How accurate and optimistic are hypertension risk perceptions in Sri Lanka?

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Word count: 8,755

Place and date: Rotterdam 20/06/2024

Abstract

Prevalence of non-communicable diseases such as hypertension is increasing in recent years, with inaccurate and optimistic perceptions of hypertension risks possibly contributing to undertreatment of the disease. I investigate the accuracy and optimism of hypertension risk perceptions among individuals between the ages of 40 and 70 in Sri Lanka. Using a nationally representative sample, I evaluate differences between respondents' subjective risks and their objective risks based on statistical associations between hypertension and risk factors (absolute bias), while also investigating respondents' comparative optimism relative to their peers (relative bias). There is no correlation between individuals' subjective and objective risks, indicating poor abilities to include risk factors incorporated in the objective risk measure to estimate their subjective risks. When controlling for age, this correlation increases somewhat but the magnitude remains moderate. Additionally, older individuals significantly underestimate hypertension risk in comparison to their younger counterparts with 0.9 pp per year. I find no absolute optimistic risk perceptions but largely inaccurate perceptions of hypertension risk overall: the sample would have been more accurate if all reported the mean objective risk. Individuals with undiagnosed hypertension do display a substantial absolute optimistic risk perception of 44.5%, while also being more inaccurate than individuals without hypertension. This study also finds a relative optimistic bias of 11.9%, driven by individuals without hypertension overestimating the risk of their peers rather than underestimating theirs. Finally, I discover no association between optimistic hypertension perceptions and risky health behaviours.

Table of contents

“Perception is like painting a scenery - no matter how beautifully you paint, it will still be a painting of the scenery, not the scenery itself.” (Naskar, 2017)

Introduction

Inaccurate perceptions of health risks could lead to undesirable outcomes through health behaviours. They may also distort other life decisions concerning saving, health insurance or retirement. Underestimating health risks might result in excessive risky or unhealthy behaviour, while overestimation might lead to foregoing preferred activities or behaviour.

Health risk perceptions are accurate when they differ relatively little from the respective objective risks that are predicted from statistical associations between a health outcome, e.g. becoming hypertensive, and known risk factors of that outcome. Health risk perceptions are optimistic when they systematically underestimate the objective risk. Accuracy of risk perceptions tells us how well people can predict their risk, while optimism gives us insight about the direction of the inaccuracy. If the perceptions are optimistic, this might be driving risky behaviour.

High blood pressure is the leading contributor to cardiovascular diseases (CVDs) (Fuchs & Whelton, 2020; Lozano et al., 2012). Over 1.2 billion people suffer from hypertension (WHO, 2023), with the majority in low- and middle-income countries (LMICs). One of those LMICs is Sri Lanka, where approximately one third of the adult population suffers from hypertension (Rannan-Eliya et al., 2022). Currently, CVDs are the primary cause of mortality worldwide claiming over 17.9 million lives every year, nearly twice the amount of cancer deaths (WHO, 2019). These numbers are on the rise: annual deaths caused by non-communicable diseases (NCDs) such as CVDs increased by 8 million from 1990 to 2010, while deaths from communicable diseases decreased by just over 2.7 million in the same timespan (Lozano et al., 2012). This shift is mostly driven by LMICs, where NCDs accounted for 74.7% of total deaths in 2019, relative to 56.8% in 1990 (Peng et al., 2023).

Hypertension, when left untreated, is thus one of the main causes of rising NCD deaths globally. High blood pressure can be managed with medication and healthy lifestyle choices, minimizing the risk of CVDs (American Medical Association, 2024; WHO, 2023). However, almost half of the individuals with hypertension are unaware of their condition, resulting in a significant undertreatment of the disease (Bharucha & Kuruvilla, 2003; Guessous et al., 2012; Mohanty et al., 2021; WHO, 2023). One factor that may contribute to the undertreatment of hypertension is risk perception. People are generally poor in estimating risks, including health risks (Azahar et al., 2017; Caruso et al., 2009; d’Uva et al., 2020).

Estimating hypertension risks specifically is particularly difficult due to the asymptotic nature of the disease (WHO, 2023). Most people tend to have optimistic health risk perceptions: "It will not happen to me" (Caponecchia, 2010; Sharot, 2011). These optimistic biases in health risk perceptions are linked to inadequate preventive measures and delayed medical care seeking (Arni et al., 2021; Ferrer & Klein, 2015; Jones, 1990; Peterson & De Avila, 1995).

Prior research on health risk perceptions has focused on longevity expectations (d'Uva et al., 2020) and risky health behaviours (Arni et al., 2021), mainly focussed on Western high-income countries. These studies found largely inaccurate longevity expectations and associations between optimistic health perception biases and risky health behaviours. Nevertheless, studies have shown differences in risk perceptions between Western and Eastern populations attributable to cultural differences (Guo et al., 2022; Kim & Lwin, 2016; Bontempo et al., 1997; Macaden & Clarke, 2006).

Empirical studies have also identified associations between untreated or undiagnosed hypertension and factors such as sex, age, number of General Practitioner (GP) visits, body weight, and absence of familial hypertension (Chau et al., 2018; Appleton et al., 2012). Additionally, Azahar et al. (2017) found that Malaysian individuals unaware of their hypertension status underestimated their CVD risks.

To the best of my knowledge, hypertension risk perceptions in LMIC's and differences between individuals with undiagnosed and no hypertension, have not been researched. Sri Lanka is a LMIC that is changing rapidly: inhabitants are getting older, urbanisation is increasing, and active lifestyles are shifting to sedentary lifestyles. These factors are usually associated with increased hypertension risk (Rannan-Eliya et al., 2022), making the country an ideal context for this study. It is reasonable to speculate that hypertension risk misperceptions contribute to the undertreatment of high blood pressure and subsequently the rising share of NCDs in LMICs and worldwide. This research therefore investigates the question: "How accurate and optimistic are hypertension risk perceptions in Sri Lanka?", with the most important sub-question: "How do hypertension risk perceptions differ between individuals with and without undiagnosed hypertension?".

Understanding hypertension risk perceptions in Sri Lanka could help policy makers address a cause of inadequate preventive measures and undertreatment in LMICs. If individuals with undiagnosed hypertension have more inaccurate and optimistic risk perceptions, this might drive undertreatment. Policy makers could respond by better informing the public about hypertension risks and prevention methods. Another potential policy following this research is investments in frequent screening for high blood pressure in LMICs to increase the detection and treatment of hypertension and other CVDs. (Sheridan et al., 2003).

First, I provide a theoretical background explaining the state of hypertension in Sri Lanka, define concepts of accuracy and health perception biases, distinguishing between absolute and relative perception biases, reflect on evidence of heterogeneity in accuracy and expand on the relationship between optimism bias and health behaviours. Next, I discuss the sample collection, variables used, and methods applied for the statistical analysis, followed by the presentation of results. Finally, I summarize the findings, discuss limitations, and offer conclusions and recommendations for future research.

Background

Hypertension

Traditionally, hypertension is defined as having a Systolic Blood Pressure (SBP) of 140 mm Hg or higher and a Diastolic Blood Pressure (SBP) of 90 mm Hg or higher (WHO, 2023). In 2017 the American College of Cardiology (ACC) and the American Heart Association (AHA) updated this threshold to 130 and 80 mm Hg the SBP and DBP, respectively (Wu et al., 2022). According to the traditional guidelines, approximately one-third of Sri Lankans are hypertensive, while the ACC/AHA guideline nearly doubles this figure (Rannan-Eliya et al., 2022). Of those being hypertensive according to traditional guidelines, more than half are not diagnosed, while this is over 70% for the recent guidelines (Rannan-Eliya et al., 2022). Rannan-Eliya et al. (2022) also found higher prevalences of hypertension among individuals who were older, obese, living in urban areas, of lower socio-economic status and of Muslim ethnicity. This is in line with the WHO (2023) report that lists several factors contributing to an increased risk of developing hypertension such as age, genetics, infrequent exercise, high-salt diets, overweight and excessive consumption of alcohol. Prevention and treatment of hypertension are thus also centred around bettering lifestyle behaviours, sometimes accompanied by medication (WHO, 2023).

