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VARIATION IN CERVICAL AND BREAST CANCER SCREENING COVERAGE IN ENGLAND: A CROSS-SECTIONAL ANALYSIS TO CHARACTERISE PRIMARY CARE TRUSTS (PCTs) WITH ATYPICAL BEHAVIOUR

Running title: Atypical Screening coverage in England

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STRENGTHS AND LIMITATIONS OF THIS STUDY

- This study reports on thorough analysis of breast and cervical screening coverage rates to identify area-level factors associated with high and low coverage.
- This is the first study to characterise English PCTs with atypically high or low cervical or breast screening coverage using a risk-adjustment approach.
- At PCT level, high rates of deprivation, urbanisation, and ethnic minority groups other than Asian, Black, or Mixed remain independent predictors of lower coverage for both programmes, and explain most of the lower cervical screening coverage seen in London.
- PCTs with atypically low screening coverage displayed distinct correlation patterns between their population characteristics, in particular distinct correlates of deprivation: these districts may benefit from the development of new approaches to target the low-attending communities living within their boundaries.
- This study deals only with area-level rather than individual-level factors. However, this is often the only data available on participation in public health interventions; the method used is fairly simple and could easily be applied to other settings.

ABSTRACT

Objectives. Reducing cancer screening inequalities in England is a major focus of the 2011 Department of Health cancer outcome strategy. Screening coverage requires regular monitoring in order to implement targeted interventions where coverage is low. This study aimed to characterise districts with atypical coverage levels for cervical or breast screening.

Design. Observational study of Primary Care Trust (PCT)-level coverage in the English Cervical and Breast screening programmes in 2012.

Setting. England, UK.

Participants. All English women invited to participate to the Cervical (age group 25-49 and 50-64) and Breast (age group 50-64) screening programmes.

Outcomes. Risk adjustment models for coverage were developed based on PCT-level characteristics. Funnel plots of adjusted coverage were constructed and atypical PCTs examined by correlation analysis.

Results. Variability in coverage was primarily explained by population factors, whereas general practice characteristics had little independent effect. Deprivation and ethnicity other than White, Asian, Black, or Mixed were independently associated with poorer coverage in both screening programmes, with ethnicity having the strongest effect; in comparison the influence of Asian, Black, or Mixed ethnic minority was limited. Deprivation, ethnicity and urbanisation largely accounted for the lower cervical screening coverage in London. However, for breast screening, being located in London remained a strong negative predictor. A subset of PCTs was identified as having atypical coverage across programmes.

Correlates of deprivation in PCTs with relatively low adjusted coverage were substantially different from overall correlates of deprivation.

Discussion. These results inform the continuing drive to reduce avoidable cancer deaths in England, and encourage implementation of targeted interventions in communities residing in districts identified as having atypically low coverage. Sequential implementation to monitor the impact of local interventions would help accrue evidence on 'what works'.

INTRODUCTION

The English National Cervical and Breast Screening Programmes aim either to prevent cancer by treating pre-cancerous changes or diagnose cancer at earlier stages when treatment outcomes are more successful^{1,2}. Their success is dependent upon high levels of participation³.

Reducing cancer screening inequalities in England is a major focus of the 2011 Department of Health cancer outcome strategy to promote early diagnosis and save lives^{4,5}. There is a need to characterise districts that require most support in reducing inequalities or those which could be used as leading examples.

Funnel plots overlapped with control limits have been shown to be a useful tool for comparing proportional outcomes between centres or districts⁶⁻⁸. The outcome is plotted against a measure of precision for each district, and control limits are set around the target value. Districts lying outside the limits are subject to ‘special-cause variation’ and may repay further investigation. Control limits can be adjusted to incorporate sources of variation such as demographic and socio-economic factors in order to identify districts with atypically high or low outcomes, given their known characteristics^{8,9}.

Identification of atypical districts might be expected to be a simple matter. It is, however, challenging due to the necessarily incomplete nature of aggregate data, the possible collinearities in such data, and the multiplicity of model choices, even with relatively small numbers of potential risk factors.

Factors associated with variation in screening coverage in England have previously been identified: deprivation, non-Caucasian ethnicity and poorer primary care-level service have

been found linked with lower attendance at both cervical^{10,11} and breast^{12,13} screening. In addition, coverage in London has generally been observed to be lower than the national average^{1,2}.

