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Research Paper

Single versus repeated blood pressure readings in hypertension screening: diagnostic misclassification and efficient re-measurement strategies in a nationally representative sample of US adults

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ABSTRACT

Background: Hypertension screening frequently relies on a single blood pressure (BP) reading, although guidelines recommend averaging repeated measurements. The consequences of this practice in nationally representative data are unquantified, and pragmatic re-measurement strategies have not been evaluated.
Objective: To quantify misclassification arising from single-reading BP screening in US adults and to evaluate conditional re-measurement strategies.
Methods: Cross-sectional analysis of 10,382 non-pregnant adults aged ≥18 years from the National Health and Nutrition Examination Survey (NHANES) 2009–2012 with three valid BP readings. The mean of the second and third readings served as the reference. The first reading alone, other averaging rules, and two conditional re-measurement strategies were compared at thresholds of 140/90 and 130/80 mmHg using survey-weighted analyses.
Results: The first reading exceeded the reference by a mean of 1.2 mmHg systolic and 0.8 mmHg diastolic, with wide individual limits of agreement (systolic −9.4 to +11.8 mmHg). Prevalence of BP ≥140/90 mmHg was 16.6% (95% CI 15.4–18.0%) by first reading versus 14.1% (13.1–15.1%) by reference, a relative overestimation of 18%. At ≥130/80 mmHg, prevalence was 38.7% versus 33.3%. Of adults classified as ≥140/90 mmHg on the first reading, 25.4% (22.6–28.5%) were not confirmed by the reference, rising to 43.9% when first-reading systolic BP was 140–144 mmHg. The first reading also missed 11.9% of reference-positive adults. Repeating measurement only when the first reading was within 10/5 mmHg of the threshold or above

required 1.6 readings per person and reduced misclassification from 5.9% to 0.2% of adults.

Conclusions: Single-reading screening substantially overstates hypertension-range BP and misclassifies a meaningful proportion of adults in both directions. Targeted repeat measurement achieves near-reference accuracy with modest additional effort and should be considered for screening programmes.

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1. INTRODUCTION

Raised blood pressure (BP) is the leading modifiable risk factor for death worldwide, accounting for an estimated 10.8 million deaths in 2019 [1]. About 1.28 billion adults aged 30–79 years were living with hypertension in 2019, and only about half had been diagnosed [2]. Closing this diagnostic gap through population and opportunistic screening is a central aim of global programmes such as the World Health Organization (WHO) HEARTS initiative and national control efforts in low- and middle-income countries [3], [4].

Screening is only as good as the measurement on which it rests. BP varies from beat to beat and is raised transiently by the alerting reaction to measurement, which can add more than 20 mmHg to systolic pressure in the first minutes of an encounter [5]. The first of a series of readings therefore tends to be the highest [6], and patient-, observer-, device- and procedure-related errors add further noise [7], [8]. For these reasons, international guidelines recommend basing decisions on the average of repeated readings [9], [10]; the European and International Society of Hypertension protocols specify three readings with the average of the last two [11], [12], [13], and the diagnosis should be confirmed on separate occasions or by out-of-office measurement [10], [14].

In practice, many screening encounters — in community campaigns, pharmacies, workplace programmes, primary care and household surveys — record a single reading. The consequences are both clinical and economic. Inaccurate measurement leads to misclassification with consequences for follow-up, treatment decisions and programme planning [15], [16]. A systematic review for the US Preventive Services Task Force found that an initial office measurement had a sensitivity of only 54% and specificity of 90% against ambulatory monitoring [17]. In India's National Family Health Survey, hypertension prevalence was 63% higher when the first reading was used instead of the mean of the second and third [18].

An earlier analysis of NHANES 1999–2008 showed that BP classification changes with the number of readings averaged [19]. However, to our knowledge, the diagnostic properties of a single reading under current thresholds — including the 2017 American College of Cardiology/American Heart Association (ACC/AHA) definition of ≥130/80 mmHg [10], [20] have not been reported using design-based estimates, and the efficiency of conditional re-measurement, in which only some people are measured again, has not been quantified. Such strategies matter most in resource-limited settings, where every additional reading costs staff time.

This study therefore used nationally representative NHANES data to (i) quantify the difference between a first BP reading and the guideline-recommended average of subsequent readings; (ii) estimate the prevalence, false-positive and false-negative rates produced by single-reading classification at the 140/90 and 130/80 mmHg thresholds; (iii) identify who is most likely to be misclassified; and (iv) compare the accuracy and measurement burden of alternative screening strategies.

2. METHODOLOGY

2.1 Data Source and Participants

This cross-sectional study used public data from the 2009–2010 and 2011–2012 cycles of NHANES, a stratified, multistage probability survey of the civilian, non-institutionalised US population conducted by the National Center for Health Statistics [21], [22]. Participants are interviewed at home and examined in a mobile examination centre, where up to three BP readings are recorded under a standardised protocol [23]. We used the NHANESraw dataset, which contains the examination variables, interview variables and survey design variables (examination weights, strata and primary sampling units) for both cycles, as distributed in the NHANES package for R, version 2.1.4 [24].

Of 20,293 participants, we included adults aged ≥18 years who had three valid systolic (SBP) and diastolic (DBP) readings, excluding women who reported being pregnant at examination (n = 125; 63 women with unknown pregnancy status were retained). Diastolic values of 0 mmHg were treated as missing. The study followed the STROBE guidelines for cross-sectional studies [25]. NHANES protocols were approved by the NCHS Research Ethics Review Board and all participants gave written informed consent; secondary analysis of these de-identified public data did not require additional approval.

2.2 Blood Pressure Definitions

The first reading (R1) represents single-reading screening. Following current measurement guidelines, which recommend three readings and averaging the last two [11], [12], [13], the mean of the second and third readings (R2–3) served as the reference standard. We also examined the mean of R1 and R2 and the mean of all three readings, the latter being the approach used in many epidemiological reports [26].

