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An intersectional approach to understanding systolic blood pressure distribution in a large French study: a MAIHDA analysis

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A B S T R A C T

Inequities in systolic blood pressure (SBP), a widely used biomarker, have been shown to be patterned by age, sex, and socioeconomic position, but few studies have investigated how they combine to result in differential SBP risk. This study brings new insights by simultaneously considering sex, age, education, as well as race/ethnicity - a dimension seldom investigated in French health studies- in an intersectional perspective.

Using data from the CONSTANCES cohort (2012–2021) in the French general population, we applied intersectionality theory and multilevel analysis of individual heterogeneity and discriminatory accuracy (MAIHDA) to examine SBP levels among 150,739 adults, not under BP lowering treatment, nested within 126 intersectional strata.

Our models revealed substantial heterogeneity in SBP across strata, mainly driven by age and sex additive main effects. Older age, male sex, lower education, and Subsaharan African (SSA) and Overseas France (DROMs) groups were associated with increased SBP. SSA and DROMs individuals with fewer years of formal education consistently exhibited among the highest SBP values within each sex-age combination. Although age explained most of the between-strata variance, 25-39-year-old SSA and DROMs with fewer years of formal education displayed higher SBP levels than some 40–59-year-old individuals from other ethnoracial backgrounds, suggesting a premature increase of SBP levels for these strata.

Our results show that SBP varies according to socially structured experiences, to the disadvantage of marginalized social groups. They emphasize the need for more intersectionality-grounded research on a wider range of biomarkers, and advocate for a more systematic inclusion of racism as a major axis of oppression in health inequities studies.

1. Introduction

High blood pressure (BP) or hypertension (defined as systolic BP (SBP) > 130 or 140 mmHg, and diastolic BP > 80 or 90 mmHg, depending on the guidelines), is a major risk factor for cardiovascular diseases and one of the leading causes of death worldwide (World Health Organization, 2023). In high-income countries, it is most often managed through readily available pharmaceutical treatments combined with lifestyle modifications. Nevertheless, the share of individuals with high BP not undergoing treatment remains significant (on average around 40% in high-income Western countries (Zhou et al., 2021)). This underscores the importance of a comprehensive social mapping of BP distribution within the population that is not treated with BP lowering medication, to identify population subgroups at risk of high BP, or of premature rise in BP, to design public health campaigns that can better address their needs.

Age (Mancia et al., 2023), sex - where adult individuals assigned male at birth have generally higher SBP levels than adult individuals assigned female at birth, until later in life (around 60–70 y.o), although female individuals show a steeper increase in their SBP as early as the third decade of life (Ji et al., 2020)- and disadvantaged socio-economic position (Mancia et al., 2023) shape inequities in BP. Studies (Mancia et al., 2023; McEvoy et al., 2024), mainly in the US, the UK and the Netherlands, also find marked ethnoracial differences, always to the disadvantage of Black populations (Modesti et al., 2016; Zhou et al., 2021). However, rare are the studies that underline the social dimension of all of these determinants, and even more so are the studies that use the intersectional framework (Cho et al., 2013; Collins, 2002; Crenshaw, 1989) to examine the effects associated with different combinations of these determinants.

The biomedical literature offers many preventive recommendations to avoid developing high BP, including awareness of personal and family

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medical history, weight control, restricted sodium intake, daily physical activity and regular exercise, moderate alcohol intake, smoking cessation, stress management, and reduced exposure to noise and air pollution (Mancia et al., 2023). According to the fundamental causes theory, we can expect the level of care and knowledge of these recommendations to be socially patterned (Link and Phelan, 1995), to the advantage of individuals with more years of formal education, higher incomes, power, prestige, and beneficial social connections who have greater "access to resources that can be used to avoid risks or minimize the consequences of disease once it occurs" (Link and Phelan, 1995).

In addition to sex as a biological factor influencing BP levels (Gerdts et al., 2022; Ji et al., 2020), explained by sex differences in autonomic, hormonal, and humoral systems (Gerdts et al., 2022; Reckelhoff, 2023), gender position, as a social construct, should also be considered (Ji et al., 2020), as structural sexism is also a driver of BP inequities. Indeed, the insufficient involvement of female individuals in cardiovascular trials (Burnier et al., 2023), the lack of sex-specific BP guidelines (except for hypertensive disorders of pregnancy) (Bastian-Pétrel et al., 2024; Burnier et al., 2023), and the overall lower cardiovascular risk assessment compared to male individuals affect knowledge and the perception of risks associated with high BP by female patients and their medical care provider (Burnier et al., 2023). For instance, recent evidence challenges the view that females' BP trajectories merely lag 10–20 years behind males', showing instead that BP rises more rapidly in females as early as in the third decade and continues over the life course (Ji et al., 2020). While these sex-specific BP trajectories offer important insight for prevention and management, they remain insufficiently reflected in public awareness and clinical guidelines (Mancia et al., 2023). The effects of structural sexism can translate in the widespread misconception that high BP is almost exclusively a condition affecting men or in the lack of awareness that sex-specific medical events (such as hypertensive disorders of pregnancy, polycystic ovary syndrome, and possibly assisted reproductive procedures) can have an impact onwomen's long-term cardiovascular health (Burnier et al., 2023).

Furthermore, structural racism, referring to "the totality of ways in which societies foster [racial] discrimination, *via* mutually reinforcing [inequitable] systems … (*e.g.*, in housing, education, employment, earnings, benefits, credit, media, health care, criminal justice, etc) that in turn reinforce discriminatory beliefs, values, and distribution of resources" (Bailey et al., 2017; Reskin, 2012) has been shown to have consequences on health (Bailey et al., 2017), including on BP (Brondolo et al., 2011; Mohottige et al., 2023), *via* multiple pathways. Patients from marginalized ethnoracial minorities more often face racism and xenophobia in the healthcare system, causing barriers to accessing care (Pattillo et al., 2023; Rivenbark and Ichou, 2020). They are also more likely to accumulate chronic stress during the life course due to socio-economic disadvantage and discrimination experiences, resulting in the embodiment of these stressors and premature biological aging, as theorized by the "weathering" hypothesis (Forde et al., 2019; Geronimus et al., 1991). In the case of BP in the US, it translates in the earlier rise of BP among the Black population compared to those defined as White (Forde et al., 2019; Ji et al., 2020) in the life course, especially among women (Ji et al., 2020; Richardson and Brown, 2016).

Age is both an indicator of biological aging and chronological aging, the latter also being a social construct that affects perceptions of high BP risks but also behaviors when diagnosed. In this context, ageism is likely a contributor to BP inequities, *via* multiple pathways. For instance, a qualitative study conducted in the US found that young patients diagnosed with high BP often face psychosocial challenges, particularly the fear of being perceived as a "sick person" by their peers, most of whom do not have high BP. This social stigma can negatively impact their willingness to adhere to prescribed treatment (Johnson et al., 2017). In contrast, such barriers are less common among older patients, as high BP is more prevalent in this age group and therefore considered a normal part of biological aging. From a gender perspective, age also signals the approach of menopause, when some women experience an accelerated increase in SBP (Samargandy et al., 2022). Around menopause, studies suggest that women with high BP frequently report symptoms (Maas and Bairey Merz, 2017), but might be overlooked or (self-)interpreted as "stress-related" (Maas, 2019) since hypertension guidelines describe the condition as largely asymptomatic and do not consider middle-aged women as a possible exception. Furthermore, combined with race/-ethnicity, age is also an indicator that reflects how long marginalized individuals have been experiencing "weathering" health (Forde et al., 2019; Geronimus et al., 1991), due to chronic stress associated with discrimination experiences and socio-economic disadvantage in the life course.