We constructed funnel plots to display the scatter of cervical and breast screening coverage around the national average in areas defined by former English Primary Care Trusts (PCTs). We developed risk adjustment models based on demographic, socio-economic and primary care-level characteristics, and control limits were adjusted accordingly. PCTs with atypically high or low coverage were identified, and associations among PCT characteristics were investigated in an attempt to highlight those districts where further investigation may be beneficial in informing policy to improve coverage.

METHODS

Data source

Coverage data were available in geographical areas defined by former English PCTs. Data from April 2011 to March 2012 were sourced from the Health & Social Care Information Centre (HSCIC)^{1,2}. *Cervical screening coverage* was defined as the percentage of eligible women registered with a general practice, who had an adequate screening test within the last 3.5 years for 25-49 year-olds, and the last 5 years for 50-64 year-olds. PCT-level data were obtained for the two age groups separately. *Breast screening coverage* was defined as the percentage of eligible women registered with a general practice, who had an adequate screening mammogram within the last 3 years. Data for 50-64 year-olds were obtained to match the older cervical screening group.

The percentage urbanisation within each PCT was derived from the urban-rural classification¹⁴. For two PCTs with missing data (Stockton-on-Tees, Isle of Wight), the Local Authority urbanisation score was used instead.

The income deprivation domain score from the English Indices of Multiple Deprivation (IMD) 2010 was obtained and the percentage deprivation calculated as a population-weighted average of Lower Super Output Area (LSOA) income deprivation score¹⁵.

Ethnicity data and the percentage of the total population without any higher education were sourced from the Office of National Statistics (ONS) 2011 Census^{16,17}. For ethnicity, two explanatory variables were derived: the percentage of Asian, Black, or Mixed ethnic minority groups, and the percentage of other ethnic minority groups, which includes Asian and African Arabs and any other minor ethnic groups (e.g. Polynesians, Melanesians and Micronesians).

General practice characteristics data were sourced from the HSCIC¹⁸, and included average list size, percentage of single-handed practices (only 1 working provider or salaried/other general practitioner (GP) with possible additional GP registrar/retainer), practitioner headcount (excluding retainers and registrars) per 10⁵ population, practice staff (excluding GPs and registrars) full-time equivalent (FTE), and percentage of GPs who attained their primary medical qualification outside the UK.

Statistical analysis

Grouped logistic regression was applied to coverage data aggregated at PCT level¹⁹. A generalized linear model with quasibinomial error distribution was used to account for within-PCT extra-binomial variation²⁰. For the purpose of the analysis, variables were

classified as "population" and "general practice" risk factors (Table 1). Continuous covariates were mean-centred. Covariates found to be significant at the 1% level using Wald tests in univariate analyses²¹ were considered for inclusion in two multiple regression sub-models, the first including population factors only and the second including general practice factors only. Correlation and collinearity were evaluated based on Pearson correlation coefficients (Supplementary file Table A1 & Figure 3a) and generalized variance-inflation factors (GVIF) for covariate coefficients, respectively²². Differences between correlation coefficients in two independent groups were assessed for significance by applying Fisher's z test on z-transformed correlations²³.

The full regression model was built by including both population and general practice factors that were significant at the 5% level in the sub-models. Percent of deviance (-2 log-likelihood statistic) explained by the adjusted model compared to the null (unadjusted) model was used as a descriptive measure of attribution of variation¹⁹.

Funnel plots of coverage against eligible population in each PCT were constructed⁹. The covariate-adjusted coverage proportion for each PCT was calculated as the product of the national average by the ratio of observed to expected values from the full regression model. The national average for coverage was used as a target value, and the 95% and 99.8% control limits were plotted around it using the asymptotic normal approximation, with a variance inflation factor for extra-binomial variation (²⁴ details available from NJM). All statistical analyses were performed in R version 3.0.2.

RESULTS

Data description

PCT-level data on cervical (age groups 25-49 and 50-64) and breast (age group 50-64) screening coverage are summarized in [Table 1](#); overall, and separately for London and the rest of England. Between-PCT variability was more pronounced for breast screening (median 76.9, IQR 6.5) and the younger cervical screening group aged 25-49 (median 74.6, IQR 5.9) than for the cervical screening group aged 50-64 (median 77.5, IQR 3.5, [Table 1](#)). The difference in coverage level between London and the rest of England was also larger for the breast and younger cervical screenings groups; with median coverage 7-8% lower in London.