BP was classified as hypertension-range at two thresholds: SBP ≥140 or DBP ≥90 mmHg, as in the JNC7, ESH, ESC and ISH guidelines [9], [11], [13], [27], and SBP ≥130 or DBP ≥80 mmHg, as in the 2017 ACC/AHA guideline [10]. Because information on antihypertensive medication was not available in the dataset used, the outcome was hypertension-range BP at the examination rather than a diagnosis of hypertension; this is the quantity that a screening encounter measures.

2.3 Screening Strategies

Five strategies were compared with the reference: (i) R1 alone; (ii) mean of R1 and R2; (iii) mean of R1–R3; (iv) confirm-if-elevated, in which R2 and R3 were taken only when R1 was at or above the threshold and the person was classified by the mean of R2–3, otherwise as below the threshold; and (v) confirm-near-threshold, in which R2 and R3 were taken when R1 was within 10 mmHg (systolic) or 5 mmHg (diastolic) of the threshold or above it. For each strategy we calculated the mean number of readings per person (1 + 2 × proportion re-measured).

2.4 Covariates

Age group (18–39, 40–59, ≥60 years), sex, race and ethnicity (Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, other or multiracial), body mass index (BMI; <25, 25–29.9, ≥30 kg/m^2), education and current smoking (asked of adults aged ≥20 years), family income-to-poverty ratio, self-reported diabetes and survey cycle were taken from the interview and examination data.

2.5 Statistical Analysis

All estimates used combined four-year examination weights (one half of the two-year weight), with variance estimated by Taylor-series linearisation accounting for 29 strata and 62 primary sampling units (33 design degrees of freedom), following NHANES analytic guidelines [23], [28]. Proportions are presented with logit-transformed 95% confidence intervals (CIs) based on the t-distribution; estimates in subgroups used domain (ratio) estimation so that the full design was retained [28].

Agreement between R1 and the reference was described by the weighted mean difference and Bland–Altman 95% limits of agreement [29]. For each strategy we estimated weighted prevalence, sensitivity, specificity, positive and negative predictive values (PPV, NPV) and Cohen's κ [30], interpreted using the Landis–Koch categories [31]; κ CIs were obtained by a stratified delete-one-PSU jackknife with within-stratum reweighting. The proportion of first-reading positives not confirmed (1 − PPV) was estimated overall, by subgroup and by 5-mmHg bands of first-reading SBP. Factors associated with non-confirmation among first-reading positives were examined with weighted logistic regression including age group, sex, race and ethnicity, BMI category, self-reported diabetes, survey cycle and the amount by which R1 exceeded the systolic and diastolic thresholds (per 5 mmHg; zero if not exceeded), with normalised examination weights and standard errors clustered on primary sampling units (stratification not incorporated). Analyses were performed in Python 3.11 using NumPy, pandas, SciPy and statsmodels [32]. Two-sided $P < 0.05$ was considered statistically significant.

3. RESULTS AND DISCUSSION

3.1 Study Population

The analytic sample comprised 10,382 adults (Figure 1), representing approximately 201 million US adults. Their weighted mean age was 46.4 years and 50.1% were women (Table 1). Mean SBP was 121.9 mmHg on the first reading and 120.7 mmHg on the mean of the second and third readings; mean DBP was 71.0 and 70.3 mmHg, respectively.

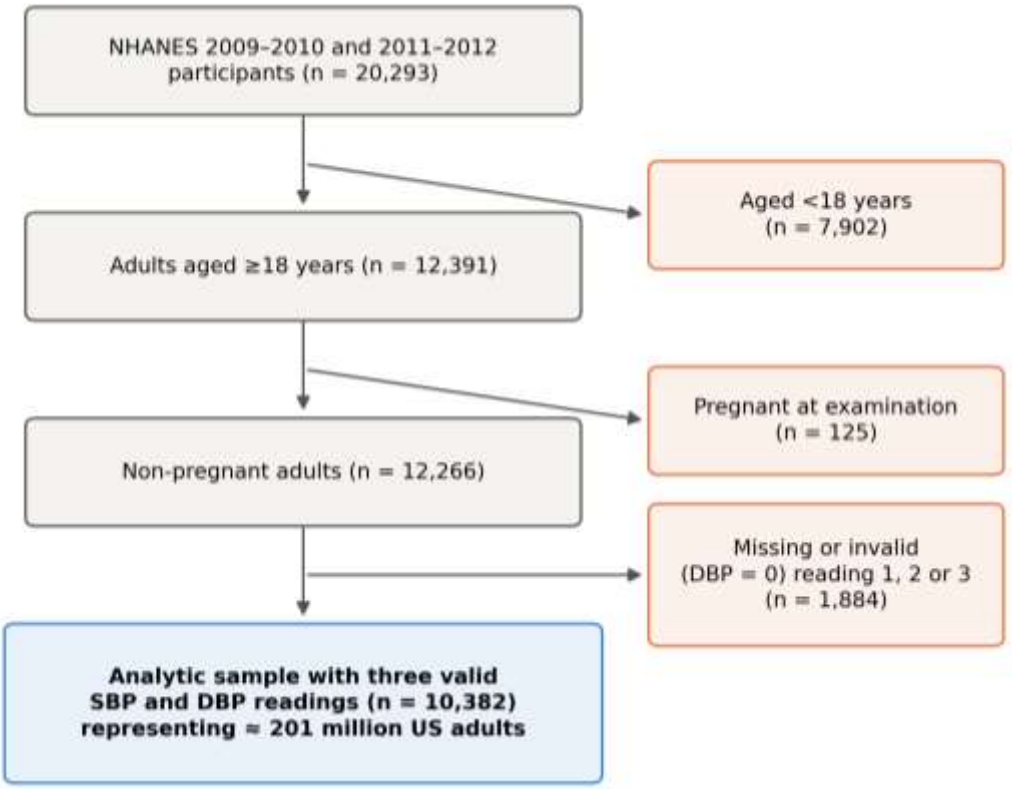


Figure 1. Selection of the Analytic Sample from NHANES 2009–2012

Table 1. Characteristics of the Study Population, NHANES 2009–2012 (n = 10,382)