Intersectionality is a theoretical framework that originates from critical Black feminist scholars (Cho et al., 2013; Collins, 2002; Crenshaw, 1989). As a form of critical theory, intersectionality posits that systems of oppression (*e.g.*, sexism, racism, ageism, socioeconomic inequity) cannot be understood individually. They are interlocking, inseparable, mutually constituted, and they intersect and shape unique social positions (*e.g.* combinations of sex, race/ethnicity, age, education, income) at the individual-level resulting in shared lived-experiences. Intersectional approaches, mainly through interaction terms, have contributed to showing that African American women in the US (Richardson and Brown, 2016), and Black women in Canada (Gagné and Veenstra, 2017) and in Brazil (da Silva et al., 2023) are at heightened risk of hypertension. However, these approaches are often limited in the number of intersections across social categories (*e.g.* simultaneous combinations of race/ethnicity, sex, age, and education) (Mahendran et al., 2022).

Multilevel Analysis of Individual Heterogeneity and Discriminatory Accuracy (MAIHDA) is a general multilevel framework, characterized by that systematic and simultaneous consideration of differences between group averages, and the extent of individual heterogeneity between these group averages (Merlo et al., 2016, 2019). MAIHDA has been shown to have various advantages compared to more traditional methods (*e.g.* main effect models, which are non-multilevel approaches that estimate the independent effects of variables without considering their intersections or contextual clustering), such as the assessment of discriminatory accuracy (DA) and the use of shrinkage, and is applicable to any structured population heterogeneity -whether geographic, institutional, and social (Evans et al., 2024b; Merlo, 2014; Merlo et al., 2019). MAIHDA was hailed as the new "gold standard" for investigating health inequities in (social) epidemiology (Merlo, 2018), biomedical and clinical (Evans, 2024), and beyond. In the study of BP inequities, the possibilities offered by MAIHDA further extend a previous multilevel analysis underlining the logic of partitioning systolic SBP into individual and contextual components (Merlo et al., 2004). Intersectional MAIHDA (or i-MAIHDA), is a specific application of MAIHDA rooted in intersectional theory that considers dimensions of social identity and position (*e.g.* racism, sexism, ageism, and social inequity) as contexts rather than individual characteristics. I-MAIHDA is an effective approach to simultaneously consider a higher number of intersections across social categories (*e.g.* race/ethnicity, sex, age, and education, simultaneously).

The study of BP inequities at the intersection of multiple systems of oppression (*e.g.* racism, sexism, ageism, and social inequity) in the untreated population is instrumental to better identify the needs of populations at high risk of developing high BP, or premature rise in BP, and eventually bring new insights for future public health interventions. This is all the more important in a French context, where no national screening campaign is organized to detect high BP in the general population, and where the collection of ethnoracial data is legally restricted in health surveys in France leading to no available BP or hypertension data across ethnoracial groups or migratory status in the general population, let alone combined with social factors (Silberzan et al., 2023). Integrating race/ethnicity would therefore render visible often-invisibilized ethnoracial subgroups while taking their heterogeneity into account, and enable the examination of racism as a structural axis of oppression shaping BP inequities in France.

In this study, we focused on SBP, an important biomarker for numerous health endpoints, that has been shown to be a stronger predictor of cardiovascular risk than diastolic BP (Flint et al., 2019). Our main research question was: how does SBP vary across intersectional strata that combine age, sex, education, and race/ethnicity in the general population that is not treated for hypertension in France? More specifically, our research had three objectives: 1) to map predicted SBP means across intersectional strata, in order to identify strata that are particularly at higher risk; 2) to examine and quantify the degree of intersectional inequity in SBP between strata; and 3) to uncover ethnoracial inequities in SBP, while taking the social heterogeneity of ethnoracial groups into account.

2. Methods

2.1. CONSTANCES

We used data from the French general population prospective cohort study CONSTANCES. All participants were selected from the French National Health Insurance Fund database, which represents 85% of the general French population. Salaried workers, professionally active or retired and their family were included, but not agricultural, self-employed workers or other specific cases of individuals who are affiliated to other (or not affiliated to any) health insurance funds. The sampling was stratified by age, sex, employment status, occupation, and region of residence (Zins and Goldberg, 2015). At inclusion, individuals aged 18–69 y.o. were invited to complete questionnaires at home (socio-economic characteristics, lifestyle factors, health behaviors, residential history), then to visit health screening centres (HSC) for comprehensive health assessments, including doctor-administered questionnaires and three standardized BP readings (Ruiz et al., 2016). The study participants' data were also linked to the French National Health Data System (SNDS), providing administrative exhaustive tracing of all outpatient data for antihypertensive prescription reimbursements.

2.2. Study population

We pooled data from 205,203 individuals included in the CONSTANCES cohort from February 2012 to May 2021 and excluded from the study 4,430 participants who were over 69 when visiting the HSC (although invitations were sent to individuals aged 18 to 69, some had surpassed the age limit by the time of their visit in the HSC, and were therefore excluded from the study). Out of these individuals, we excluded individuals who did not complete the HSC visit, whose data were not available through linkage with the SNDS database (did not accept the linkage and/or the data could not be found in the SNDS database), and/or did not have three valid measures of hypertension (n = 15,208). Participants who had been reimbursed for antihypertensive drugs (Anatomical Therapeutic Chemical (ATC) codes are available in Supplementary Table 1) in the 6 months preceding inclusion (n = 22,427) were not included in the study. Excluding individuals on antihypertensive treatment avoided treatment-induced alterations in BP—which could be socially patterned and could potentially bias comparisons across strata—, and allowed for a focus on individuals that are more likely not to be engaged in a care trajectory. Furthermore, we excluded pregnant women (n = 884) to avoid specific cases of congenital high SBP, as well as individuals younger than 25 y.o. (n = 8,054) as they may not have reached their highest education diploma before that age. We further excluded participants with missing data on their highest education diploma (n = 2,422) and on migration status (n = 1,023). Lastly, we excluded individuals with extremely high SBP values (>220 mmHg) (Kulkarni et al., 2023) (n = 16). The final sample consisted of 150,739 individuals (aged 25–69).

Participants who were excluded were older (mean age (standard deviation): 48 (17)) than those included (46 (12)), and there was no significant difference in sex distribution between the two groups.

A flowchart is available in the S2. Supplementary Material (Supplementary Figure 1).

2.3. Systolic blood pressure (SBP)

Standardized BP measurements were conducted three times at the HSC after a 5-min rest in a lying position, according to the standardized operating procedure provided by the CONSTANCES study team for data collection (Ruiz et al., 2016). The first measurement was taken on the right arm, followed by the second on the left arm after a 1-min interval. The third measurement was then taken on the reference arm (the arm with the highest value) after another 1-min interval. The SBP (in mmHg) was determined by averaging the two systolic readings from the reference arm.