[\[Table 1 here\]](#)

Table 1. PCT-level summary of population factors, general practice factors, and screening coverage in England in 2012 (n = 151)

Population factors	Min-Max	Mean (SD)	Median (IQR)
% Urbanisation	31.0 - 100.0	81.2 (21.5)	91.0 (35.03)
% Deprivation	6.8 - 33.8	16.2 (5.8)	15.3 (8.4)
% Asian, Black, or Mixed ethnicity	1.3 - 67.6	15.1 (15.4)	8.9 (20.5)
% Other minor ethnicity	0.1 - 11.1	1.2 (1.6)	0.6 (1.3)
% No higher education	10.1 - 35.2	23.0 (5.1)	23.0 (6.8)
% Registered women aged 25-29	12.2 - 32.2	19.5 (4.2)	18.3 (5.2)
General practice factors	Min-Max	Mean (SD)	Median (IQR)
Average practice list size	4026.4 - 9566.2	6656.2 (1371.2)	6537.1 (2236.0)
% Single-handed practices	0.0 - 41.0	13.45 (10.2)	11.0 (16.0)
Practitioner headcount per 10 ⁵ population	50.9 - 95.3	68.7 (8.3)	67.7 (10.8)
Practice staff FTE	146.3 - 1884.2	513.7 (296.7)	424.0 (283.7)
% Practitioners qualified outside UK	3.0 - 70.0	26.4 (14.7)	25.0 (19.2)
Screening coverage (%)	Min-Max	Mean (SD)	Median (IQR)
Cervical group aged 25-49			
Overall	58.7 - 80.4	73.4 (4.4)	74.6 (5.9)
London SHA (Q36)	58.7 - 77.7	67.8 (4.6)	67.8 (5.7)
Rest of England	67.4 - 80.4	74.8 (3.0)	75.4 (3.8)
Cervical group aged 50-64			
Overall	69.1 - 82.0	77.2 (2.5)	77.5 (3.5)
London SHA (Q36)	69.1 - 80.9	75.7 (2.8)	75.6 (3.1)
Rest of England	70.1 - 82.0	77.6 (2.3)	77.9 (2.8)
Breast group aged 50-64			
Overall	59.5 - 84.7	75.6 (5.1)	76.9 (6.5)
London SHA (Q36)	59.5 - 78.8	69.0 (4.9)	68.8 (8.6)
Rest of England	64.6 - 84.7	77.3 (3.6)	78.1 (5.5)

FTE, Full-Time Equivalent; IQR: Inter Quartile Range; SD, Standard Deviation; SHA, Strategic Health Authority

Relationships between population and general practice factors, and coverage

Tables 2.1, 2.2 and 2.3 show the unadjusted and adjusted odds ratios of the associations between population and general practice risk factors with coverage. Each factor was found to be univariately associated with coverage in all screening groups, except for the percentage of population with no higher education and the practitioner headcount, which were only significant for the cervical screening group aged 25-49.

Variability in coverage was primarily explained by population factors with general practice characteristics only accounting for a small fraction of the residual variability (< 2% of total deviance after adjustment for population factors). Population covariates explained a lesser percentage of the total deviance among the cervical screening group aged 50-64 (45%, Table 2.2) than the cervical screening group aged 25-49 (78%, Table 2.1) or the breast screening group (72%, Table 2.3); overall variability was also lowest among the former group (IQR 3.5 versus IQR 5.9 and 6.5, respectively, Table 1).

With regard to general practice factors, only staff FTE remained positively associated with cervical screening coverage after accounting for population factors (Table 2.2).

After adjusting for deprivation, ethnicity and education, residing in London and urbanisation were no longer significantly associated with lower cervical screening coverage, but both remained associated with lower breast screening coverage.

Deprivation remained inversely associated with coverage in all screening groups, but displayed some collinearity with other factors for the cervical screening group aged 25-49 (Tables 2.1).

Absence of higher education remained associated with higher coverage in the cervical screening group aged 25-49 after adjusting for other population factors ([Table 2.1](#)). In this latter group, the effect of deprivation and education were no longer significant when the model accounted for the percentage of registered women aged 25-29 ([Supplementary file Table A2.1](#)).