Hypertension risk perceptions

We can define accuracy of hypertension risk perceptions as a small, or even no, difference between individuals' subjective and objective hypertension risk. The objective risk of hypertension represents the actual (estimated) risk of developing hypertension, whereas the subjective risk reflects an individual's perceived risk of developing the condition (Arni et al., 2021). Put simply, this means that people can correctly estimate their health risk. The objective risk of hypertension is generally calculated using risk factors that are associated with high blood pressure like age, gender and Body-Mass-Index (BMI) (Parikh et al., 2008; Sathish et al., 2015). Nonetheless, it is possible that individuals have private information not incorporated in objective risk calculations to estimate their subjective risk, causing them to be more accurate than this risk score would suggest. It should therefore be noted that the current definition of accuracy might not fully represent the real-world case but does provide a meaningful overview based on relevant characteristics.

Under- or overestimation of health risks is referred to as health perception bias (Arni et al., 2021). There are two types of perception biases: absolute and relative perception bias (Arni et al., 2021). Absolute perception bias represents the difference between the subjective (perceived) and objective (real) risk, where overestimation can be described as pessimistic bias and underestimation as optimistic bias. The causes of optimistic biases are not within the scope of this study but have been associated with personal motivation through positive thinking (Benabou & Tirole, 2002) and social image adherence (Burks et al., 2010; Charness et al., 2017; Goette et al., 2015).

Where absolute perception bias represents the discrepancies within individuals, relative perception bias represents how the discrepancies relate to others (Arni et al., 2021). Arni et. Al (2021) defined relative risk perception as the difference between the ranking of the subjective and objective risk of an individual within a certain sample. For example, imagine a sample of 100 individuals where one individual ranks 20th in subjective health risk but 10th in objective health risk (with rank 1 being the highest risk), then this person would be optimistically biased by 10 ranks.

Another way to define relative bias is as the difference between an individuals' subjective risk and the estimated risk for an average person of the same age and gender (Peterson et al., 2011; Williams & Clarke, 1997). Within psychology, this phenomenon is referred to as the 'better-than-average' effect (Zell et al., 2020). It could be, for example, that individuals have accurate perceptions of the risk of developing hypertension for their peers, but they (incorrectly) perceive them to be healthier than the average person. Empirical foundation for this theory, however, is scarce. Conversely, Rothman et al. (1996) found that relative optimistic biases are driven more by overestimating risks of the average person, rather than underestimating one's own risk. Similar results were found by Kim et al. (2017), who concluded that the better-than-average-effect is mainly driven by individuals perceiving average as below-median when estimating abilities (rather than risks).

Naturally, a portion of a population can be healthier than average, but the prevalence of such a belief among the majority fosters an overarching optimism bias (Weinstein, 1982). I examine this by answering the sub-question: "Do individuals perceive themself to be healthier than the average person their age and gender?". It is important to note that this research uses the latter definition of relative risk perception bias in the analysis.

Heterogeneity and health behaviours

Differences between subjective and objective risk perceptions have found to be heterogeneous with regard to education, with the least educated individuals being less able to accurately estimate their chances of survival (d'Uva et al., 2020). Additionally, d'Uva and O'Donnell (2022) found larger inaccuracies among females and the least educated, indicating demographic variability in probability judgments. Risk perceptions also vary among different age groups (Bonem et al., 2015; De Bruin, 2020; Heckhausen et al., 1989) and socio-economic status (SES) (Lee et al., 2008; Reed-Thryselius et al., 2022). Older individuals are more likely to overestimate risks, while those from lower SES groups are more likely to underestimate them.

Hence, it is reasonable to hypothesize that the accuracy of hypertension risk perceptions varies across demographic characteristics, with some groups processing objective risk information more efficiently, resulting in more accurate predictions. I will investigate this heterogeneity by answering the sub-question: "Is the association between the objective and subjective risk heterogeneous for age, gender, education, SES and residential area?".

Optimistic perception biases can affect health behaviours (Arni et al., 2021; De Bruin & Bennett, 2020; Ferrer & Klein, 2015; Strecher et al., 1995; Weinstein et al., 2005). Some studies show that smokers tend to underestimate the health risks relating to smoking and often believe they can mitigate smoking effects by exercising (Strecher et al., 1995; Weinstein et al., 2005). More recently, Arni et al. (2021) found that people who underestimate their health risks are more likely to sleep and exercise less, while they are more likely to consume more alcohol and unhealthy food. On top of that, individuals incorrectly perceived themselves as healthy enough to engage in unhealthy behaviours. The opposite pattern regarding risk perception and health behaviour was apparent during the Covid-pandemic, where people with higher perceived Covid-19 risks were more likely to take preventive measures such as social distancing or wearing face masks (De Bruin & Bennett, 2020). Finally, an extensive literature review by Ferrer and Klein (2015) went as far to conclude that health risk perceptions are crucial determinant of health.

Thus, existing empirical literature provides evidence to believe that hypertension perception bias could be associated with health behaviours in Sri Lanka. Therefore, I investigate the sub-question: "How is hypertension risk perception associated with (risky) health behaviours?". Based on the current literature, I expect that optimistic health perception bias is associated with more risky behaviour, while the opposite is expected for pessimistic health perception bias

Gaps in the current literature

My research fits in well with existing literature with respect to accuracy, optimism biases and heterogeneity of health risk perceptions in general, as well as the association with health behaviour. However, studies evaluating health risk perceptions in LMICs are scarce, while studies investigating hypertension risk perceptions are non-existent. My study could therefore bridge the gap in knowledge between health- and hypertension risk perceptions, contributing one possible cause to the rise of untreated hypertension in LMICs.

Research methods

Data

For this quantitative research, I used data from Sri Lanka Health and Aging Survey (SLHAS). This is a questionnaire-based survey that centres around chronic disease, healthcare use, financial protection and disability in Sri Lanka (Sri Lanka Health And Ageing Survey, 2020). The researchers selected a nationally representative sample based on gender, SES and geographical distribution using stratification and clustered probability sampling (Rannan-Eliya et al., 2024). Recruitment teams visited the sampled households encouraging participation and explaining the study details. Of the households that agreed to participate, one adult member was randomly selected using weighted probabilities to ensure an equal distribution of respondents by sex and age (Rannan-Eliya et al., 2024) Out of the 10,689 sampled households, 10,062 agreed to participate, of which 6,627 respondents attended a field clinic, resulting in a response rate of 65%. Overall, the sample is nationally representative based on gender, SES and geographical distribution. By design, older individuals were overrepresented, while Muslims were under-represented.

The section concerning subjective hypertension risk perception was administered to two random sub-samples with ages over 40 during the initial wave in 2018/2019. One subgroup was prompted to assess their subjective risk of developing hypertension within the next decade using a numerical scale, while the other utilized a categorical scale for their assessments.

Since this analysis is focussed on the risk of getting hypertension in the future, individuals with diagnosed hypertension and people over the age of 70 are excluded. The upper age limit is imposed because elderly people might think they will not live another 10 years and so their answers to the hypertension risk perception question may be confounded by their longevity expectations. It is important to stress that only individuals with diagnosed hypertension are excluded but not all individuals with measured high blood pressure at the time of the survey interview. Undiagnosed hypertension is prevalent in Sri Lanka (Rannan-Eliya et al., 2022) and elsewhere (Mohanty et al., 2021; Zhou et al., 2017). These exclusions limit the whole sample to 4,138 observations and the sub-sample with numerical risk perceptions to 445 observations and the sub-sample with categorical risk perceptions to 573.