2.4. Intersectional social variables

The following variables that were chosen to build the strata have been shown to be associated with health inequities (O'Neill et al., 2014) and have a differential impact on SBP levels, but with limited evidence on intersectionality when considered together.

- Race/ethnicity

In France, unlike other countries including the UK, the USA, Canada or Australia, systematic collection of self-reported race/ethnicity is hindered by a national legal framework (Simon, 2011). The main approach to compensate for this absence of established ethnoracial categories is to use migration status as an imperfect proxy for race/ethnicity. Since migration status is closely linked to race/ethnicity (Simon and Clement, 2006) and is more frequently collected and available in routine data in France, it can offer insights into potential discrimination driven by racism and xenophobia (Simon, 2011). In this study, race/ethnicity is a hybrid term that refers to a social relation—specifically, a power relation that categorizes groups of individuals and positions them hierarchically within a given society (Brun, 2024). This process of categorization relies heavily on perceived heredity and is closely tied to the colonial division of the world. Importantly, in this study, race/ethnicity does not refer to the specificities of biological or cultural markers (which is often considered at the origin of the distinction between the two concepts), but rather to the social mechanisms of stratification that emerge from these constructed categories (Brun and Cosquer, 2022). From this perspective, the distinction between the ethnoracial groups is made on the assumption that individuals within the same group share common experiences of being subjected to discrimination on similar—or at least comparable—ethnoracial grounds (covering perceived origin and skin color) (Beauchemin et al., 2018). In our study, migration status was therefore used as a proxy for race/ethnicity and was assessed using the participant's response to questions about their nationality at birth and their parents' and their own "geographical area of origin" (*i.e.* "metropolitan France", "DROMs" (French territories located outside Europe, largely made up of the remaining parts of the former French colonial empire), "Europe", "North Africa", "Subsaharan Africa", "Asia", "Other") (Supplementary Fig. 2). First- and second-generation immigrants were then grouped together, as well as migrants and descendants from DROMs (Beauchemin et al., 2018), as our primary focus was to explore hypotheses related to discrimination and racism rather than those associated with migration trajectories. If participants were neither first- nor second-generation immigrants, nor migrants nor descendants from DROMs, they were considered as part of the Majority group (which captures both a statistical overrepresentation and an advantaged position within the stratified structure of French society (Beauchemin et al., 2018)). Race/ethnicity was therefore recoded as follows: Majority population, Subsaharan African (SSA), North African, Asian, DROMs, Europe, and Other.

- Sex

Sex (categorised as female and male) was collected in administrative records. Sex was used as a proxy to represent the position of the participants in the gender system for further interpretation and discussion of the results. We acknowledge the substantial limitations of this approach, as sex and gender do not always align, and the variable excludes individuals who identify outside the binary gender categories.

- Age

Age, collected in administrative records (categorised as young (25–39 y.o), mid-age (40–59 y.o), older adults (60–69 y.o)).

- Education

Education was used to represent socio-economic position and was assessed through self-reported highest level of education regrouped as less than (<) high school diploma (<12 years of education), high school diploma (12 years of education), and more than (>) high school diploma (>12 years of education).

Social strata were constructed for each of the possible unique combinations of age, sex, race/ethnicity, and education level for a total of 126 social strata.

2.5. Statistical analysis

We used the i-MAIHDA method, an application of multilevel models to quantify intersectional inequities that models both individual heterogeneity and group-level contextual effects (Evans et al., 2024b), using social positions (in this study, sex, age, race/ethnicity, education) as proxies of systems of oppression. Individuals were nested in the first level and the 126 intersectional strata (*i.e.,* the combination of race/ethnicity, age, sex, and education) at the second level. We estimated the mean predicted SBP levels across strata and 95% Confidence Intervals (CI). Statistical details of these models can be found in the supporting information (S1 Statistical details). All analyses were conducted on complete cases.

2.5.1. Model 1: The "simple" or null intersectional model

The first model included only an intercept and a random effect for the intersectional strata with no covariates.

(i) General contextual effect

In order to measure between-stratum inequity and variance, we computed the Variance Partition Coefficient (VPC), which mathematically is expressed as the percent of between stratum variance across the total variance. The VPC indicates the strata's contextual influence (*i.e.* the influence of age, sex, education, and race/ethnicity) for understanding SBP inequities. In other words, the VPC quantifies the proportion of total variance in SBP attributable to the intersectional strata. In this sense, the VPC from the intersectional null model measures the influence of intersectional strata on SBP without specifying any specific characteristics of the strata. This measurement can be referred to as the "general contextual effect". The VPC also quantifies the clustering of individual SBP within the strata.

$$\%VPC = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_e^2} * 100$$

Where σ_u^2 denotes the between-stratum variance in SBP levels and $\sigma_u^2 + \sigma_e^2$ the total individual variance.

(ii) Discriminatory Accuracy (DA)

The VPC also provides an indication of the model's DA —that is, the extent to which intersectional strata differentiate individuals according to their SBP. However, DA and VPC are not equivalent for continuous outcomes (Goldstein et al., 2002), when group sizes are unbalanced and within-group heterogeneity can be found (which is the case in our study). To approximate the DA of our model, we used a threshold-based Area Under the Receiver Operating Characteristic Curve (AUC) approach. To do so, we conducted another "simple" intersectional model, but this time using the logistic version, with the outcome being binary (1: having a SBP in the highest quintile/0: not having a SBP in the highest quintile) (Model 1bis - DA approximation). In our study, this model is used solely to provide an approximation of the DA and will not be discussed further for other purposes. The AUC approach assessed how accurately the predicted probabilities derived from stratum membership distinguish individuals not having SBP in the highest quintile from those in the highest quintile. Statistical details can be found in the supporting information (S1 Statistical details).

2.5.2. Model 2: The "complete" or additive main effects intersectional model

(iii) Specific contextual effects

This model provided a clear social mapping of the inequities in SBP by calculating the SBP predicted levels and the 95% CI for every intersectional stratum, after adjusting for all additive main effects (S1 Statistical details). These, along with regression coefficients of the additive main effects model, represent what can be referred to as the "specific contextual effects".

MAIHDA's precision weighting has been shown to produce more reliable prediction of stratum means when stratum sizes are small than single-level regression approaches (Evans et al., 2024b), thanks to the shrinkage of the stratum random effects in the model. In Model 2, shrinkage pulls the observed differences of smaller strata towards the model-implied means derived from the additive model which avoids overinterpreting predictions led by extreme values in these strata (Evans et al., 2024b).

In this model, the VPC now represents the remaining percentage of between stratum variance after adjustment for additive effects.