Characteristic	Unweighted n	Weighted % or Mean (95% CI)
Age, years, mean	10,382	46.4 (45.3–47.4)
Women	5,121	50.1 (49.0–51.2)
Age group		
18–39	3,863	38.0 (35.1–41.0)
40–59	3,316	37.6 (36.0–39.1)
≥60	3,203	24.4 (22.7–26.3)
Race/ethnicity		
Non-Hispanic White	4,393	67.3 (61.8–72.4)
Non-Hispanic Black	2,289	11.3 (9.0–14.3)
Mexican American	1,531	8.4 (5.9–11.7)
Other Hispanic	1,057	5.8 (4.1–8.1)
Other/multiracial	1,112	7.2 (5.8–8.8)
BMI (kg/m^2)		
<25	3,207	31.9 (29.7–34.2)
25–29.9	3,415	33.8 (32.0–35.6)
≥30	3,654	34.3 (32.7–36.0)
Education		
< High school	2,590	17.8 (15.7–20.1)
High school	2,153	21.3 (19.6–23.2)
Some college	2,874	31.6 (29.8–33.4)
College graduate	2,233	29.3 (26.5–32.3)
Income-to-poverty ratio		
<1.30	3,306	23.3 (21.1–25.7)
1.30–3.49	3,409	35.4 (32.9–38.1)
≥3.50	2,754	41.2 (38.0–44.6)
Self-reported diabetes	1,413	10.5 (9.7–11.4)
Current smoker	2,077	20.3 (18.9–21.8)
SBP reading 1, mmHg, mean	10,382	121.9 (121.1–122.7)
SBP mean of readings 2–3, mmHg, mean	10,382	120.7 (119.9–121.5)
DBP reading 1, mmHg, mean	10,382	71.0 (70.3–71.8)
DBP mean of readings 2–3, mmHg, mean	10,382	70.3 (69.4–71.1)

Percentages exclude participants with missing values for that characteristic (education n = 532, income n = 913, BMI n = 106, smoking n = 522, diabetes n = 6 missing); education and smoking were asked only of adults aged ≥20 years. BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure.

3.2 Difference between the First Reading and the Reference

The first reading was higher than the reference by a weighted mean of 1.2 mmHg systolic (95% CI 1.0–1.4) and 0.8 mmHg diastolic (0.5–1.0) (Table 2, Figure 2). Individual differences were large: the 95% limits of agreement were −9.4 to +11.8 mmHg for SBP and −9.0 to +10.5 mmHg for DBP. The first SBP reading was at least 5 mmHg above the reference in 24% of adults and at least 10 mmHg above it in 6%, whereas it was at least 5 mmHg below the reference in 13%. The systolic first-reading excess rose with age, from 0.7 mmHg at 18–39 years to 2.4 mmHg at ≥60 years, was slightly larger in women than in men (1.4 vs 1.0 mmHg), and was larger in the 2009–2010 than in the 2011–2012 cycle (1.7 vs 0.7 mmHg).

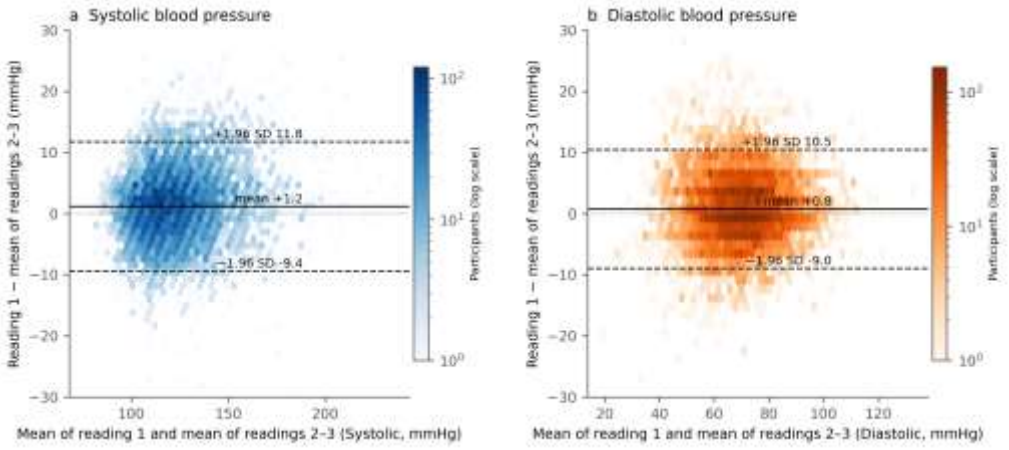


Figure 2. Bland–Altman Plots of the First Reading Versus the Mean of Readings 2–3 for (a) Systolic and (b) Diastolic Blood Pressure. Shading Shows the Number of Participants (Log Scale); Solid Lines Show the Weighted Mean Difference and Dashed Lines the 95% Limits of Agreement

Table 2. Difference between the First Reading and the Mean of Readings 2–3 (Reading 1 Minus Reference), Overall and by Subgroup