Variables

Respondents were asked about their subjective risk of developing hypertension within the next 10 years using two methods: numerical probability and categorical assessment. The numerical probability was rated on a scale from 0 to 100 in response to the question "How likely are you to develop hypertension within the next 10 years?", this is the variable $Subjective\, risk_i$. Categorical assessment included five options which ranged from 'none, very low' to 'very high'. It should be noted that this study primarily focusses on the numerical scale. Nevertheless, since individuals may struggle with accurately estimating numerical risks, the categorical assessment will be used as a secondary analysis. Additionally, respondents estimated the risk of developing hypertension within the next 10 years for the average individual of their age and gender, which is henceforth referred to as 'benchmark risk'.

The objective risk of hypertension is calculated using a standardised equation based on associations between hypertension and risk factors from cohorts of the Framingham Heart Study (FHS), first derived in Parikh et al. (2008). The FHS started in the US in 1948 with examinations focussed on cardiovascular disease and continued with recurring examinations of their offspring from 1971 onwards (Kannel et al., 1979). Sathish et al. (2015) provides a risk score based on an Indian population using age, current smoking, blood pressure and waist circumference as determinants for the objective hypertension risk. However, this risk score is crude and less sensitive to detect change because it has only three possible outcomes for the objective risk: 3.6%, 22.4% and 53,2% (Sathish et al., 2015). This makes the Parikh et al. (2008) risk score a more reliable predictor for this research. Nonetheless, I apply the Sathish et al. (2015) risk score as a robustness test in the discussion and conclusion section.

The variables needed to calculate the objective risk of hypertension are Body Mass Index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), presence of hypertension within parental lineage, age (years), sex (Female = 1 if female) and whether the respondent is currently smoking. BMI is an indicator of body fat and is measured by dividing weight by the squared height (in meters) (*Calculate Your BMI - Standard BMI Calculator*, z.d.). Height, weight and blood pressure of the respondents were all measured in the first wave of 2018/2019. SBP and DBP were measured twice and the mean of the two measurements was reported as the final metric of blood pressure. BMI is measured in kg/m^2, while SBP and DBP are reported in mmHg. The hypertension history of respondents' parents can take up the values 0,1 or 2 for the number of parents that have been diagnosed with hypertension (Parental). Finally, the smoking variable is a dummy that is 1 when the respondent currently smokes every day (Smoking). With these input variables, the following objective hypertension risk for individual i is constructed (Parikh et al., 2008):

$$Objective\,risk_i \;=\; 1 - \;\exp\left(-\exp\left(\frac{(\ln(X) - Y_i)}{0.8769}\right)\right)$$

where X stands for the number of years (in this case 10) over which the risk of becoming hypertensive is predicted and Y_i is constructed with the equation:

$$Y_i \;=\; 22.9495 \;-\; 0.1564 \cdot Age_i \;-\; 0.2029 \cdot Female_i \;-\; 0.0593 \cdot SBP_i \;-0.1285 \cdot DBP_i \;-0.1907 \cdot Smoking_i \;-\; 0.1661 \cdot Parental_i \;-\; 0.0339 \cdot BMI_i \;+\; 0.001624 \cdot (Age_i \;\times DBP_i)$$

With the subjective and objective hypertension risk I create a new measure called 'Absolute bias' for sample size n :

$$Absolute\ bias = \frac{1}{n}\sum_{i=1}^{n} Subjective\ risk_i \;- Objective\,risk_i$$

Where a negative value would indicate an absolute optimistic bias and a positive value a pessimistic bias. This absolute bias, however, might not be informative about the accuracy of hypertension risk perceptions in the sample: positive and negative biases could cancel each other out while calculating the mean. Consider the extreme case in which half of the sample has a pessimistic bias of 100%, while the other half has an optimistic bias of 100%. In this case, the overall bias of the sample would be 0, while in fact the sample could not be more inaccurate. I account for this discrepancy with the accuracy variable, which functions as a Mean Squared Error (MSE) of the perceived hypertension risk, similar to the design used by D'Uva et al. (2020). To achieve complete accuracy for the sample, the accuracy score would be 0. Accuracy is calculated as follows:

$$Accuracy = \frac{1}{n}\sum_{i=1}^{n}(Subjective\, risk_i - Objective\ \ risk_i)^2$$

To further assess the accuracy of hypertension risk perceptions in this sample, I calculate a skill score based on the method developed by Nash and Sutcliffe (1970). This approach was also employed by D'Uva et al. (2020) to assess the accuracy of longevity expectations. This skill score is derived as follows:

$$Skill\, score = 1 - \frac{Accuracy}{\sigma^2}$$

Where σ^2 indicates the variance of the objective risk. If the skill score is 1, it indicates that the subjective risk is equal to the objective risk for all individuals. A skill score of 0 means that all individuals report the mean of the objective risk as their subjective risk. This results in no absolute bias, but it indicates that the objective risk information is not used at the individual level. Values between 0 and 1 are acceptable, suggesting that individuals use relevant information to estimate their subjective risk. Scores below 0 imply worse performance than if all individuals reported the mean objective risk. By incorporating the skill score into the analysis, I can account for the difficulty of estimation: the higher the variance of the objective risk, the more challenging it is to accurately estimate the risk.

Additionally, to look at relative optimism bias, I created a variable called 'Relative bias':

$$Relative\ bias = \frac{1}{n}\sum_{i=1}^{n} Subjective\ \ risk_i - Benchmark\, risk_i$$

Naturally, it can be true for part of the sample to have a lower risk of developing hypertension than the average person their age, but a negative relative bias value for the whole sample indicates an overarching optimism bias.

Furthermore, for heterogeneity analysis I distinguished between individuals by socioeconomic status (SES), physical exercise and the aforementioned variable smoking. SES is proxied using Principal-Component Analysis (PCA) of household assets such as house materials, sanitation and water supply (Rannan-Eliya et al., 2024; Filmer & Pritchett, 2001). Physical exercise in the number of Metabolic Equivalent of Task (MET) minutes per week. MET minutes per week is a measure of physical activity intensity and duration, calculated by multiplying the MET value of an activity by the minutes performed per week (Ainsworth et al., 2011). This MET value was derived from questions about activity at work or leisure activities, such as: "In a typical week, on how many days do you do vigorous-intensity activities as a part of your work?" and "In a typical week, on how many days do you do vigorous-intensity sports, fitness or recreational (leisure) activities?". I transform this measure to a logarithmic measure to enhance the interpretability.

Finally, I include education and residential sector as control variables. In Sri Lanka, primary education spans grades 1 to 5, while secondary education covers grades 6 to 13 (Primary and Secondary Education - Sri Lanka, Nuffic, n.d.). Students undertake national Ordinary-level (O-level) examinations after grade 11, and Advanced-level (A-level) examinations after grade 13, which qualify them for higher education (Primary and Secondary Education - Sri Lanka, Nuffic, n.d.). The residential sector variable differentiates between rural and urban areas, as well as individuals living on estates, which can exist in both rural and urban settings.

Statistical analysis

The data analysis for the assessment on hypertension risk perceptions consists of several parts. Firstly, I present a calibration plot between the subjective and objective risk of developing hypertension as a graphical representation of the relationship between the two. Additionally, this informs us about the accuracy of hypertension risk perceptions of the sample: a relationship along the 45-degree line indicates a perfect one on one relationship between subjective and objective risk of developing hypertension, which would mean that individuals in the sample can accurately estimate their risk. Deviations from this line therefore indicate more inaccurate estimates.

Secondly, I regress the subjective risk on the objective risk of hypertension to see whether there is an association between the two. A statistically significant and strong association could imply that individuals, to some extent, are able to use the information captured in the objective risk measure to estimate their risk of developing hypertension. Potential covariates age, education, sector, SES, smoking and gender will also be included and interacted with the objective risk to assess whether these variables have any impact on the association between the objective and subjective risk of developing hypertension.

$$Subjective\,risk_i = \alpha + \beta \cdot Objective\,risk_i + \varphi \cdot Z_i + \theta \cdot (Objective\,risk_i \cdot Z_i) + \epsilon_i$$

With constant α, error term ϵ_i and Z_i is a vector of the covariates mentioned above. I regress three different models: one with only the objective risk as independent variable, one with the covariates included and the full model as described above. A positive and significant value for φ (e.g., education) would suggest that, on average, individuals with higher levels of education tend to perceive their risk of developing hypertension as higher than those with lower levels of education, while keeping the objective risk and other covariates zero. On top of that, a positive and statistically significant estimate for would indicate that the perception of risk is also more sensitive to variations in the objective risk among higher educated individuals compared to their lower educated counterparts.