To quantify the extent to which the adjustment for additive effects in Model 2 reduced the between-stratum variance in Model 1, we calculated the Proportional Change in Variance (PCV):

$$\%PCV = \frac{\sigma_u^2(Model\ 1) - \sigma_u^2(Model\ 2)}{\sigma_u^2(Model\ 1)} * 100$$

The %PCV is interpreted as the percentage of the total between-stratum variance (in the "simple"/null intersectional model) that is explained by adjustment for the additive main effects (Evans et al., 2024b). A high %PCV means that a large portion of the between stratum variance is accounted for by additive main effects. This indicator allowed us to underscore the extent to which intersectional inequities were following an additive pattern (Evans et al., 2024b). When intersectional inequities follow an additive pattern, it suggests that a given stratum's SBP level is equal to the level expected for it based on the additive contributions of age, sex, race/ethnicity, and education. For some strata, the final predicted value may be different from that based on an additive pattern, suggesting a difference attributable to residual interaction effects.

2.6. Partially-adjusted intersectional models

The partially adjusted models aimed to assess the extent to which each of the various dimensions used to define the intersectional strata (*i.e.* sex; age; race/ethnicity; and education) contributed to the between-stratum variance observed in Model 1. In different iterations of the partially-adjusted intersectional models, we built upon Model 1 ("simple"/null model) by adjusting for one dimension at a time (*i.e.*, creating a separate model for each dimension). Subsequently, we calculated the PCV for each of the partially-adjusted intersectional models (S1 Statistical details). $\%PCV_{sex}$, $\%PCV_{race/ethnicity}$, $\%PCV_{education}$, and $\%PCV_{age}$ showed the extent to which the sex, race/ethnicity, education, and age dimension, respectively, contributed to the total between-stratum variance. Although using partially-adjusted models provides valuable information on the dimensions' respective power to "partition" the variance between the intersectional strata, it should be underlined that these models are antithetical to an intersectional approach, which sees these systems as inherently inseparable.

2.7. Sensitivity analyses

Although the aim of this study was to quantify and uncover intersectional inequities rather than to identify the factors that produce them, we conducted a sensitivity analysis adjusting the "complete"/main effects model on BMI (following standardized measures of height and weight at the HSC (Ruiz et al., 2016) and computed as weight/height^2), that has been shown, in the literature, to be strongly associated with SBP. The sensitivity analysis was conducted on a sub-sample (N = 149, 647) with no missing value for BMI (>99% of the study sample).

We used R statistical software (version 4.3.0) to fit MAIHDA models using the "lme4" package.

3. Results

3.1. Socio-demographic

The sample mean SBP was 127.8 (standard deviation (SD) 15.4) mmHg (Table 1). The sample was sex-balanced, with 53% female and 47% male participants, and a mean age of 46 y.o (SD: 12) (Table 1). Almost two thirds (63%) had more than a high school diploma and almost a quarter (22%) had less than a high school diploma. The sample was large enough (N = 150,739) to combine race/ethnicity with sex, age, and education, despite underrepresentation of some ethnoracial minorities (with 81% majority population, 1% DROMs, 9% European, 3% North Africa, 1% SSA, 1% Asia, 2% Other).

Most (91.3%) of the 126 strata had N > 20 (Table 2). The eleven strata with N < 20 were all respondents aged 60 to 69 y.o., mainly from SSA, but also other minority groups (DROMs, Asia, and Other) (Supplementary Table 2).

Table 1
Characteristics of the study respondents.

	Total (N = 150,739)	
	N (%)	SBP in mmHg (SD)
Total		127.8 (15.4)
Age		
25-39	50,896 (34%)	122.5 (12.3)
40-59	73,592 (49%)	127.9 (15.0)
60-69	26,251 (17%)	137.2 (17.1)
Sex		
Female	80,633 (53%)	122.8 (14.9)
Male	70,106 (47%)	133.4 (13.9)
Education		
Less than high school	32,724 (22%)	133.2 (16.3)
High school	22,417 (15%)	129.0 (15.3)
More than high school	95,598 (63%)	125.6 (14.6)
Race/ethnicity		
Majority group	122,010 (81%)	128.0 (15.4)
DROMs	1,957 (1%)	127.9 (15.0)
North African	7,550 (5%)	125.0 (14.3)
Subsaharan African	1,683 (1%)	129.4 (15.6)
Asian	1,842 (1%)	122.4 (15.1)
Europe	13,387 (9%)	127.6 (15.8)
Other	2,310 (2%)	124.3 (14.5)

Note: SBP: systolic blood pressure; SD: Standard deviation; DROMs: French overseas *départements* and regions.

Table 2
Sample Size of Intersectional Strata, defined as a combination age, sex, age education, and race/ethnicity (N = 126 strata).

Sample Size	Number of Strata	% of Strata
0	0	0
1–19	11	8.7
20–49	19	15.1
50–99	22	17.5
100–499	43	34.1
501 - 1000	4	3.2
1001–20,354	27	21.4
Total	126	100

3.2. Quantifying SBP inequities

Parameter estimates for Models 1 and 2 are presented in Table 3. The VPC in Model 1 (unadjusted for main effects) was 26.3% [18.4;33.9%], indicating a high proportion of total variance in SBP attributable to the intersectional strata. It showed considerable SBP inequities between strata, but also a large within-stratum variance in SBP (73.7%). Overall the high VPC we observed (Evans et al., 2024a) indicated that intersectional strata provided a strong general contextual effect, and a high level of DA (≃0.74) (Supplementary Fig. 3). The VPC decreased to 0.8%

Table 3
SBP estimates (and 95% CI) from intersectional MAIHDA models.

	Model 1		Model 2	
	Estimates	95% CI	Estimates	95% CI
Fixed Effects: Regression Coefficients				
Intercept	129.96 ***	[128.53;131.39]	117.00 ***	[116.18;117.82]
Age (ref = 25–39 years)				
40-59			5.19 ***	[4.55;5.83]
60-69			14.49 ***	[13.74;15.23]
Sex (ref = Female)				
Male			9.81 ***	[9.25;10.37]
Race/ethnicity (ref = majority group)				
North African			−2.14 ***	[-3.02;-1.25]
Subsaharan African			2.71 ***	[1.62;3.81]
Asian			−2.28 ***	[-3.39;-1.17]
Other			−1.41 **	[-2.44;-0.37]
DROMs			1.42 **	[0.36;2.47]
European			−0.22	[-1.06;0.61]
Education (ref= >HS)				
HS			2.29 ***	[1.60;2.99]
<HS			3.48 ***	[2.81;4.14]
Random Effects:Variances				
Individual-level (σ_e^2)	180.34		180.35	
Stratum-level (σ_u^2)	64.27		1.40	
Summary Statistics				
%Variance Partition Coefficient (VPC)	26.3% [18.4;33.9%]		0.8% [0.3;1.6%]	
%Proportional Change in Variance (PCV)			97.8%	

*p < 0.05 **p < 0.01 ***p < 0.001.
Notes. SBP: systolic blood pressure (in mmHg); DROMs: French overseas *départements* and regions; < HS: less than high school diploma, HS: high school diploma, >HS: more than high school diploma (see methods).

in Model 2, suggesting that the majority of between strata variation was explained by additive main effects and that stratum interaction effects accounted for very little of the remaining variation between individuals. The PCV of 97.8% in Model 2 confirmed that only a small part of the stratum inequity was left unexplained by additive main effects. This does not imply that BP inequities are not intersectional, as intersectional effects, empirically expressed by the mapping of SBP means across strata in Model 2, exist even when traditional interaction terms are small. Furthermore, partially adjusted models (Supplementary Table 3) showed that age and sex alone explained most of the between-strata variance in SBP found in Model 1 ($PCV_{age} = 53.7\%$ and $PCV_{sex} = 35.3\%$). Education and race/ethnicity alone did not contribute to explaining that variance ($PCV_{education}$ and $PCV_{race/ethnicity} < 2\%$).