Group	N	SBP Difference, mmHg (95% CI)	DBP Difference, mmHg (95% CI)
Overall	10,382	1.18 (0.97 to 1.38)	0.75 (0.54 to 0.97)
95% limits of agreement		−9.4 to 11.8	−9.0 to 10.5
Reading 1 ≥5 mmHg higher, %		23.6	19.5
Reading 1 ≥10 mmHg higher, %		6.2	3.9
Reading 1 ≥5 mmHg lower, %		12.7	11.9
Age			
18–39	3,863	0.66 (0.45 to 0.88)	0.41 (0.15 to 0.66)
40–59	3,316	0.90 (0.61 to 1.18)	0.71 (0.46 to 0.96)
≥60	3,203	2.40 (2.00 to 2.79)	1.37 (1.05 to 1.68)
Sex			
Female	5,121	1.36 (1.10 to 1.62)	0.85 (0.56 to 1.14)
Male	5,261	0.99 (0.77 to 1.20)	0.66 (0.44 to 0.88)
Race/ethnicity			
Non-Hispanic White	4,393	1.11 (0.85 to 1.36)	0.73 (0.46 to 1.00)
Non-Hispanic Black	2,289	1.34 (1.01 to 1.66)	1.01 (0.68 to 1.34)
Mexican American	1,531	1.47 (1.18 to 1.77)	0.79 (0.43 to 1.15)
Other Hispanic	1,057	1.37 (0.90 to 1.84)	0.50 (0.16 to 0.84)
Other/multiracial	1,112	1.07 (0.56 to 1.57)	0.74 (0.28 to 1.20)
BMI			
<25	3,207	1.17 (0.84 to 1.49)	0.61 (0.27 to 0.95)
25–29.9	3,415	1.17 (0.85 to 1.49)	0.90 (0.65 to 1.16)
≥30	3,654	1.18 (0.96 to 1.40)	0.75 (0.49 to 1.01)
Cycle			
2009–2010	5,511	1.69 (1.51 to 1.88)	1.02 (0.66 to 1.38)
2011–2012	4,871	0.67 (0.33 to 1.01)	0.50 (0.31 to 0.68)
Reference SBP			
<120	5,256	1.33 (1.12 to 1.55)	0.63 (0.37 to 0.89)
120–129	2,246	0.76 (0.41 to 1.12)	0.75 (0.44 to 1.05)
130–139	1,322	1.30 (0.83 to 1.78)	0.82 (0.45 to 1.18)

140–159	1,172	1.00 (0.36 to 1.64)	1.16 (0.57 to 1.75)
≥160	386	1.57 (0.45 to 2.70)	1.55 (0.65 to 2.45)

3.3 Prevalence and Classification Accuracy

Using R1 alone, 16.6% (95% CI 15.4–18.0%) of adults had BP ≥140/90 mmHg, compared with 14.1% (13.1–15.1%) by the reference — a relative overestimation of 18% (Figure 3, Table 3). At the ACC/AHA threshold of 130/80 mmHg, prevalence was 38.7% (36.9–40.6%) versus 33.3% (31.6–35.2%), a 16% relative overestimation. Averaging R1 with R2 reduced but did not remove the excess (14.7% and 35.1%).

At 140/90 mmHg, R1 had a sensitivity of 88.1% (85.5–90.3%), specificity of 95.1% (94.3–95.8%), PPV of 74.6% (71.5–77.4%) and κ of 0.77 (0.75–0.80), indicating substantial rather than almost perfect agreement; averaging R1 and R2 raised κ to 0.87. Thus 25.4% (22.6–28.5%) of adults classified as hypertension-range by the first reading were below the threshold on the reference, while 11.9% of reference-positive adults were missed by the first reading. At 130/80 mmHg, 20.5% (18.8–22.3%) of first-reading positives were not confirmed and 7.6% of reference-positive adults were missed (κ 0.77). Overall, single-reading classification misclassified 5.9% of all adults at 140/90 mmHg and 10.5% at 130/80 mmHg, most of them as false positives (4.2% and 7.9% of all adults).

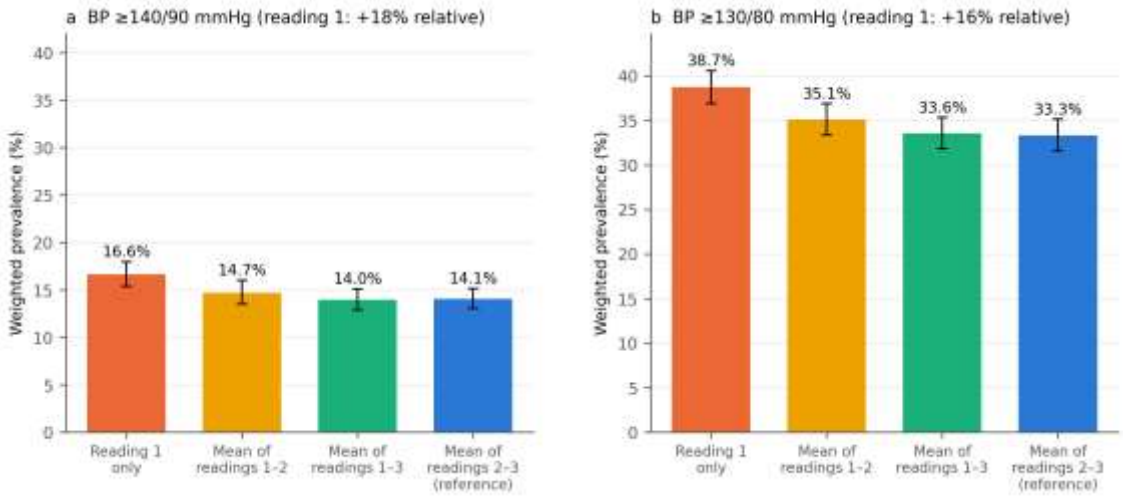


Figure 3. Weighted Prevalence of Blood Pressure (a) ≥140/90 mmHg and (b) ≥130/80 mmHg by Measurement Strategy, with 95% Confidence Intervals

Table 3. Prevalence and Diagnostic Performance of Screening Strategies Against the Reference (Mean of Readings 2–3).