To test whether there is an absolute bias, I make use of a t-test to test whether this mean is statistically different from 0. A positive value would mean an overall pessimism bias, while a negative value implies an absolute optimism bias of the whole sample. The same statistical analysis applies to the accuracy and skill score variables. As described above, a deviation from 0 for the accuracy variable would mean at least some inaccuracy of risk perceptions. A skill score between 0 and 1 would be an acceptable prediction, whereas a value below 0 would be a worse performance than every individual reporting the mean objective risk.

The relative bias will also be tested with a t-test to test whether this significantly differs from 0. If both the absolute and relative biases are negative and significantly different from 0, this would indicate that at least part of the optimistic bias of developing hypertension is due to individuals believing themselves to be healthier than average. (Williams & Clarke, 1997; Peterson et al., 2011). Furthermore, I regress the relative bias on the covariates to assess differences in relative bias between groups:

$$Relative\ bias_i = \alpha + \rho \cdot Z_i + \epsilon_i$$

Where depicts α the constant, Z_i the vector of covariates and ϵ_i the error term.

In addition to evaluating absolute bias, accuracy, and relative bias for the sample as a whole, I assess the differences in these means between individuals with undiagnosed hypertension and those without hypertension using a t-test.

Since individuals might struggle with defining risks in numerical terms, the bias of the sample will also be evaluated using a contingency table constructed with the categorical scale of subjective risk and categorized ranges of objective risk. Given that the categorical subjective risk comprises five categories, I categorized the objective risk into 20% ranges. Individuals with an objective risk between 0 and 20% make up the first category (none, very low), while those with an objective risk between 80 and 100% fall into the last category (very high). Subsequently, a Pearson-Chi squared test is conducted to assess whether a significant association exists between subjective and objective risk categories. I also conduct an ANOVA test to determine if the means of objective risk of developing hypertension differ significantly across the subjective risk categories.

Finally, to evaluate whether (absolute) bias is associated with smoking and physical activity for individual i , I regress the following model:

$$Health\ behaviour_i = \alpha + \gamma \cdot Subjective\ risk_i + \delta \cdot Objective\ risk_i + \gamma \cdot Z_i + \epsilon_i$$

Where α depicts the constant, Z_i the vector of covariates and ϵ_i the error term. The equation above again presents the full model, but I also regress the model without covariates. I regress this model twice: once with smoking as dependent variable and once with physical activity as dependent variable.

This regression informs us about the association between the subjective risk and health behaviours (smoking and physical activity) while keeping objective risk fixed. In other words, for two individuals with the same objective risk how does a higher subjective risk compare with the health behaviours? An increase in subjective risk could either mean greater pessimism (subjective risk > objective risk) or less optimism (subjective risk < objective risk). A positive value for γ suggests that an increase in subjective risk relative to the objective risk on average is associated with an increase in the probability to smoke and the number of MET-minutes/week, while a negative estimate indicates the opposite.

I apply sample weights in all analyses and adjust standard errors and confidence intervals for sample clustering, ensuring they are robust to general heteroskedasticity.

Results

Table 1 presents the descriptive statistics for the entire sample, the numerical risk perceptions sub-sample, and the categorical risk perceptions sub-sample. One notable contrast between the numerical sub-sample and the entire sample lies in the age distribution: individuals in the sub-sample are, on average, 12.4 years older than those in the entire sample. This disparity stems from the sub-sample's narrower age range of 40 to 70, compared to the entire sample, which includes individuals aged 17 to 70. Moreover, undiagnosed hypertension appears to be more prevalent among the sub-sample, suggesting that the elderly may be driving the elevated rate of undiagnosed hypertension. The SES quintiles are based on the whole sample (without exclusions), making some quintiles over- and underrepresented in the numerical- and categorical risks perceptions samples. The weighting does fix some of this, for example lowering the overrepresentation of the first quintile.

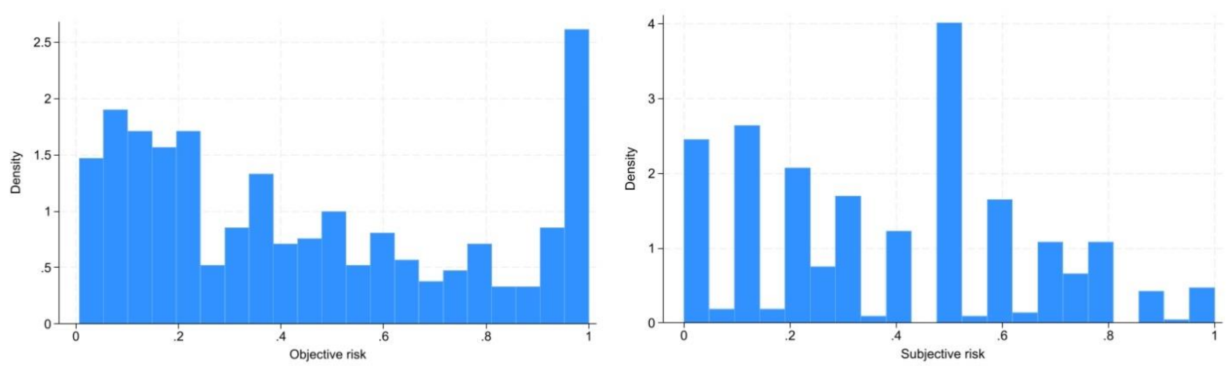
Table 1 Descriptive statistics (numerical risk perceptions sample), N=445

Variables	Entire sample, n= 4,138	Numerical risk perceptions sample, n = 445	Categorical risk perceptions sample, n = 573
Gender			
Male	2,108 (49.2%)	225 (45.5%),	297 (47.0%),
Female	2,030 (50.8%)	220 (54.5%)	276 (53.0%)
Age (years)	38.8 (13.6)	51.2 (7.8)	52.0 (8.2)
Education			
No schooling	114 (2.0%)	20 (3.1%)	12 (1.5%)
Primary education	417 (7.7%)	64 (11.5%)	76 (12.9%)
Secondary education	1,503 (36.1%)	135 (30.3%)	210 (34.9%)
Passed O-Level	1,073 (26.3%)	121 (26.6%)	162 (29.5%)
Passed A-level	839 (23.0%)	84 (20.5%)	91 (18.2%)
Degree or above	185 (5.0%)	21 (5.1%)	19 (3.0%)
Undiagnosed hypertension			
Yes	719 (14.8%)	99 (19.1%)	123 (21.0%)
No	3,419 (85.2%)	346 (80.9%)	450 (79.0%)
Smoker			
Yes	663 (16.1%)	53 (9.5%)	81 (13.5%)
No	3,475 (83.9%)	392 (90.5%)	492 (86.5%)
BMI	23.7 (4.6)	24.3 (3.9)	24.3 (4.2)
SES quintiles			
First	997 (20.1%)	116 (21.8%)	135 (22.6%)
Second	828 (20.0%)	79 (17.0%)	100 (16.0%)
Third	788 (19.8%)	83 (19.3%)	110 (21.1%)
Fourth	753 (20.0%)	89 (23.6%)	106 (19.6%)
Fifth	772 (20.1%)	78 (18.3%)	122 (20.6%)
Sector			
Urban	1,103 (19.2%)	151 (26.3%)	173 (20.2%)
Rural	2,415 (70.2%)	221 (60.7%)	309 (68.9%)
Estate	620 (10.7%)	73 (13.1%)	91 (10.9%)
MET minutes/week	7,450.8 (8,997.7)	8,393.2 (9,018.8)	8067.9 (8,201.5)

Note: The numbers for categorical variables represent the unweighted frequencies, whereas the percentages in parentheses reflect the weighted frequencies. Both the mean and standard deviation of continuous variables were calculated using weighting.