When adjusting for all the covariates in Model 2 (Table 3), we found that, compared to respondents aged 25 to 39 y.o., older respondents had increased SBP (+5.19 mmHg 40 to 59 y.o. and +14.49 mmHg 60 to 69 y.o.). Male participants (+9.81 mmHg) had higher SBP than female participants. SBP also followed an inverse educational gradient (+3.48 mmHg and +2.29 mmHg for respondents with respectively < high school and high school diploma, compared to > high school diploma). Compared to respondents from the majority group, SSA (+2.71 mmHg) and DROMs (+1.42 mmHg) origins showed an increased SBP; while North African (−2.14 mmHg), Asian (−2.28 mmHg), and Other (−1.41 mmHg) origins a decreased SBP.

3.3. Mapping SBP inequities

Fig. 1 provides the ten high/low predicted SBP levels across intersectional strata (based on Model 2). Supplementary Table 2 provides predictions in all strata and Supplementary Fig. 4A and B the visualization of these predictions. The predicted SBP values ranged from 113.6 [95% CI, 112.2; 115.1] mmHg (young Asian females with > high school diploma) to 146.9 [144.4; 149.4] mmHg (older SSA males with < high school diploma). The magnitude of SBP levels was therefore over 30 mmHg, which is substantial in the case of SBP.

The ten highest predicted SBP levels were all older males and exceeded 140 mmHg. All older male participants from SSA and DROMs with a high school diploma or less were in the top ten predicted SBP levels. Conversely, the ten lowest predicted SBP levels were all young female participants from all origins, except SSA and DROMs (Fig. 1). Moreover, for each combination of sex and age, strata of SSA and DROMs with high school diploma or less had among the highest predicted SBP values. Conversely, all Asian, North African, and Other strata with > high school diploma had among the lowest predicted values (Supplementary Table 2). Fig. 2 provides a visualization of the relationship between age and SBP for all strata, stratified by sex, and highlighting the position of the strata aforementioned. Identification of all strata are available in Supplementary Fig. 5A and B.

Fig. 2 suggests particular age patterns of SBP according to combinations of sex, race/ethnicity, and education. We compared SBP levels between the three age groups in our cross-sectional study. Male participants seemed to have an overall steeper increase after 59 y.o., while this result was not always visible for women, especially for female participants from SSA and DROMs with a high school diploma or less who have a steeper increase before 40 y.o. Furthermore, the figure also suggested a larger spread of SBP values for females in age groups 25–39 and 40–59 y.o., compared to men of the same age groups, while this result is not visible at age 60–69 y.o.

At younger ages, age gradients were not always consistent. Fig. 3 provides a visualization of age gradients in SBP across intersectional strata among both sexes. Almost all strata aged 25 to 39 y.o. had lower SBP than strata aged 40 to 59 y.o., who in turn had lower SBP than strata aged 60 to 69 y.o. However, for both sexes, some individuals aged 25 to 39 y.o. (DROMs, SSA and the majority group with less than a high school diploma) had higher SBP levels than older individuals aged 40 to 59 y.o. (with from Asia, North Africa, and Other with more than a high school diploma) As for the highest SBP levels among 40 to 59 y.o., they almost never exceeded that of older individuals, but were still very close.

3.4. Sensitivity analyses

Notably, after adjusting the complete Model (Model 2) for BMI, some effects observed in the complete Model decreased, especially for age categories, sex, education levels, and people of DROMs and SSA origins.

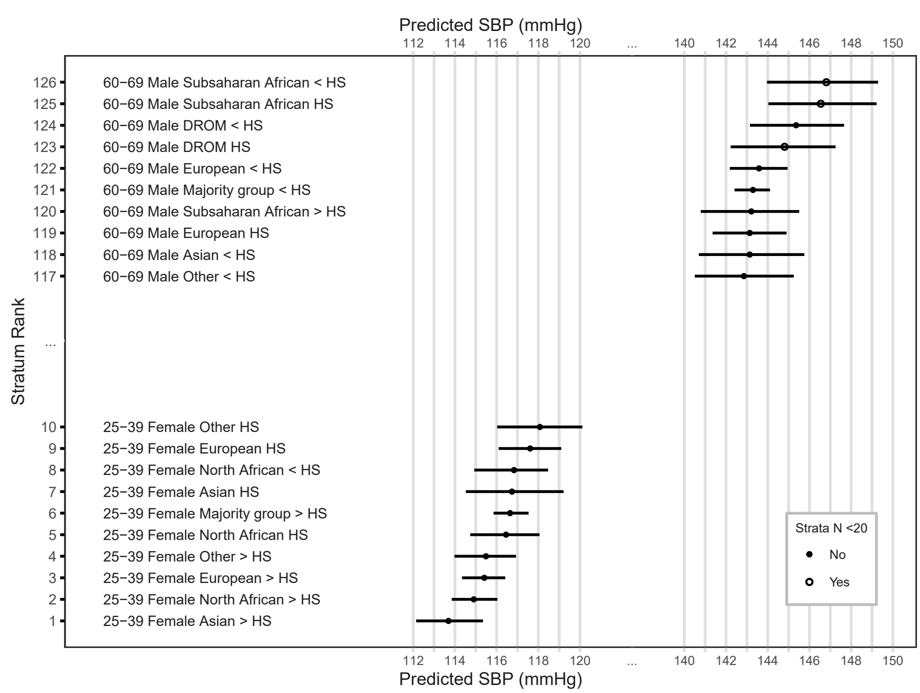

Fig. 1. Ten lowest and highest predicted SBP. Notes: All predictions are from Model 2. SBP: systolic blood pressure (in mmHg), DROM: French overseas *départements* and regions, < HS: less than high school diploma, HS: high school diploma, >HS: more than high school diploma (see methods).