Threshold / Strategy	Readings per Person	Prevalence, % (95% CI)	Sensitivity, % (95% CI)	Specificity, % (95% CI)	PPV, % (95% CI)	NPV, % (95 % CI)	κ (95 % CI)	Misclassified, % of Adults
≥140/90 mmHg								
Reference: mean of readings 2–3	3	14.1 (13.1–15.1)	—	—	—	—	—	—

Reading 1 only	1	16.6 (15.4–18.0)	88.1 (85.5–90.3)	95.1 (94.3–95.8)	74.6 (71.5–77.4)	98.0 (97.5–98.4)	0.77 (0.75–0.80)	5.9
Mean of readings 1–2	2	14.7 (13.5–16.0)	91.1 (88.3–93.3)	97.8 (97.3–98.2)	87.2 (85.2–88.9)	98.5 (98.1–98.9)	0.87 (0.86–0.89)	3.1
Mean of readings 1–3	3	14.0 (12.9–15.1)	93.6 (90.8–95.5)	99.1 (98.7–99.3)	94.3 (92.2–95.9)	98.9 (98.5–99.3)	0.93 (0.91–0.94)	1.7
Repeat if reading 1 ≥ threshold	1.33	12.4 (11.4–13.4)	88.1 (85.5–90.3)	100 (by construction)	100 (by construction)	98.1 (97.7–98.4)	0.93 (0.91–0.94)	1.7
Repeat if reading 1 ≥ threshold – 10/5 mmHg	1.61	13.9 (12.9–14.9)	98.4 (95.8–99.4)	100 (by construction)	100 (by construction)	99.7 (99.3–99.9)	0.99 (0.98–1.00)	0.2
≥130/80 mmHg								
Reference: mean of readings 2–3	3	33.3 (31.6–35.2)	—	—	—	—	—	—
Reading 1 only	1	38.7 (36.9–40.6)	92.4 (91.4–93.3)	88.1 (87.1–89.1)	79.5 (77.7–81.2)	95.9 (95.4–96.3)	0.77 (0.76–0.79)	10.5
Mean of readings 1–2	2	35.1 (33.4–36.9)	94.3 (93.4–95.1)	94.5 (93.7–95.1)	89.5 (88.0–90.9)	97.1 (96.7–97.5)	0.88 (0.86–0.89)	5.6
Mean of readings 1–3	3	33.6 (31.8–35.4)	95.5 (94.7–96.1)	97.4 (96.9–97.8)	94.8 (93.8–95.7)	97.7 (97.3–98.0)	0.93 (0.92–0.94)	3.3
Repeat if reading 1 ≥ threshold	1.77	30.8 (29.0–32.7)	92.4 (91.4–93.3)	100 (by construction)	100 (by construction)	96.3 (95.9–96.7)	0.94 (0.94–0.95)	2.5
Repeat if reading 1 ≥ threshol	2.20	33.0 (31.2–34.9)	99.1 (98.7–99.3)	100 (by construction)	100 (by construction)	99.5 (99.4–99.7)	0.99 (0.99–1.00)	0.3

d – 10/5 mmHg								

All estimates survey-weighted. Conditional strategies classify by the mean of readings 2–3 when re-measurement is triggered, so their specificity and PPV are 100% by construction. The mean of readings 1–3 shares two readings with the reference, which inflates its agreement. NPV, negative predictive value; PPV, positive predictive value.

3.4 Who is Misclassified?

The probability that a positive first reading was not confirmed depended strongly on how close the reading was to the threshold (Figure 4, Table 4). Among adults whose first SBP was 140–144 mmHg, 43.9% (38.6–49.2%) were below 140/90 mmHg on the reference; the proportion fell to 17.9% at 145–149 mmHg, 13.5% at 150–154 mmHg and ≤3% at 155 mmHg or more, and no participant with a first SBP ≥165 mmHg was reclassified. At the 130/80 mmHg threshold, 32.6% of adults with a first SBP of 130–134 mmHg were reclassified.

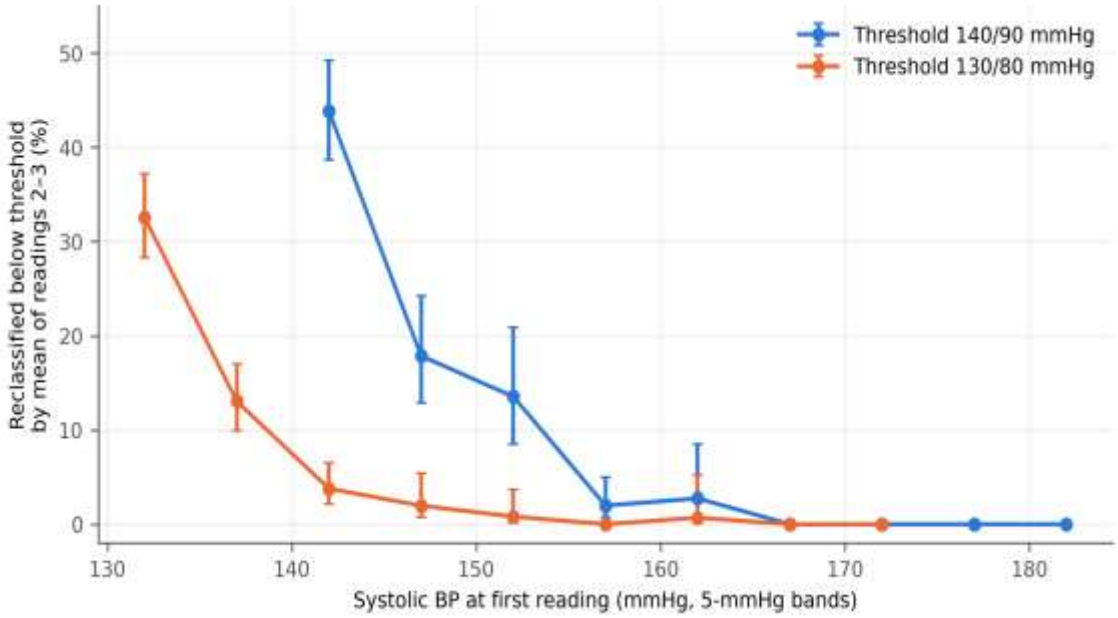


Figure 4. Proportion of Adults Reclassified Below the Threshold by the Mean of Readings 2–3, by Systolic Blood Pressure at the First Reading (5-mmHg Bands), with 95% Confidence Intervals

Non-confirmation was more common in younger adults (35.2% at 18–39 years vs 22.7% at ≥60 years for 140/90 mmHg; 28.1% vs 15.7% for 130/80 mmHg) and, at 130/80 mmHg, less common among adults with diabetes (13.9% vs 21.6%) (Figure 5). Younger first-reading positives were close to the threshold: their mean first SBP was 2.9 mmHg below 140 mmHg (many crossed the threshold on DBP alone), compared with 14.1 mmHg above it among those aged ≥60 years. Age differences were attenuated after adjustment. In multivariable models (Table 5), each 5 mmHg by which the first SBP exceeded 140 mmHg reduced the odds of non-confirmation by 69% (odds ratio [OR] 0.31, 95% CI 0.24–0.41), and each 5 mmHg of DBP above 90 mmHg reduced them by 84% (OR 0.16, 0.09–0.27); age, sex, race and ethnicity, BMI and diabetes were not independently associated with non-confirmation at this threshold. At 130/80 mmHg, the margins above threshold were again the strongest predictors, but other or multiracial adults (OR 1.55, 1.06–2.26) and possibly Mexican American adults (OR 1.44, 1.00–2.09) had higher odds of non-confirmation, and the 2011–2012 cycle had lower odds (OR 0.64, 0.48–0.87).