After adjusting for other population factors, the percentage of other ethnic minority groups remained negatively correlated with coverage in all screening groups, whereas the percentage of Asian, Black, or Mixed ethnic minority groups was no longer associated with lower breast screening coverage ([Tables 2.2-2.3](#)).

[\[Tables 2.1-2.3 here\]](#)

Table 2.1 Regression modelling for cervical screening coverage among women aged 25-49

Model	Univariate			Population		General practice		Population & General practice	
Deviance explained by model	–			78.2%		46.4%		79.1%	
Population factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
% Urbanisation	0.993 (0.992, 0.995)	< 0.001	41.9%	0.999 (0.998, 1.000)	0.03	–	–	0.999 (0.998, 1.000)	0.3
London SHA (Q36)	0.696 (0.653, 0.741)	< 0.001	46.2%	1.011 (0.939, 1.088)	NS (0.8)	–	–	–	–
% Deprivation	0.977 (0.973, 0.981)	< 0.001	41.1%	0.987 (0.981, 0.993)	< 0.001	–	–	0.989 (0.981, 0.996)	0.004 ^s
% Asian, Black, or Mixed ethnicity	0.989 (0.988, 0.990)	< 0.001	63.3%	0.997 (0.995, 0.999)	0.005	–	–	0.997 (0.995, 0.999)	0.005
% Other minor ethnicity	0.901 (0.889, 0.912)	< 0.001	62.4%	0.958 (0.941, 0.975)	< 0.001	–	–	0.963 (0.946, 0.980)	< 0.001
% No higher education	1.012 (1.005, 1.020)	0.001	7.3%	1.011 (1.004, 1.017)	0.001	–	–	1.011 (1.004, 1.018)	0.003
General practice factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
Average practice list size	1.00008 (1.00005, 1.00010)	< 0.001	23.3%	–	–	0.99999 (0.99996, 1.00002)	NS (0.6)	–	–
% Single-handed practices	0.990 (0.987, 0.993)	< 0.001	20.6%	–	–	0.990 (0.985, 0.995)	< 0.001	0.998 (0.996, 1.000)	0.1
Practitioners headcount per 10 ⁵ population	0.993 (0.989, 0.997)	= 0.001	6.5%	–	–	0.989 (0.985, 0.992)	< 0.001	0.9993 (0.9963, 1.0022)	0.6
Practice staff FTE	1.0003 (1.0002, 1.0004)	< 0.001	22.8%	–	–	1.0002 (1.0001, 1.0003)	< 0.001	1.00005 (0.99999, 1.00011)	0.06
% Practitioners qualified outside UK	0.994 (0.992, 0.997)	< 0.001	13.7%	–	–	0.998 (0.996, 1.001)	NS (0.2)	–	–

CI, Confidence Interval; FTE, Full-Time Equivalent; NS, Considered non-significant (see Methods for details); SHA, Strategic Health Authority

^s The variance of the coefficient estimate is being inflated by multicollinearity with other factors ($\sqrt{\text{GVIF}} = 2.7$).

Table 2.2 Regression modelling for cervical screening coverage among women aged 50-64