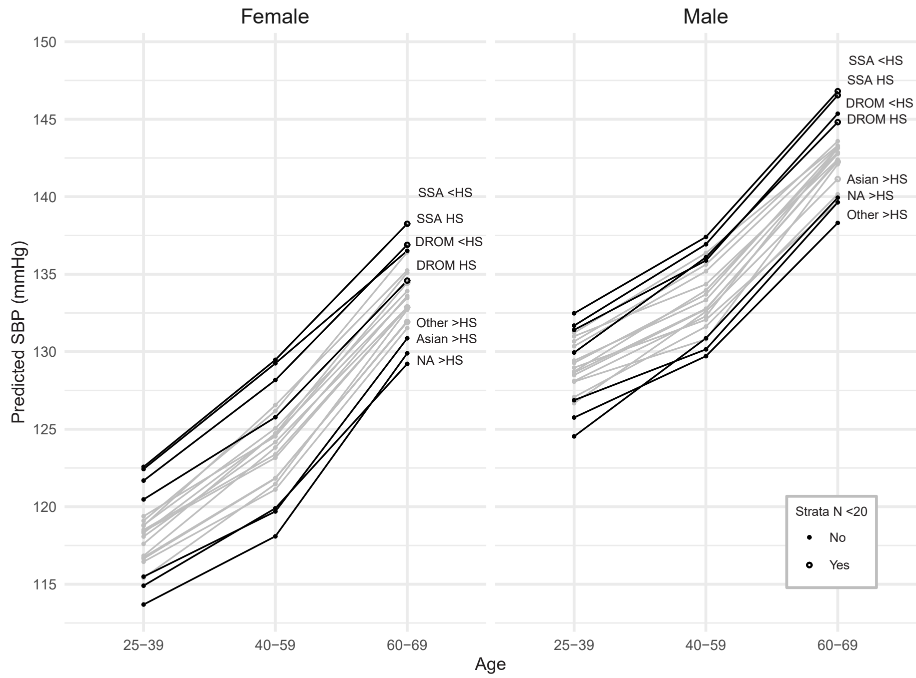

Fig. 2. Predicted SBP levels by Age, Sex, Education and Race/ethnicity. Notes. All predictions are from Model 2. SBP: systolic blood pressure (in mmHg), SSA: Subsaharan Africans, DROMs: French overseas *départements* and regions, NA: North Africans < HS: less than high school diploma, HS: high school diploma, >HS: more than high school diploma (see methods).

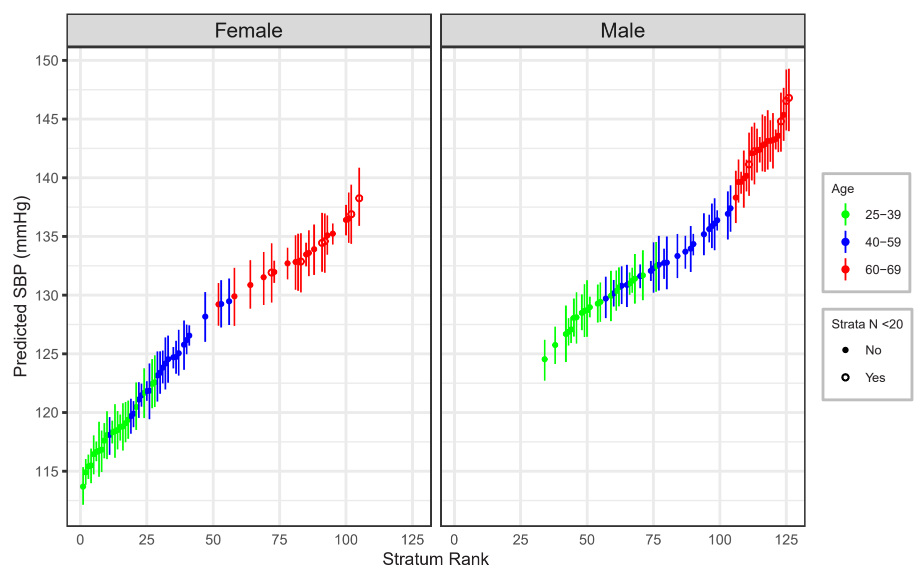

Fig. 3. Predicted SBP levels and associated ranking by Sex and Age. Notes. All predictions are from Model 2. SBP: systolic blood pressure (in mmHg).

However, the overall results remained consistent with the intersectional effects and distribution presented in the study (S3 Supplementary Material: sensitivity analysis).

4. Discussion

This study explored inequities in SBP distribution in a general population cohort in France. Our goal was to quantify and map SBP at the intersection of age, sex, race/ethnicity, and education in the general population who are not treated with BP lowering medications. Our findings reveal an exceptionally high percentage (26.3%) (Evans et al., 2024a) of the total between-stratum variance that occurred at the intersectional stratum level, which suggests that the intersecting systems of oppression under study (*i.e.*, sexism, ageism, racism, social inequity) play a major role in shaping SBP, reflecting both a very strong general contextual effect and a high level of DA. Our findings reveal that certain social groups within the population are more likely to have higher SBP, putting them at risk of numerous adverse health outcomes. We also aimed to uncover ethnoracial inequities that are often invisibilized in France. We observed higher predicted SBP for participants from SSA and DROMs with fewer years of formal education, among men and women at all ages. Furthermore, our results suggested a premature rise of SBP among these strata at a younger age, while more educated Asian, North African, and Other participants had lower predicted SBP levels.

We chose to put the focus on the distribution of SBP rather than hypertension prevalence, because definitions of hypertension vary and are debatable, and to describe the overall distribution of a biomarker that is important for numerous health endpoints, rather than a clinically defined subgroup. Indeed, the conventional hypertension thresholds defined by the European Society for Hypertension (ESH) and the American Heart Association (AHA) differ (Mancia et al., 2023). According to the latter and since 2017, an SBP over 130 mmHg is considered as hypertension, while it should reach 140 mmHg according to the ESH. Not to mention that these conventional thresholds, historically established on male populations (Saklayen and Deshpande, 2016), are debatable and do not include sex-specific definitions of hypertension that could improve CVD risk detection in women (Gerdts and De Simone, 2021). Although SBP is not sufficient to account for the total hypertension-related global disease, it still captures the large majority of the CVD effects of hypertension (Le et al., 2022).

Our intersectional approach allowed us to underline the relative and combined contributions of the sex, age, race/ethnicity and socioeconomic power systems to the SBP distribution. Specifically, we found that, considered individually, the age and sex power systems alone explained most of the between-stratum variance. Overall, we found that SBP tended to increase with age in men and women (as operationalized through "male" and "female", respectively in our study), and that, on average, men had higher SBP than women, in accordance with the scientific literature (Mancia et al., 2023). On the other hand, the education and race/ethnicity dimensions alone did not contribute to explaining the between-stratum variance, although education and race/ethnicity positions were significant predictors of the variation of SBP levels in the fully adjusted model. In other words, when considered alone, these respective dimensions did not have the statistical power to "partition" the variance between the intersectional strata. However, when considered together with the other dimensions, they had an impact on SBP levels. Our results suggest that investigating the impact of racism and socioeconomic inequality in the shaping of BP inequities might be relevant only if sexism and ageism are also simultaneously included. Lower education levels were associated with higher SBP. Compared to individuals who had more than a high school level, individuals with lower education levels were more likely to have higher SBP. It supports previous work on the relation between education, and more broadly socioeconomic position and hypertension prevalence (Nakagomi et al., 2022). Specifically, a different study also using the CONSTANCES cohort found an inverse education gradient in both genders and at all ages (Neufcourt et al., 2020). Our study also shed light on ethnoracial differences in SBP, which had not been investigated in the French general population before. When race/ethnicity was considered simultaneously with sex, age, and education, we found that, compared to individuals in the majority group, people with SSA and DROMs origins had higher SBP; while North African, Asian, and Other origin had lower SBP. These results underline the importance of taking an intersectional approach when examining health inequities. Furthermore, our results, by assessing the relative and combined contributions of the different social dimensions under study, and by adding age and ethnoracial groups, complemented the findings of another study applying MAIHDA to SBP in the UK elderly (Holman et al., 2020).