Figure 1 below shows the distribution of the objective (left) and the subjective (right) risk of developing hypertension within the next ten years for this sample. The objective risk has a right-skewed distribution with a large peak around the 1, which mostly represents the individuals with undiagnosed hypertension: out of 56 individuals in the highest bin, 53 have undiagnosed hypertension. The subjective risk also displays a right-skewed distribution but with a peak around the 0.5 risk. This peak could possibly be due to individuals having difficulties with estimating risk and thus believing a 50/50 risk is most likely in this case or because individuals simply have no idea and report 0.5 as their best guess (Bruine de Bruin & Carman, 2012;Fischhoff & De Bruin, 1999). The means of the objective and subjective risk of developing hypertension at first glance might indicate rather accurate risk perceptions, since they barely differ. However, these distributions already show that it is likely that optimistic and pessimistic differences in objective and subjective risks are cancelling each other out.

Figure 1 Distribution objective risk (left, mean= 0.409) and subjective risk (right, mean= 0.397) of hypertension



There appears to be no significant correlation between objective and subjective hypertension risks, both shown in the calibration plot (Figure 2) and the regression (Table 2, Column 1). An increase of the objective risk from 0 to 1 is associated with an increase of the subjective risk of 6.6 percentage points (pp), but this estimate is insignificant on a 10% level. The calibration plot visually presents this relationship, showing a near-horizontal fitted line between the values of objective and subjective risk, with widely scattered points that deviate significantly from the 45-degree line. This indicates that individuals' perceptions of hypertension risk do not align well with objective risk predictions.

However, this association changes when covariates are included in the regression model (Table 2, Column 2). With all covariates fixed, an increase in objective risk from 0 to 1 is now associated with a 15.4 pp increase in subjective risk, which is significant at the 5% level. Despite the substantial improvement, the magnitude remains moderate. It should be noted, however, that the variation in objective risk now only relies on factors other than age, sex and smoking since these variables are fixed. Another notable association is between age and subjective risk: keeping objective risk and other covariates fixed, a one-year increase in age is associated with a 0.9 pp decrease in subjective risk, significant at the 1% level. This indicates that older individuals in this sample underestimate their hypertension risk more than younger individuals.

Additionally, there is a significant association between sector and subjective risk: individuals living in estates underestimate their hypertension risk by 10.5 pp relative to those living in urban areas, ceteris paribus. This association is significant at the 10% level. All other covariates are insignificant at the 10% level, suggesting that these estimates are not statistically different from zero.

The change in magnitude and significance of the objective risk from column 1 to column 2 indicates that age and sector were masking (part of) the relationship between objective and subjective risk. Overall, individuals are somewhat able to use the information captured in the objective risk to estimate their subjective risk, but on average older individuals and individuals living in estates (relative to individuals in rural areas) estimate lower risk using the same information.

A joint F-test on a model with a full set of interaction terms for this regression resulted in a p-value of 0.295. I can thus not reject the null-hypothesis of all interaction terms being zero, indicating no heterogeneity in the association between objective and subjective risks with regard to the covariates. The full model with interaction terms is presented in Table A1 of the appendix.

Figure 2 Calibration plot of subjective on objective risk

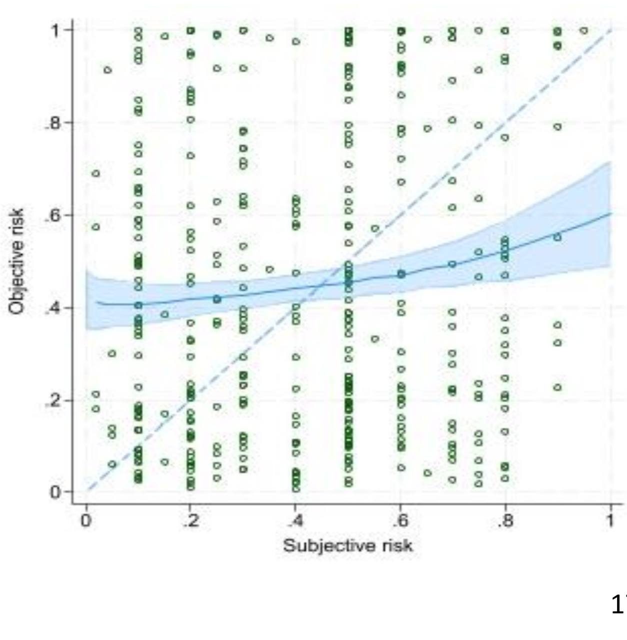


Table 2 Regressions of subjective risk on objective risk and covariates

	(1)	(2)
Objective risk	0.066 (0.072)	0.154** (0.074)
Age		-0.009*** (0.003)
Female		-0.016 (0.036)
Smoker		0.025 (0.059)
SES Quintiles		
Second		-0.017 (0.045)
Third		-0.014 (0.064)
Fourth		-0.086 (0.052)
Fifth		-0.026 (0.063)
Education		
Grade 1-5		0.096 (0.093)
Grade 6-12		0.073 (0.097)
Passed O-level		0.095 (0.102)
Passed A-level		0.058 (0.112)
Degree and above		0.152 (0.128)
Sector		
Rural		-0.004 (0.039)
Estate		-0.105** (0.048)
Constant	0.370*** (0.034)	0.761*** (0.175)

Note: *p <0.1, **p <0.05, ***p <0.01. Standard errors in parentheses and are clustered at the Grama Niladhari Division (GND) level. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness. Education categories are relative to 'No schooling', while Sector categories are relative to 'Urban'.

Panel A of Table 3 shows the overall means of the absolute bias, accuracy and skill score of the sample, including the t-values of testing the statistical differences with zero. Overall, there only seems to be a slight bias of -0.012, meaning that the subjective risk of developing hypertension is on average 0.012 lower than the objective risk (optimistic bias), as already seen in the difference of means in Figure 1. However, the t-test did not yield a statistical difference from zero thus it can not be concluded that there is an absolute optimistic bias for the sample as a whole. However, when dividing the sample in groups of individuals with undiagnosed hypertension and no hypertension, this insignificance changes (Table 3, Panel B). Individuals with undiagnosed hypertension on average underestimate their risk of developing hypertension by 0.445, while those without hypertension overestimate their risk by 0.09. To put this in perspective, the mean objective risk among individuals with undiagnosed hypertension is 0.893, meaning that the average reported risk of developing hypertension for this group was 0.448, around half of their real risk. Both means are statistically different from zero and from each other. Figure A1 in the appendix shows that individuals with undiagnosed hypertension are more represented among older individuals than among younger individuals, which is also in line with the age effect seen in Table 2. In conclusion, the older people get, the more likely they are to develop (undiagnosed) hypertension and the more likely they are to underestimate their risk of hypertension. However, since there is no causal inference, you cannot conclude whether this underestimation is due to age or due to having undiagnosed hypertension.

The second and third columns of Table 3 present the accuracy of risk perceptions. Overall, the sample shows an accuracy of 0.160 and a skill score of –0.684 (Panel A). While interpreting the accuracy variable alone is difficult, a skill score below 0 suggests that individuals in the sample would have been more accurate if they all reported the mean objective risk as estimate. The mean of the skill score is statistically different form 0 on a 1% level. Similar to bias, accuracy varies substantially between the undiagnosed and no hypertension groups (Panel B). The accuracy of individuals without hypertension is significantly closer to zero, indicating higher accuracy compared to individuals with undiagnosed hypertension. Both the skill scores for the undiagnosed hypertension group and the group without hypertension are negative and statistically different from zero. The statistical difference between the skill scores of both groups could not be tested, but the large difference and the 95% confidence intervals provide reasonable evidence that these skill score do significantly differ. Thus, based on the Mean Squared Error (MSE) and skill scores, individuals with undiagnosed hypertension make more inaccurate predictions than those without hypertension.

