation in obesity and BP variables was observed in the study. Seasonal gender differences in obesity indices and BP were also observed in this study, and they differ by age group. The longitudinal analyses also showed an association between autumn and spring obesity and BP variable over time. The development of obesity and blood pressure is associated with seasonal, and the development of obesity and BP in autumn may lead in the development of obesity and BP in spring and this relationship may be maintained overtime.

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