In our study, people with SSA and DROMs origins with a high school or lower diploma had among the highest SBP levels, among each age category for men and women. In European countries, individuals of SSA origin have been found to have disproportionately higher SBP (Modesti et al., 2016), however there is a paucity of research aiming to understand this phenomenon (Mancia et al., 2023). Structural racism (Bailey et al., 2017) has been shown to impact BP (Brondolo et al., 2011; Mohottige et al., 2023) *via* multiple pathways. In France, when questioned on their ethnoracial origin, a majority of SSA and DROMs individuals report "Black" (Simon and Clement, 2006). As such, they share common discrimination experiences (Haddad, 2018), mainly based on their skin color, post-colonial identity, and other aspects of their geographical origins (Beauchemin et al., 2018; Haddad, 2018; Simon and Clement, 2006), which contribute to their higher unemployment rates (Beauchemin et al., 2018), segregated housing (Beauchemin et al., 2018), and barriers to healthcare (Rivenbark and Ichou, 2020). We hypothesize that chronic stress caused by these discrimination experiences contributes to higher SBP rates. Furthermore, structural racism also impacts high BP risks (Brondolo et al., 2011), such as overweight and obesity, although the observed inequities remain similar overall, even after accounting for the latter (sensitivity analysis). Our study suggests that focusing on individual responsibility in high BP (as often the case for overweight/obesity (Brownell et al., 2010)) without questioning its structural roots, will not be sufficient to reduce inequities in BP. Finally, a possible genetic explanation to explain the observed inequities, long emphasized in biomedical research, is contentious (Flack et al., 2010), poorly substantiated (Mancia et al., 2023), and offers limited insight into the inequities, especially when compared to more robustly documented social and environmental determinants (Flack et al., 2010).

Beyond the observation that individuals of SSA and DROMs origins with lower education levels had high levels of SBP, it is also noteworthy that, for men and women, these levels of SBP were higher or very close to those of older individuals from other origins with a higher education level, suggesting that the overall age gradient in the population was no longer salient when considering the combination or race/ethnicity and education. This finding suggests that less educated SSA and DROMs individuals prematurely attained SBP levels that we would expect to observe among older participants. These different SBP trajectories across intersecting social groups are consistent with the "weathering" hypothesis (Geronimus et al., 1991). This hypothesis stipulates that the experience of socio-economic disadvantage and discrimination over the life course leads to physiological wear-and-tear and a gradual embodiment of stressors resulting in the early onset of pathologies among disadvantaged populations (Forde et al., 2019; Geronimus et al., 1991). Weathering has been shown to be even worse in disadvantaged socio-economic contexts, especially among Black populations in an American study (Forrester et al., 2019), which could explain the particularly high predicted rates among the less educated SSA and DROMs individuals in our study. By underlining the added risk of lower education levels, our findings contribute to the most recent literature on age-trajectories that found steeper increase in SBP among women as early as the third decade of life, especially among Black individuals (Ji et al., 2020). Furthermore, a "marked rise in women after menopause" (Mancia et al., 2023) could have been expected in our findings. In our study, 94% of women aged 60 to 69 y.o. reported being postmenopausal (data not shown), however, we did not observe an homogeneous steeper rise in SBP between mid- and older-age among them. Heterogeneity is high among the studied population, resulting in a variety of SBP trajectories. Our findings seem to align with a recent study in the US that found a diversity of SBP trajectories in women around menopause, with only 35% of women showing a significant accelerated rise in SBP after menopause (Samargandy et al., 2022). Interestingly, a threshold was not visible in men. Additionally, life course studies on hypertension suggest that after age 65, hypertension in women may even exceed that of men (Mancia et al., 2023). In our study, the women's strata were always lower than the men's in terms of the SBP distribution. Although we still observed that lower educated older women of SSA and DROMs origin had SBP levels comparable to those of older more educated men from other origins. This result should be interpreted cautiously. Indeed, these specific strata contained only a few dozen individuals or fewer (mainly due to the age structure of these ethnoracial minorities), although the MAIHDA methodology protects us from overinterpretation predictions in smaller strata (shrinkage of the predicted means).). Future intersectional research on longitudinal data, should be undertaken to further describe SBP trajectories among men and women, to analyse the contribution of menopause in SBP variation among women, and to investigate the social profile of those who are more likely to increase rapidly at older age. Our findings suggest that special attention should be put on older disadvantaged SSA and DROMs women.

Conversely, Asian individuals with more than a high school diploma were in the lowest predicted SBP levels across each age category for men and women. Our results seem to be in accordance with a systematic review and meta-analysis conducted in Europe that examined BP in non-selected adult SSA, South Asian and EU subjects (Modesti et al., 2016) that found lower SBP levels among South Asians. However, in our study, Asian origin was not limited to South Asia, but also included South-East Asia and China, combining the numbers of participants of different Asian origins living in France (Beauchemin et al., 2018). We also found that individuals from North Africa with more than a high school diploma were in the lowest predicted SBP levels. By underlining the possible role of education, our results seem to nuance a clinical study that found no difference between the European and North African population living in France, after individually matching for age and sex (Lepoutre-Lussey et al., 2010). Due to French colonial history, people of North African origin are the most represented minority ethnoracial group in France (Beauchemin et al., 2023), but again, research remains limited to better understand the mechanisms at hand in our study.

Along with substantive contributions to inequities in SBP in a French context, our findings also shed light on the need for more intersectional health inequities research that includes race/ethnicity to investigate the impact of structural racism in European contexts. Indeed, racism reinforces inequities in healthcare access and quality for racialized people across various European contexts (Pattillo et al., 2023). It is critical that future studies on health inequities systematically include this dimension in a large scope of countries and health care systems. In 2016, a systematic review and meta analysis in panethnic differences in BP in Europe (Modesti et al., 2016), including twenty-three studies in the analysis showed a clear unbalance in the represented countries: eighteen were from the UK, two from Norway, two from the Netherlands, one from Italy, and none from other countries, such as France or Germany, where ethnoracial minorities make up a significant part of the population and where it has been shown that racism was present in healthcare services (Pattillo et al., 2023).

Furthermore, our results advocate for a more systematic use of the intersectional framework to tackle health inequities. While highlighting the needs of high-risk and often overlooked populations is a key contribution, our findings do not imply that attention or recommendations should be confined solely to targeted clinical interventions for these subgroups. Indeed, our results also call for multi-level, multi-actor actions at the population level to reduce the social gradient -patterned intersectionally-in high BP and hypertension in general. To do so, an intersectional framework appears instrumental to the concept of “proportionate universalism” (Marmot, 2010) (*i.e.,* health actions must be implemented with proportionate scale and intensity, depending on the level of disadvantage of a given population), and its implementation within the framework offered by Carey et al. (2015). The detailed identification of strata that are at particular risk of developing high SBP (older men with fewer years of formal education from all ethnoracial origins) and those that encounter premature rise in their SBP (younger DROMs and SSA men and women with fewer years of formal education), can contribute to designing policies and programs targeted to addressing their needs. These actions should be included at all levels, especially the community level, which has been proven efficient in hypertension management (Pasha et al., 2021). Furthermore, our results could help tailor prevention messages for specific disadvantaged groups of the population and therefore contribute to empowering them to make decisions on their own health. For instance, women could benefit from additional information on sex-specific risks of high BP at several stages of their lives (Burnier et al., 2023). These actions should be undertaken along with overall population policies, such as large-scale hypertension prevention and detection campaigns or free individual BP monitor distribution. In keeping with the activist origins of intersectionality, our findings also call for fighting against the systems of oppression under study (*i.e.,* racism, sexism, ageism, and social inequality) that shape marginalized positions in health.