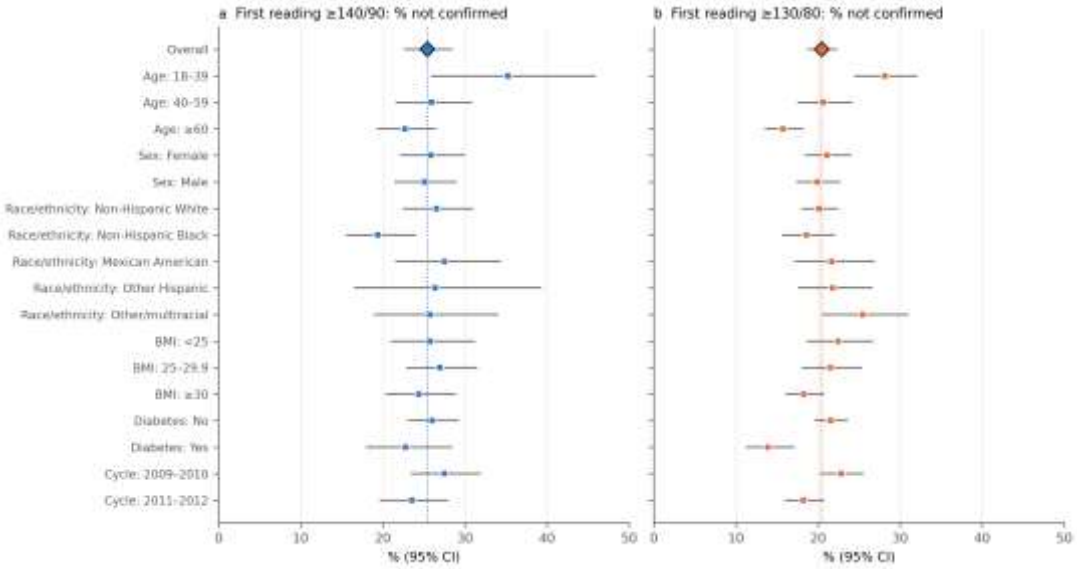


Figure 5. Proportion of Adults with a Positive First Reading Who Were Not Confirmed by the Reference, by Subgroup, at (a) 140/90 mmHg and (b) 130/80 mmHg. Dotted Lines Show the Overall Estimate

Table 4. Proportion of Adults with a Positive First Reading Who Were Below the Threshold on the Reference (Not Confirmed), by First-Reading Systolic BP and by Subgroup

Group	≥140/90 mmHg: n	≥140/90 mmHg: % Not Confirmed (95% CI)	≥130/80 mmHg: n	≥130/80 mmHg: % Not Confirmed (95% CI)
Overall	2,040	25.4 (22.6–28.5)	4,312	20.5 (18.8–22.3)
Age				
18–39	211	35.2 (25.9–45.8)	820	28.1 (24.5–32.0)
40–59	626	25.9 (21.6–30.8)	1,516	20.6 (17.6–24.1)
≥60	1,203	22.7 (19.4–26.4)	1,976	15.7 (13.6–18.2)
Sex				
Female	957	25.9 (22.2–29.9)	1,924	21.1 (18.5–24.0)
Male	1,083	25.0 (21.5–28.9)	2,388	19.9 (17.5–22.6)
Race/ethnicity				
Non-Hispanic White	826	26.5 (22.5–30.9)	1,797	20.1 (18.1–22.3)
Non-Hispanic Black	579	19.4 (15.6–23.9)	1,135	18.6 (15.7–22.0)
Mexican American	274	27.5 (21.6–34.4)	552	21.7 (17.3–26.8)
Other Hispanic	179	26.4 (16.6–39.2)	402	21.8 (17.6–26.5)
Other/multiracial	182	25.8 (19.0–34.0)	426	25.4 (20.5–31.0)
BMI				
<25	494	25.8 (21.0–31.1)	1,022	22.4 (18.7–26.6)
25–29.9	683	27.0 (22.9–31.4)	1,455	21.5 (18.1–25.3)
≥30	842	24.4 (20.4–28.8)	1,788	18.3 (16.1–20.6)
Diabetes				
No	1,586	26.0 (23.1–29.1)	3,497	21.6 (19.7–23.6)
Yes	453	22.8 (18.0–28.3)	813	13.9 (11.3–17.0)
Cycle				

2009–2010	1,092	27.5 (23.5–31.9)	2,289	22.8 (20.4–25.5)
2011–2012	948	23.5 (19.7–27.9)	2,023	18.2 (16.0–20.7)

First-reading SBP band (all adults in band; % below threshold on the reference)

SBP Band at Reading 1, mmHg	N	% Reclassified, ≥140/90 (95% CI)
140–144	559	43.9 (38.6–49.2)
145–149	259	17.9 (12.9–24.2)
150–154	300	13.5 (8.5–20.9)
155–159	160	2.0 (0.8–5.0)
160–164	182	2.7 (0.8–8.5)
165–169	97	0.0 (not estimable)
170–174	79	0.0 (not estimable)
175–179	41	0.0 (not estimable)
≥180	120	0.0 (not estimable)

SBP Band at Reading 1, mmHg	N	% Reclassified, ≥130/80 (95% CI)
130–134	965	32.6 (28.3–37.2)
135–139	536	13.1 (9.9–17.0)
140–144	559	3.8 (2.2–6.5)
145–149	259	2.0 (0.7–5.4)
150–154	300	0.8 (0.2–3.7)
155–159	160	0.0 (not estimable)
160–164	182	0.7 (0.1–5.2)
165–169	97	0.0 (not estimable)
≥170	240	0.0 (not estimable)

In bands in which no adult was reclassified, the logit-transformed confidence interval is undefined and is reported as not estimable; the absence of observed events in these bands does not establish that the true proportion is zero. SBP, systolic blood pressure.