Model	Univariate			Population		General practice		Population & General practice	
Deviance explained	–			44.6%		26.7%		45.3%	
Population factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
% Urbanisation	0.997 (0.996, 0.998)	< 0.001	25.5%	0.9986 (0.9976 – 0.9995)	0.004	–	–	0.999 (0.9978 – 0.9998)	0.02
London SHA (Q36)	0.886 (0.837, 0.937)	< 0.001	10.6%	0.940 (0.875, 1.010)	NS (0.09)	–	–	–	–
% Deprivation	0.987 (0.984, 0.990)	< 0.001	31.1%	0.989 (0.985, 0.992)	< 0.001	–	–	0.990 (0.985, 0.994)	< 0.001
% Asian, Black, or Mixed ethnicity	0.997 (0.996, 0.998)	< 0.001	9.9%	1.005 (1.003, 1.007)	< 0.001	–	–	1.004 (1.002, 1.006)	< 0.001
% Other minor ethnicity	0.959 (0.947, 0.972)	< 0.001	19.6%	0.970 (0.952, 0.988)	0.001	–	–	0.963 (0.946, 0.980)	< 0.001
% No higher education	0.997 (0.993, 1.002)	NS (0.3)	0.9%	–	–	–	–	–	–
General practice factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
Average practice list size	1.00004 (1.00003, 1.00006)	< 0.001	20.2%	–	–	1.000025 (1.000003 – 1.000047)	0.02	0.999996 (0.999979, 1.000012)	0.6
% Single-handed practices	0.995 (0.993, 0.997)	< 0.001	13.1%	–	–	0.999 (0.995, 1.002)	NS (0.4)	–	–
Practitioner headcount per 10 ⁵ population	0.998 (0.996, 1.001)	NS (0.2)	1.2%	–	–	–	–	–	–
Practice staff FTE	1.00015 (1.00010, 1.00020)	< 0.001	19.5%	–	–	1.00010 (1.00005, 1.00016)	< 0.001	1.000058 (1.000007, 1.000109)	0.03
% Practitioners qualified outside UK	0.997 (0.996, 0.999)	< 0.001	7.8%	–	–	1.001 (0.998, 1.002)	NS (0.5)	–	–

CI, Confidence Interval; FTE, Full-Time Equivalent; NS, Considered non-significant (see Methods for details); SHA, Strategic Health Authority

Table 2.3 Regression modelling for breast screening coverage among women aged 50-64

Model	Univariate			Population		General practice		Population & General practice	
Deviance explained by model	–			70.7%		31.0%		70.6%	
Population factors	OR (95% CI)	p-value (Wald, χ2)	Deviance explained	OR (95% CI)	p-value (Wald, χ2)	OR (95% CI)	p-value (Wald, χ2)	OR (95% CI)	p-value (Wald, χ2)
% Urbanisation	0.992 (0.991, 0.993)	< 0.001	50.5%	0.996 (0.995, 0.998)	< 0.001	–	–	0.996 (0.995, 0.998)	< 0.001
London SHA (Q36)	0.642 (0.587, 0.703)	< 0.001	37.7%	0.896 (0.811, 0.990)	0.03	–	–	0.885 (0.806, 0.970)	0.009
% Deprivation	0.972 (0.967, 0.978)	< 0.001	38.8%	0.991 (0.986, 0.997)	0.002	–	–	0.991 (0.985, 0.997)	0.004
% Asian, Black, or Mixed ethnicity	0.987 (0.985, 0.989)	< 0.001	49.1%	0.999 (0.996, 1.002)	NS (0.5)	–	–	–	–
% Other minor ethnicity	0.880 (0.863, 0.898)	< 0.001	50.8%	0.948 (0.923, 0.973)	< 0.001	–	–	0.945 (0.922, 0.969)	< 0.001
% No higher education	1.010 (1.001, 1.019)	NS (0.03)	3.1%	–	–	–	–	–	–
General practice factors	OR (95% CI)	p-value (Wald, χ2)	Deviance explained	OR (95% CI)	p-value (Wald, χ2)	OR (95% CI)	p-value (Wald, χ2)	OR (95% CI)	p-value (Wald, χ2)
Average practice list size	1.00010 (1.00007, 1.00012)	< 0.001	26.5%	–	–	1.000046 (1.000006, 1.000087)	0.03	1.00001 (0.99998, 1.00003)	0.6
% Single-handed practices	0.988 (0.984, 0.991)	< 0.001	24.2%	–	–	0.9945 (0.9886, 1.0004)	NS (0.07)	–	–
Practitioner headcount per 10 ⁵ population	0.996 (0.991, 1.001)	NS (0.1)	1.7%	–	–	–	–	–	–
Practice staff FTE	1.00025 (1.00015, 1.00035)	< 0.001	14.1%	–	–	1.000099 (0.999990, 1.000209)	NS (0.07)	–	–
% Practitioners qualified outside UK	0.993 (0.990, 0.995)	< 0.001	16.0%	–	–	0.9992 (0.9957, 1.0027)	NS (0.6)	–	–

CI, Confidence Interval; FTE, Full-Time Equivalent; NS, Considered non-significant (see Methods for details); SHA, Strategic Health Authority

Identification of PCTs with atypical coverage

Figure 1 illustrates the PCTs with coverage estimates lying outside the control limits prior to (Figure 1a-c) and after full covariate adjustment (Figure 1a'-c'). The geographical location of PCTs with atypical coverage is shown in Figure 2.