In summary, the whole sample has inaccurate perceptions of hypertension risks, where individuals with undiagnosed hypertension are more inaccurate than those without hypertension. On top of this, individuals with undiagnosed hypertension show a substantial absolute optimistic bias, while the other group has an absolute pessimistic bias.

Table 3 Means of Absolute bias, Accuracy and Skill score, confidence intervals and statistical differences from zero

Panel A. Overall

	Absolute bias	**95% CI**	**Accuracy**	**95% CI**	**Skill score**	**95% CI**
Overall (N=445)	-0.012	[-0.066;0.042]	0.160***	[0.130;0.191]	-0.684***	[-1.000;-0.367]

Panel B. By hypertension group, including difference from each other

	Absolute bias	**95% CI**	**Accuracy**	**95% CI**	**Skill score**	**95% CI**
Undiagnosed Hypertension (N= 99)	-0.445***	[-0.569;-0.321]	0.288***	[0.168;0.409]	-16.175***	[-23.377; -8.974]
No hypertension (N=346)	0.090***	[0.033;0.147]	0.130***	[0.102;0.158]	-1.873***	[-2.485;-1.261]
Difference	-0.535***	[-0.641;-0.429]	0.158***	[0.078;0.238]	-14.302•	-

Note: *p <0.1, **p <0.05, ***p <0.01. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness. •The difference between the skill score of both groups could not be statistically tested.

Table 4 presents the means of subjective risk, benchmark risk, and relative bias of the sample. Overall, individuals believe that a person of their age and gender has a 0.524 risk of developing hypertension within the next ten years, while they estimate their own risk at 0.405, resulting in an optimistic bias of –0.119. This optimism is statistically significant at the 1% level. However, when dividing this mean into the two groups from the previous segment, only the subgroup without hypertension shows relative bias that is statistically different from zero. For individuals with undiagnosed hypertension, it cannot be concluded that they perceive themselves to be healthier than the average person of their age and gender. This conclusion does hold for the other subgroup, but since their objective risk of developing hypertension is indeed lower than the overall objective risk, their perception can be considered justifiable. Their relative optimism bias thus stems from the fact that they overestimate the average objective risk of developing hypertension of their peers, rather than incorrectly perceiving them to be healthier than average.

Table 4 Means risk perceptions, confidence intervals and statistical differences from zero

	Overall	95% CI	Undiagnosed hypertension	95% CI	No hypertension	95% CI
Subjective Risk	0.405***	[0.375;0.435]	0.460***	[0.323;0.597]	0.392***	[0.358;0.425]
Objective risk	0.413***	[0.370;0.455]	0.890***	[0.861;0.919]	0.296***	[0.255;0.337]
Benchmark risk	0.524***	[0.493;0.556]	0.551***	[0.426;0.676]	0.518***	[0.483;0.552]
Relative bias	-0.119***	[-0.152; -0.086]	-0.091	[-0.217;0.034]	-0.126***	[-0.162;-0.090]
Observations	384		85		299	

Note: *p <0.1, **p <0.05, ***p <0.01. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness.

The regression analysis of relative bias on the covariates (Table 5) yields results that are largely consistent with those in Table 2, except for the sector variable, which is now insignificant. The analysis shows that a one-year increase in age is associated with a 0.9 pp decrease in relative bias, holding other factors constant. This effect is significant at the 1% level. This negative coefficient suggests that older individuals tend to have more relative biases in optimistic directions (or less pessimistic) than younger individuals. For instance, in this sample, a 70-year-old estimates their risk of developing hypertension relative to their peers to be 27 pp (0.9 * 30) lower than that of a 40-year-old, controlling for all other factors. Therefore, age appears to be correlated not only with absolute perception biases but also with relative perception biases. No other covariates were found to be significant at the 10% level.

Table 5 Regression of relative bias on covariates

Age	-0.009*** (0.002)
Female	-0.023 (0.037)
Smoker	0.028 (0.046)
SES Quintiles	
Second	-0.040 (0.041)
Third	0.032 (0.044)
Fourth	-0.044 (0.039)
Fifth	-0.008 (0.037)
Education	
Grade 1-5	-0.058 (0.105)
Grade 6-12	-0.016 (0.094)
Passed O-level	-0.039 (0.101)
Passed A-level	-0.031 (0.100)
Degree and above	0.062 (0.100)
Sector	
Rural	0.049 (0.038)
Estate	0.051 (0.041)
Constant	0.331** (0.134)

Note: *p <0.1, **p <0.05, ***p <0.01. Standard errors in parentheses and are clustered at the Grama Niladhari Division (GND) level. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness. Education categories are relative to 'No schooling', while Sector categories are relative to 'Urban'.

Table 6 presents the contingency table of the categorical subjective and objective risk of developing hypertension as a share of the total sample. The red colour depicts the share of the sample with an optimistic bias, orange the share with a pessimistic bias and green the share that correctly estimated their risk of developing hypertension within the next ten years. In total, 43.1% of the sample is optimistically biased, while 36.3% is pessimistically biased. This is thus in line with the findings in Table 3: both optimistic and pessimistic differences between the subjective and objective risk are present in the sample, resulting in no real overall bias in one direction. Surprisingly, 20.9% of the sample has a very high objective risk of hypertension, while only 0.5% perceive themself to be of very high risk. This discrepancy is again driven by the subgroup with undiagnosed hypertension: 9 out of 10 people in the objective very high-risk category have undiagnosed hypertension.

The Pearson chi-squared test conducted on the contingency table below yielded a p-value of 0.680, indicating a failure to reject the null hypothesis of independence. This suggests that there is no significant association between the categorical variables, resonating with the inaccuracy of hypertension risk perceptions as seen in Table 3.

Table 6 Contingency table categorical risk perceptions

Objective	Subjective					Total
	Very low	Low	Neither high nor low	High	Very high	
Very low	7.4%	15.4%	5.4%	4.4%	0%	32.6%
Low	5.7%	8.3%	4.4%	3.8%	0.5%	22.7%
Neither high nor low	3.2%	5.7%	3.3%	1.9%	0.4%	14.5%
High	1.9%	3.9%	2.3%	1.1%	0.1%	9.2%
Very high	3.9%	6.4%	6.4%	3.7%	0.5%	20.9%
Total	22.1%	39.8%	21.7%	14.9%	1.5%	

Note: Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness.

Table 7 presents the mean objective risk across different categories of subjective risk, along with the results of an ANOVA test for equal means. The p-value of the ANOVA test is significant at the 5% level, leading to the rejection of the null hypothesis that the means are equal across all five categories. The mean objective risk exhibits a somewhat increasing trend as subjective risk categories increase. However, only the mean objective risk of the 'neither high nor low' group significantly differs from those of the 'low' and 'very low' groups. The 'very high' group has too few observations to calculate a 95% confidence interval. These findings align with the limited evidence for an association between subjective and objective risk observed in the calibration plot in Figure 2 and the regression results in Table 2.

Table 7 Mean objective risk by subjective risk categories and ANOVA test for equal means

Subjective risk category	Mean Objective risk	95% CI	P-value
Very low	0.403	[0.325 ; 0.480]	-
Low	0.389	[0.297; 0.482]	-
Neither high nor low	0.514	[0.426; 0.601]	-
High	0.454	[0.268; 0.639]	-
Very high	0.602	-	-
ANOVA test	-	-	0.0268

Note: Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness.

Table 8 shows the regression output of the health behaviours smoking and physical activity on the subjective and objective risk of developing hypertension. Subjective risk, while keeping objective risk fixed, does not seem to be correlated with smoking. This does not change when covariates are included: subjective risk remains insignificant on a 10% level. However, the analysis reveals that females and individuals with higher education (except those with degrees) are less likely to smoke compared to males and those with no schooling, respectively.

Similarly, subjective risk is not significantly correlated with (logarithmic) physical activity in both models, with and without covariates. Education appears to be associated with physical activity, as individuals with Grade 1-6 education, A-level graduates, and those with degrees engage in less MET minutes per week compared to those without schooling. These associations are barely significant at the 10% level.