Table 5. Factors Associated with Non-Confirmation of a Positive First Reading (Survey-Weighted Logistic Regression)

Variable	≥140/90 mmHg: OR (95% CI)	P	≥130/80 mmHg: OR (95% CI)	P
Age 18–39 (vs ≥60)	1.03 (0.60–1.78)	0.912	0.79 (0.56–1.10)	0.163
Age 40–59 (vs ≥60)	0.81 (0.52–1.26)	0.349	0.72 (0.51–1.02)	0.062
Women (vs men)	1.13 (0.79–1.61)	0.507	1.25 (0.98–1.60)	0.073
Mexican American (vs NH White)	1.01 (0.66–1.53)	0.977	1.44 (1.00–2.09)	0.050
Non-Hispanic Black (vs NH White)	0.86 (0.58–1.28)	0.460	1.22 (0.91–1.63)	0.185
Other Hispanic (vs NH White)	1.13 (0.63–2.04)	0.678	1.29 (0.88–1.91)	0.195
Other/multiracial (vs NH White)	0.73 (0.40–1.34)	0.316	1.55 (1.06–2.26)	0.024
BMI 25–29.9 (vs <25)	0.85 (0.52–1.38)	0.504	0.97 (0.64–1.48)	0.893
BMI ≥30 (vs <25)	0.64 (0.41–1.02)	0.060	0.77 (0.55–1.07)	0.114
Self-reported diabetes	1.09 (0.79–1.51)	0.593	0.81 (0.56–1.17)	0.264
Cycle 2011–2012 (vs 2009–2010)	0.79 (0.55–1.11)	0.172	0.64 (0.48–0.87)	0.004

Reading-1 SBP above threshold, per 5 mmHg	0.31 (0.24–0.41)	< 0.001	0.25 (0.20–0.30)	< 0.001
Reading-1 DBP above threshold, per 5 mmHg	0.16 (0.09–0.27)	< 0.001	0.19 (0.14–0.25)	< 0.001

Models restricted to adults with a positive first reading and complete covariates (n = 2,018 and 4,263). Standard errors clustered on primary sampling units. NH, non-Hispanic; OR, odds ratio.

3.5 Efficiency of Re-Measurement Strategies

Conditional re-measurement achieved most of the benefit of repeated readings at a fraction of the effort (Figure 6, Table 3). At 140/90 mmHg, re-measuring only the 16.6% of adults whose first reading was at or above the threshold eliminated false positives by design and reduced overall misclassification to 1.7% of adults, at 1.33 readings per person, but it could not recover the 1.7% of adults missed by the first reading. Extending re-measurement to first readings within 10/5 mmHg below the threshold (30.6% of adults re-measured) required 1.61 readings per person, raised sensitivity to 98.4% (95.8–99.4%) and reduced misclassification to 0.2% of adults. At 130/80 mmHg the corresponding near-threshold strategy required 2.20 readings per person and reduced misclassification from 10.5% to 0.3%.

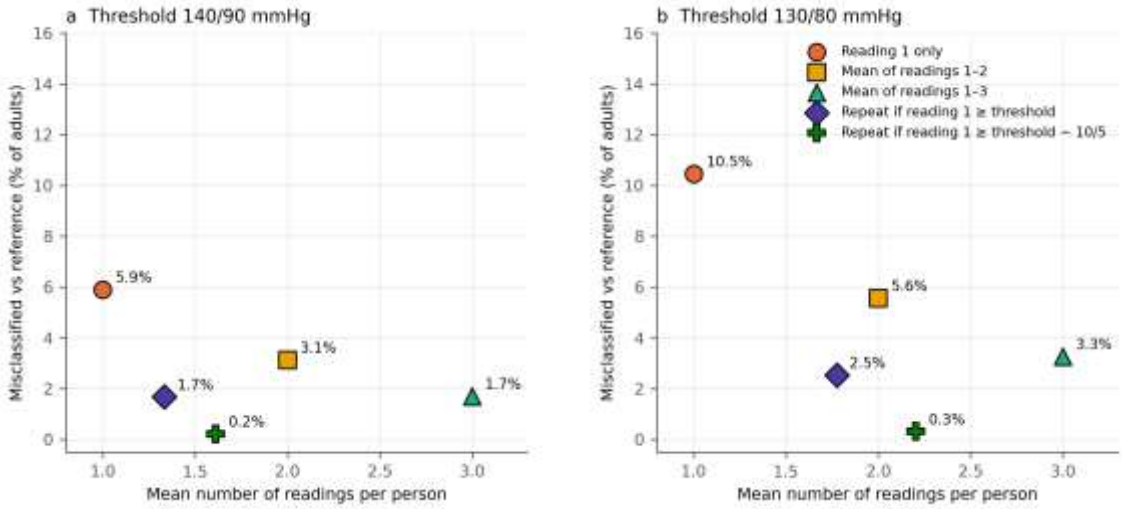


Figure 6. Measurement Burden (Mean Readings per Person) and Misclassification (% of All Adults) for Five Screening Strategies at (a) 140/90 mmHg and (b) 130/80 mmHg

3.6 Discussion

3.6.1 Principal Findings

In this nationally representative sample of US adults, a single BP reading overestimated the prevalence of hypertension-range BP by 16–18% relative to the guideline-recommended average of the second and third readings. One in four adults with a first reading of ≥140/90 mmHg, and one in five with a first reading of ≥130/80 mmHg, was not confirmed on the same visit. Misclassification was concentrated among people whose first reading lay just above the threshold; at 140/90 mmHg it was not explained by demographic characteristics once that distance was considered. A simple rule — repeat the measurement whenever the first reading is near or above the threshold — reproduced the reference classification for more than 99% of adults while requiring about half (at 140/90 mmHg) to three-quarters (at 130/80 mmHg) of the readings of a full three-reading protocol.