4.1. Limitations

There are evident limitations to our study. First, the migratory classification that was used as a proxy for race/ethnicity could not identify third-generation immigrants, who, in some cases report different ethnoracial identification than the native population (Zhao and Drouhot, 2024) and might be exposed to discrimination. Furthermore, some individuals had to be excluded due to missing data or the inability to determine their migration status, a challenge amplified by the complexities of France's postcolonial context. Compared to representative samples of the French ethnoracial diversity, our cohort underestimated the SSA, DROMs and Asian minorities (Beauchemin et al., 2023). Not to mention that the CONSTANCES cohort did not have any Health Screening Center (HSC) in Seine-Saint-Denis, the poorest department in Metropolitan France, which also has the highest concentration of immigrants (39%), descendants of immigrants (28%), and individuals of DROMs origin (7%). Although our models converged, these reasons could possibly lead to an underselection of more marginalized minorities. Finally, while migratory status has been recognized as a valid proxy for race/ethnicity in French studies (Simon, 2011) and allows for hypotheses related to racism and ethnoracial discrimination to help explain the observed inequities, it is essential to highlight their differences. The use of migratory status as a proxy can obscure the distinction between the lived experiences of migration and those of racialization and racism. Although both intersect, they are fundamentally distinct, each entailing different social dynamics and health implications (Brun and Cosquer, 2022). Similarly, using sex (dichotomized as male/female in the administrative data that was used in this study) as a proxy for gender has important limitations, as previously discussed. While acknowledging these limitations, the reliance on proxies for gender and race/ethnicity provided valuable insights into the role of racism and sexism in shaping SBP while the CONSTANCES cohort offers an exceptional data infrastructure, its representativeness may be limited by selection factors inherent to cohort design and healthcare system access. These elements should be kept in mind when extrapolating the results to the broader French population—or to other European countries with different migration histories and health system structures—.

Third, although the three measures of SBP were standardized, the influence of the "white coat effect" could not be eliminated, potentially leading to a potential overestimation of SBP, especially among women and older individuals (Franklin et al., 2013), but not among Black participants according to a meta-analysis of data from the UK and the US (Agyemang et al., 2005). Differential effects, based on the French context, should be investigated. A recent study showed that women and immigrants from Africa or DROMs were more likely to forgo care and report discrimination in healthcare (Rivenbark and Ichou, 2020), which could suggest and entail mistrust in the medical system and increase alerting reaction when in a clinical environment. A white coat effect could be expected to be higher among those groups.

Fourth, socio-economic position was assessed only through education, which could be argued to show limitations. Income was not included in the strata, as it was not an individual-level variable in the CONSTANCES cohort, where only the average household monthly income is asked, which relates more to age-dependent capture of socio-economic circumstances of the household than to a social individual identity. Furthermore, in France, income-based health inequities tend to be reduced by the French universal health coverage and tax-based income redistribution policies, compared to other high-income countries (Nay et al., 2016). Education, on the other hand, hypothesized to be established at age 25 in our study, provides a good socio-economic individual-level factor that has been shown to be a fundamental determinant of social inequities -including health inequities-, especially in France, despite income redistribution (Etile, 2014). Thus, education provides a good socio-economic individual-level factor that influences health outcomes (Nay et al., 2016), and more precisely hypertension in the CONSTANCES study (Neufcourt et al., 2020). Our study could benefit from additional research testing our results using other variables (*i.e.,* individual income, social class) to account for socioeconomic inequity.

Fifth, in our study, some strata had a small sample size: eleven strata with a sample size of twenty participants or less. However, simulation studies have shown that MAIHDA reliably produces estimates for strata even with very small samples and are more accurate than conventional methods for intersectional analyses (Mahendran et al., 2022). Furthermore, confidence intervals often overlapped in our study, which enabled us to only note distinctions on either end of the distribution, and to suggest trends for the rest. Lastly, age accounted for a very large part of the between stratum variance, which may have masked the relative contribution of the other axis of oppression. Further studies could investigate the latter by conducting similar analyses stratified on age groups.

Lastly, although using registry-based data to identify individuals on hypertensive drugs presents valuable strength, some limitations can be underlined. By design, the SNDS database only contains information on drug purchases that have been reimbursed by the French national health insurance. Therefore, it does not capture the use of medications that are prescribed but not reimbursed or over-the-counter drug purchase. For antihypertensive medications, these limitations are minimal, as they are prescription-only drugs and almost always reimbursed in France. Furthermore, antihypertensive drugs cannot be reimbursed in a private channel unless they are at least partially reimbursed by the French national health insurance, and therefore captured in our study.

5. Conclusion

Taking an intersectional framework, enabled us to quantify and map inequities in SBP in France, highlighting patterns of inequities shaped by age, gender, race/ethnicity, and education. Particular attention should be given to the needs of SSA and DROMs with fewer years of formal education, who are intersectionally marginalized. More broadly, our results bring new insights for designing future interventions to reduce the social gradient in SBP and advocate for addressing the needs of marginalized sub-populations who face more harm and challenges in the unequal society that produces these inequities. Our study encourages a more systematic inclusion of racism as a major axis of oppression in research on health inequity, and advocates for more research that relies on the intersectionality framework to bring new insights for minimizing social determinants in health inequities, such as those found on SBP.

Regulatory and ethical approvals

Regulatory and ethical approvals, consent The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. All procedures have been approved by the Institutional review board (IRB) of the French Institute of Health (Inserm) (Opinion n°01–011, then n°21–842), and authorized by the by the French Data Protection Authority (“Commission Nationale de l’Informatique et des Libertés”, CNIL) (Authorization #910486). The biobank obtained a favorable advice from the Committee for the protection of individuals – CPP Sud Est I (#2018-32) and an authorization from the CNIL (#DR-2-2018-137). All participants signed a written consent form for their participation in CONSTANCES, and, where applicable, for their participation in the biobank. All information and regulatory authorizations relating to the publication are available on the French version page ‘Rights and data protection’.

CRediT authorship contribution statement

Léna Silberzan: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Fé·e Santos:** Conceptualization, Methodology, Writing – review & editing. **Ainhoa Ugarteche-Perez:** Conceptualization, Methodology, Writing – review & editing. **Emmanuel Wiernik:** Project administration. **Nathalie Bajos:** Funding acquisition, Supervision, Writing – review & editing. **Michelle Kelly-Irving:** Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2026.119054.

Data availability

Data will be made available on request.

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