Thus, it can not be concluded that changes in subjective risk are associated with health behaviours in this sample.

Table 8 Regression output of health behaviours on subjective and objective risk

	Smoker	**Smoker**	**Physical activity**	**Physical activity**
Subjective risk	0.012 (0.066)	0.025 (0.058)	-0.452 (0.700)	-0.348 (0.689)
Objective risk	-0.002 (0.051)	-0.044 (0.055)	0.447 (0.756)	0.594 (0.708)
Age		0.001 (0.002)		-0.014 (0.021)
Female		-0.207***(0.032)		-0.523 (0.332)
SES Quintiles				
Second		0.048 (0.037)		0.361 (0.486)
Third		0.015 (0.034)		-0.185 (0.583)
Fourth		0.071 (0.048)		-0.239 (0.550)
Fifth		-0.008 (0.056)		-0.853 (0.920)
Education				
Grade 1-5		-0.229** (0.112)		-0.677 (0.710)
Grade 6-12		-0.282***(0.103)		-0.962* (0.516)
Passed O-level		-0.359*** (0.103)		-0.774 (0.491)
Passed A-level		-0.335*** (0.101)		-1.212* (0.627)
Degree and above		-0.187 (0.174)		-2.838* (1.699)
Sector				
Rural		0.043 (0.037)		-0.313 (0.595)
Estate		0.073 (0.049)		-0.223 (0.806)
Constant	0.091** (0.038)	0.408***(0.142)	7.752*** (0.428)	10.068*** (1.182)

Note: *p <0.1, **p <0.05, ***p <0.01. Standard errors in parentheses and are clustered at the Grama Niladhari Division (GND) level. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness. Education categories are relative to 'No schooling', while Sector categories are relative to 'Urban'.

Discussion and conclusion

I find no significant absolute bias but inaccurate perceptions of hypertension risks for the sample as a whole. In fact, the sample would have been more accurate if all individuals reported the mean objective risk of developing hypertension as their estimate, indicating that little to no information captured in the objective risk can be used by individuals to estimate their subjective risk. This result is in line with the research of D'Uva et al. (2020) who found more inaccurate longevity predictions than if the whole sample would have reported a 50-50 chance. The association between objective and subjective risk increases when conditioning for age and sector, but the magnitude of this association remains moderate.

When dividing the sample into individuals with undiagnosed hypertension and individuals without hypertension, the first group has a substantial optimistic absolute bias while the latter has a slight pessimistic bias. This result is consistent with the findings of Azahar et al. (2017), who concluded that hypertensive patients unaware of their disease substantially underestimated their risks of CVDs. Additionally, people with undiagnosed hypertension have more inaccurate predictions than those without hypertension.

In terms of relative perception bias, I find that there is an overarching optimism bias in the sample, meaning that the majority of the respondents perceived themselves to have lower risk of developing hypertension than the average person. This is similar to the outcome of Peterson et al. (2011), who found underestimations of hypertensive patients regarding heart attack risks relative to their peers. This optimistic bias, however, is driven by individuals without hypertension overestimating the average objective risk of developing hypertension, rather than falsely perceiving them to be healthier than average, consistent with Kim et al. (2017) and Rothman et al. (1996).

Additionally, differences between subjective and objective risks of developing hypertension are heterogeneous for age, with older individuals underestimating their risks relative to their younger peers. Older individuals also tend to have more relative biases in optimistic directions (or less pessimistic) than younger individuals. This result contrasts the findings of Bonem et al. (2015) , De Bruin (2020) and Heckhausen et al. (1989) who found that older individuals over-estimate (health) risks. One possible explanation could be that hypertension awareness is something of the current day and age, making younger individuals more receptive to the risks. Furthermore, individuals living in estates underestimate their risks relative to people living in urban areas, while other covariates did not yield significant differences.

Finally, I observe no significant associations between the subjective risk and health behaviours (smoking and physical exercise), keeping objective risk fixed. Arni et al. (2021) also did not find a significant association between health perception bias and smoking, arguing that the addictive nature of smoking impairs individuals' ability to properly evaluate its health consequences, supported by the model of Darden (2017). Contrastingly, Arni et al. (2021) did find that individuals with optimistic health perception biases were on average less likely to engage in physical activity. This discrepancy could be due to the high age of my sample: older people are less likely to engage in physical exercise (Elgaddal et al., 2022), which could make it less sensitive to changes in health risk perceptions.

The hypertension risk score used to calculate the objective risk of developing hypertension is based on an American population from the Framingham Heart Study (Parikh et al., 2008). However, the applicability of these risk factors may differ for an Asian population. For example, lower BMI thresholds for indicating overweight should apply for Asian populations compared to Western populations (Wang et al., 1994 ; *Ethnic Differences in BMI And Disease Risk*, 2016). Robustness tests done with the risk score created by Sathish et al. (2015), which was based on an Indian population, are in Appendix Tables A4-A7. This risk score yields similar results in terms of accuracy but finds an overall pessimistic bias of the sample with no statistically significant differences between the undiagnosed- and no hypertension group. However, this score only yields two different objective risk estimations: either 22.4% or 53.2%. Initially, it would have three outcomes but since the whole sample is above the age of 35, nobody classifies for the 3.6% objective risk (Sathish et al., 2015). The choice of the Parikh et al. (2008) risk score is validated by the figures in Table A7, showing it as a superior predictor of hypertension risk compared to the Sathish et al. (2015) score.

The rise of undertreatment and unawareness of hypertension, as discussed in the introduction, is a concerning trend in low- and middle-income countries. This study suggests that the optimistic and inaccurate risk perceptions of individuals with undiagnosed hypertension may contribute to this issue; individuals who perceive themselves to be at low risk are less likely to seek medical attention. Consequently, policymakers in Sri Lanka could invest in national informational campaigns about the dangers of developing hypertension to bridge the gap between subjective and objective risk perceptions. Furthermore, because older individuals tend to substantially underestimate their risk of developing hypertension relative to their younger counterparts, those informational campaigns might be most effective when targeted at the elderly.

Another potential effective policy to decrease the undertreatment of hypertension in Sri Lanka and other LMICs could be regular screening for high-risk individuals of hypertension. Screening of hypertension and CVDs have found to be effective in detecting hypertension and applying treatment to minimize risk of CVDs (Sheridan et al., 2003; Wijemunige et al., 2022). On top of that, hypertension screening of high-risk individuals has already been established to be potentially cost-effective in Sri Lanka (Wijemunige et al., 2022).

The effectiveness of both policy measures might depend on the cause of hypertension risk perceptions: are these misperceptions due to lack of information or simply because people are not able to process the information well enough to make accurate predictions? If the first is the case, then informational campaigns alone might prove to be effective. If the latter is the case, then governments might need more active policies like screening to decrease undertreatment. Future research could thus focus on the causes of hypertension risk perceptions inaccuracies to further validate this study's findings.