3.6.2 Interpretation

The small mean difference between the first and later readings (about 1 mmHg) contrasts with the large effect on classification. This apparent paradox is explained by the distribution of BP: a large share of

the population lies close to the diagnostic thresholds, so even a modest upward shift moves many people across them, and the first SBP reading exceeded the reference by 10 mmHg or more in 6% of adults. The pattern is consistent with the alerting reaction and with regression to the mean [5], [6]. Because random variability operates in both directions, the first reading also missed some people whose subsequent readings were elevated, a point often neglected when single readings are viewed only as a source of over-diagnosis.

Our estimates agree with earlier NHANES work showing that BP classification depends on the number of readings averaged [19], and they are more conservative than the 63% relative excess reported in India's NFHS-4 [18]. That difference may reflect the standardised measurement conditions of the NHANES mobile examination centre. Under the less standardised conditions of community screening, pharmacies and busy clinics, the first-reading excess may be larger [7], [33], [34], so our estimates are likely to be conservative for routine practice.

The higher non-confirmation proportion in younger adults is explained by the margin above the threshold: younger adults who screen positive do so by small margins, often on diastolic pressure alone, so a given measurement error is more likely to reverse their classification. At 140/90 mmHg, demographic factors did not predict non-confirmation once this margin was accounted for, suggesting that a single rule based on the first reading can be applied across population groups; at 130/80 mmHg some residual differences by race and ethnicity and by survey cycle remained and deserve confirmation. The larger first-reading excess in older adults is consistent with greater BP variability and a stronger pressor response with age, although we could not examine mechanisms.

3.6.3 Implications for Prevention and Screening

Three practical implications follow. First, screening programmes and surveys should not classify people on a single reading. Where staff time is limited, the conditional rule evaluated here — take a second and third reading only when the first is within 10/5 mmHg of the threshold or above it — offers near-reference accuracy with on average 1.6 readings per person at 140/90 mmHg. Because about 69% of adults have a first reading well below the 140/90 mmHg threshold, most need only one reading. Second, prevalence estimates and programme targets based on single readings should be interpreted with caution, because they overstate the number of people needing follow-up by about 16–18%. Third, the same-visit average is itself only the first step: guidelines recommend confirmation on separate occasions or with home or ambulatory monitoring before diagnosis and treatment [9], [10], [14]. Accurate same-visit classification reduces the number of people who must return, which matters for programmes such as the India Hypertension Control Initiative and WHO HEARTS that operate at scale [3], [4]. Automated devices that take repeated readings, validated against accepted accuracy standards, make the conditional strategy straightforward to implement [8], [35].

3.6.4 Strengths and Limitations

The main strengths are the use of a large, nationally representative sample with three standardised readings per participant, design-based estimation throughout, examination of both current diagnostic thresholds, and the explicit evaluation of conditional re-measurement strategies.

Several limitations should be noted. The reference standard the mean of the second and third readings at one visit is not a diagnosis of hypertension, which requires confirmation on separate occasions or by out-of-office monitoring; our results describe same-visit classification only. Information on antihypertensive treatment was not available in the dataset used, so treated individuals with controlled BP were classified by their measured values. The R1–R3 average shares readings with the reference, which inflates its apparent agreement. The data are from 2009–2012, and the first-reading excess differed between the two cycles, so estimates may not apply to current measurement procedures or other settings. The conditional strategies were simulated on readings taken in a fixed sequence; their 100% specificity and PPV hold by construction because the reference classifies everyone who is re-measured, and in practice the decision to re-measure might itself influence the patient's BP. Finally, the logistic models did not incorporate stratification.

4. CONCLUSION

A single BP reading misclassifies a substantial proportion of adults at both the 140/90 and 130/80 mmHg thresholds, overestimating hypertension-range BP by 16–18% and failing to confirm one in four positive screens at 140/90 mmHg. Misclassification is concentrated just above the threshold. Repeating the measurement when the first reading is near or above the threshold restored near-reference accuracy at modest additional cost in this analysis. Screening programmes, primary care and population surveys should consider such targeted repeat measurement, and its performance should be evaluated prospectively in routine settings.

Author Contribution Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Matsakov Kanybek	✓	✓	✓		✓				✓		✓			
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Begaly uulu Samidin			✓				✓				✓		✓	✓

C: **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

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Conflict of Interest Statement

No conflict of interest.

Informed Consent

Not Applicable. The study used only publicly available, anonymised data.

Ethical Approval

Not Applicable. The study is a secondary analysis of publicly available, anonymised data and involved no contact with human participants.

Data Availability

This study uses the publicly available NHANES 2009–2012 data of the National Center for Health Statistics, obtained from wwwn.cdc.gov/nchs/nhanes. No new datasets were created. The analysis code is available from the corresponding author on reasonable request.

Use of Generative AI

Generative AI tools were not used to generate the scientific content, data, analyses or results of this study. Any AI-assisted language editing was reviewed and revised by the authors, who take full responsibility for the content of this article.

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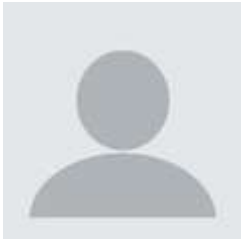
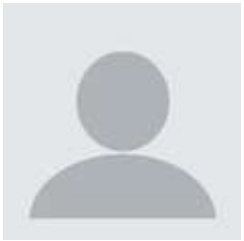
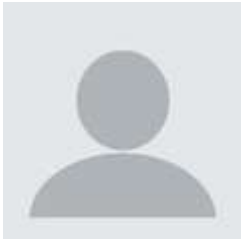
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