Over two-thirds of the PCTs initially lying below limits for cervical screening - for most, located within London - no longer lay *below* limits after adjustment. For the breast screening group, only one out of the four initial outliers (Kensington & Chelsea in London – data not shown) was found to lie within limits after adjustment, while a new London PCT was uncovered as atypically low (Wandsworth, London). For two London PCTs, the adjusted coverage remained below the 99.8% lower limit for the cervical screening group aged 25-49, and ranked among the 15 lowest PCTs for the other two screening groups (Hammersmith and Fulham, and Camden, Figure 2).

In contrast to what was observed for the PCTs lying below limits, the PCTs lying above the 95% upper limits *after* adjustment were mostly different from those identified prior to adjustment: only 1 in 2 PCTs for the cervical screening group aged 25-49, 1 in 5 for the cervical screening group aged 50-64, and 2 in 5 for the breast screening group would have been identified as atypically high performers without adjustment (Figure 1 & data not shown). Two PCTs displayed atypically high coverage in all screening groups irrespective of age (Enfield, London and Nottinghamshire County Teaching, East Midlands).

Characteristics of PCTs with relatively high and low adjusted coverage

PCTs were ranked according to their adjusted coverage values ([Supplementary file Tables A3.1 & A3.2](#)). Associations between population factors were investigated among the 15 lowest- ([Figure 3b](#)) and the 15 highest-ranking PCTs ([Figure 3c](#)).

For all screening groups, we noted strong positive associations between deprivation and non-white ethnicities among the highest-ranking PCTs, which differed significantly from the associations seen among lowest-ranking PCTs (Fisher’s z test $p<0.05$ for cervical screening and $p=0.05$ for breast screening group among minor ethnicity groups only, [Figure 3d](#)).

For cervical screening, a strong positive correlation between deprivation and absence of higher education was observed among lowest-ranking PCTs ($p=0.77$ and 0.68 for age group 25-49 and 50-64, respectively), which tended to not be as strong overall or among highest-ranking PCTs, in particular for the younger age group (Fisher’s z test $p=0.04$).

Lowest-ranking PCTs tended to have populations of other minor ethnicity with a higher level of education ($p=-0.88$, -0.77 and -0.70 for cervical age groups 25-49 and 50-64, and breast age group 50-64 respectively) compared with overall or high-ranking PCTs, in particular for cervical screening (Fisher’s z test $p=0.1$ for both cervical age groups).

DISCUSSION

This aim of this analysis was to identify and characterise PCTs that displayed atypically high or low cervical or breast screening coverage given population and general practice PCT-level risk factors. We found that a subset of PCTs with atypical coverage levels was common to both programmes, while other sets were more specific to the programme or age group.

Our risk adjustment results confirm the importance of demographic and socio-economic characteristics for coverage levels, and highlight the comparatively minor impact of various aspects of primary care. This suggests that strategies targeted at raising awareness or addressing barriers among socially- and culturally-diverse populations are likely to be the most effective at increasing coverage.

The number of practice staff FTE remained positively associated with cervical screening coverage but not breast screening coverage after adjusting for population factors. The finding that cervical screening coverage is more likely to be influenced by general practice factors is unsurprising since many women are screened at their local practice²⁵, and previous studies have shown the number of nurses per practice to be associated with cervical screening coverage in deprived areas¹⁰.

Coverage in London has generally been observed to be lower than the national average^{1,2}, in spite of some other public health features (for example obesity rates) being better in London²⁶. We found that urbanisation, ethnicity, and deprivation, largely accounted for the lower cervical screening uptake in London. For breast screening however, being located in London, remained a strong independent negative risk factor, which warrants further investigation.

Deprivation was an independent negative risk factor for all screening groups, as also found for cervical screening by Bang and coll.²⁷. In the cervical screening group aged 25-49, this effect was in part explained by numbers of women under 30, as was the positive impact of lack of higher education on coverage. Cervical screening coverage has been reported to be lower in younger women²⁸, but younger women of lower socio-economic status or with fewer educational qualifications, regardless of ethnicity, have also been shown to be positively influenced by the 2009 Jade Goody's story with respect to cervical screening behaviour²⁹, giving hints as to potential strategies for improving uptake.