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Appendix

Table A1 Regression output of objective on subjective risk including interaction effects

	(1)	(2)
Objective risk	0.0543	0.339
	(0.390)	(0.522)
Age	-0.00992***	-0.00882**
	(0.00366)	(0.00342)
Age*objective risk	0.00253	-0.000491
	(0.00663)	(0.00643)
2.sesquintile	-0.0126	-0.0512
	(0.0456)	(0.0684)
3.sesquintile	-0.0135	-0.0375
	(0.0648)	(0.0914)
4.sesquintile	-0.0794	-0.0870
	(0.0508)	(0.0888)
5.sesquintile	-0.0186	0.00726
	(0.0616)	(0.105)
2.sesquintile*objective risk		0.0631
		(0.153)
3.sesquintile *objective risk		0.0815
		(0.186)
4.sesquintile *objective risk		0.0299
		(0.196)
5.sesquintile *objective risk		-0.0751
		(0.199)
Primary education	0.109	0.145
	(0.0859)	(0.136)
Secondary education	0.0761	0.212
	(0.0909)	(0.161)
Passed O-level	0.0986	0.149
	(0.0970)	(0.174)
Passed A-level	0.0652	0.287
	(0.106)	(0.174)
Degree or above	0.159	0.188
	(0.122)	(0.204)
Primary education *objective risk		0.0416
		(0.333)
Secondary education *objective risk		-0.218

		(0.320)
Passed O-level *objective risk		-0.0186
		(0.335)
Passed A-level *objective risk		-0.430
		(0.363)
Degree or above *objective risk		-0.00957
		(0.370)
Female	-0.0177	-0.0447
	(0.0362)	(0.0629)
Female *objective risk		0.0640
		(0.107)
Smoker	0.0210	-0.0167
	(0.0573)	(0.0840)
Smoker *objective risk		0.115
		(0.175)
Rural	0.0306	0.0684
	(0.0899)	(0.0887)
Estate	-0.156	-0.122
	(0.107)	(0.0904)
Rural *objective risk	-0.0826	-0.110
	(0.176)	(0.176)
Estate *objective risk	0.0965	0.0786
	(0.225)	(0.187)
Constant	0.791***	0.620**
	(0.230)	(0.253)
Observations	445	445

Note: *p <0.1, **p <0.05, ***p <0.01. Standard errors in parentheses and are clustered at the Grama Niladhari Division (GND) level. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness. Education categories are relative to 'No schooling', while Sector categories are relative to 'Urban'.

Figure A1 Distribution age for the whole sample (left) and individuals with undiagnosed hypertension (right)

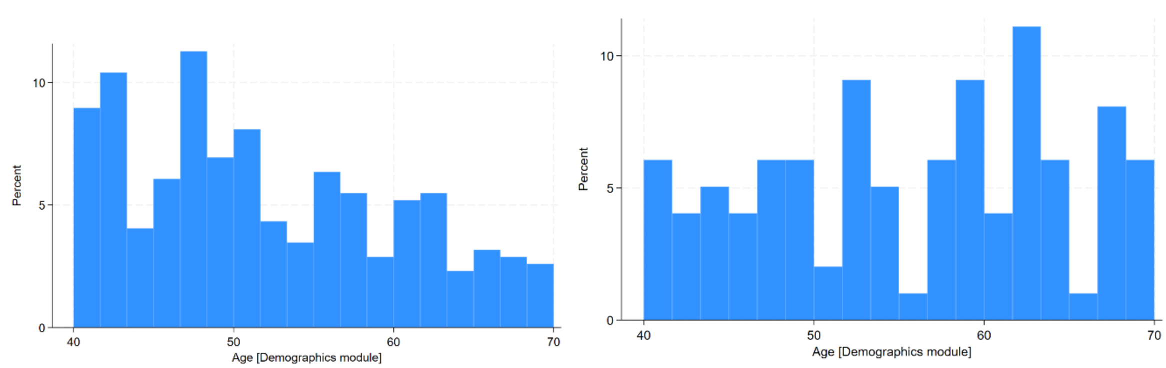

Table A4 Robustness regression output of objective (Satish (2016)) on subjective risk including interaction effects

	(1)	(2)	(3)
Objective risk	0.113 (0.169)	0.108 (0.162)	0.526
			(1.171)
Age		-0.00682*** (0.00218)	0.00177
			(0.00484)
Age*objective risk		0.00253	-0.0245*
		(0.00663)	(0.0141)
2.sesquintile		-0.0126	-0.137
		(0.0456)	(0.109)
3.sesquintile		-0.0135	0.0880
		(0.0648)	(0.147)
4.sesquintile		-0.0794	0.0438
		(0.0508)	(0.137)
5.sesquintile		-0.0186	-0.0634
		(0.0616)	(0.170)
2.sesquintile*objective risk			0.344
			(0.298)
3.sesquintile *objective risk			-0.314
			(0.388)
4.sesquintile *objective risk			-0.346
			(0.366)
5.sesquintile *objective risk			0.0462
			(0.426)
Primary education		0.0756	-0.282
		(0.107)	(0.355)

Secondary education	0.0604	-0.317
	(0.109)	(0.336)
Passed O-level	0.0895	-0.424
	(0.113)	(0.343)
Passed A-level	0.0605	-0.323
	(0.120)	(0.362)
Degree or above	0.176	-0.314
	(0.140)	(0.375)
Primary education *objective risk		0.830
		(0.722)
Secondary education *objective risk		0.880
		(0.662)
Passed O-level *objective risk		1.274*
		(0.690)
Passed A-level *objective risk		0.931
		(0.735)
Degree or above *objective risk		1.179
		(0.786)
Female	-0.0223	-0.0306
	(0.0355)	(0.0850)
Female *objective risk		0.0146
		(0.240)
Smoker	0.00860	-0.150
	(0.0611)	(0.160)
Smoker *objective risk		0.414
		(0.360)
Rural	-0.00991	0.0526
	(0.0377)	(0.155)
Estate	-0.0838	-0.101
	(0.0528)	(0.173)

Rural *objective risk			-0.203
			(0.391)
Estate *objective risk			-0.0146
			(0.432)
Constant	0.358 (0.060)	0.695***	0.622
		(0.185)	(0.494)
Observations	445	445	445

Note: *p <0.1, **p <0.05, ***p <0.01. Standard errors in parentheses and are clustered at the Grama Niladhari Division (GND) level. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness. Education categories are relative to 'No schooling', while Sector categories are relative to 'Urban'.

Table A5 Robustness test for Means of Bias and Accuracy, t-values for statistical differences from zero

Panel A. Overall

	Bias	t	Accuracy	t	Skill score	t
Overall (N=445)	0.045	2.22**	0.098	12.48***	-3.236	-9.53***

Panel B. By hypertension group, including difference from each other

	Bias	t	Accuracy	t	Skill score	t
Undiagnosed Hypertension (N= 99)	0.083	1.43	0.115	4.04***	-3.968	-3.22***
No hypertension (N=346)	0.037	1.53	0.094	10.16***	-3.057	-7.56***
Difference	0.046		0.021		-0.911	

Note: *p <0.1, **p <0.05, ***p <0.01. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness.

Table A6 Robustness regression output of health behaviours on subjective and objective risk

	Smoker	Smoker	Physical activity	Physical activity
Subjective risk	0.003 (0.070)	0.008 (0.057)	-0.442 (0.692)	-0.281 (0.646)
Objective risk	0.262** (0.117)	0.275** (0.106)	0.839 (1.437)	1.124 (1.290)
Age		0.001 (0.002)		-0.005 (0.017)
Female		-0.211***(0.031)		-0.543* (0.319)
SES Quintiles				
Second		0.028 (0.037)		0.320 (0.492)
Third		-0.003 (0.034)		-0.239 (0.589)
Fourth		0.041 (0.045)		-0.300 (0.561)
Fifth		-0.033 (0.056)		-0.952 (0.878)

Education				
Grade 1-5		-0.191 (0.121)		-0.669 (0.756)
Grade 6-12		-0.247**(0.110)		-0.917 (0.554)
Passed O-level		-0.328*** (0.109)		-0.705 (0.497)
Passed A-level		-0.299*** (0.107)		-1.098* (0.617)
Degree and above		-0.160 (0.174)		-2.657 (1.611)
Sector				
Rural		0.046 (0.039)		-0.340 (0.601)
Estate		0.065 (0.051)		-0.149 (0.772)
Constant	0.002 (0.044)	0.300**(0.151)	7.637*** (0.585)	9.411*** (1.183)

Note: *p <0.1, **p <0.05, ***p <0.01. Standard errors in parentheses and are clustered at the Grama Niladhari Division (GND) level. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness. Education categories are relative to 'No schooling', while Sector categories are relative to 'Urban'.

Table A7 Means objective risk by risk scores

	Overall	**Undiagnosed hypertension**	**No hypertension**
Objective risk (Parikh)	0.413	0.890	0.296
Objective risk (Sathish)	0.352	0.366	0.349

Note: *p <0.1, **p <0.05, ***p <0.01. Sampling weights were applied to adjust for unequal probabilities of selection and ensure national representativeness.