The impact of Asian, Black, or Mixed ethnic minority groups on coverage differed between programmes after controlling for other population factors. For breast screening, it was no longer significant. For cervical screening, we found it negatively influenced coverage in the age group 25-49, but was associated with greater coverage in the age group 50-64. Previously, only an overall negative overall association after adjustment for other population factors had been reported for cervical screening in women aged 25-64²⁷.

For both programmes, and regardless of age, other ethnic minority groups were still associated with poorer coverage after accounting for deprivation and urbanisation, with a particularly strong effect in breast screening. In addition, our results suggest that women of other ethnic minority background, who may be well educated and living in areas with smaller Asian, Black, or Mixed ethnic minority populations, are less likely to go for screening. Arabs communities account for a moderately large subset of the 'other' ethnic minority groups (40%), and uptake of cervical and breast screening has been shown to be low in these populations for a number of reasons, including religious beliefs, emotional barriers (embarrassment/fear), language barriers or taboos surrounding sexual activity (for cervical

screening)³⁰⁻³². These populations may therefore require newly targeted interventions to promote screening.

Our correlation analyses suggest that PCTs with atypical coverage levels differ from one another not only in respect of a number of population- and general practice-level characteristics, but also in how these characteristics relate to each other. Correlates of deprivation in PCTs with relatively low adjusted coverage were substantially different from the general results, and even more so for cervical screening. In particular, the nature of the relationship between deprivation and non-White ethnicity differed, with an inverse relationship between deprivation and non-White ethnic groups among lowest-ranking PCTs.

Using funnel plots based on crude performance data to assess quality of care at area level may overestimate the number of "underperforming" districts, and overdispersion needs to be addressed *a priori*. We chose a risk adjustment approach to uncover PCTs with atypically high or low coverage given particular population and general practice characteristics. PCTs with adjusted coverage values lying outside control limits display a behaviour which cannot solely be explained by the area-level risk factors investigated.

PCTs with atypically high coverage were singled out and could be investigated to identify any local health interventions and policies that might help improve coverage in districts with similar characteristics but lower performance. Unfortunately, there is a general lack of reporting in the research literature across PCTs on the impact of local interventions that have been implemented to improve screening uptake (ED, unpublished PhD thesis), so identifying 'what works' is challenging.

Simultaneously, PCTs with atypically low coverage were distinguished from those lying within bounds after accounting for urbanisation, deprivation and ethnicity, in particular for the London region. These districts may benefit from further investigation to uncover the features driving their atypically low coverage and help design population-specific strategies. Additional risk factors that may explain low coverage, as well as differences in PCT performance between programmes, include the percentage of women who are disabled³³, incarcerated³⁴, have greater difficulty in accessing services as indexed by time to screening centre¹³, and differential utilization behaviour as a result of socio-cultural factors, such as marital status³⁵, occupation³⁶, sexual orientation³⁷, and overseas birthplace or religious beliefs^{11,38} that might apply to particular programmes.

Our results are limited by the aggregated nature of the data, which may conceal ecological associations within districts. This could account for the weak association seen between coverage and general practice characteristics after adjustment for population factors. However, similar trends were observed when analysing general practice-level data for cervical screening coverage²⁷. Another limitation is that PCT no longer exist, but the findings can easily be applied to the newly defined English Clinical Commissioning Group level (CCG) by direct mapping³⁹.

The strength of the approach of combining risk adjustment modelling with funnel plots was to allow us to identify districts with unusual level of screening coverage after accounting for some of the important demographic and socio-economic characteristics of their populations and their primary care settings, known to affect coverage level. Such an approach could be implemented sequentially to monitor the impact of local interventions in a centralised fashion. This method could also be adapted for use with other health indicators.

Our results demonstrate that population factors largely explain the lower coverage in London. In addition, PCTs in London and other urban centres with specific population characteristics such as non-deprived ethnic minority groups were identified as requiring targeted intervention to improve coverage levels. Bilingual outreach and community-based advocacy, such as support from family and community leaders including GPs, has been found to be valuable in increasing uptake of cancer screening in ethnic minorities⁴⁰.

We hope these results will inform the continued drive to reduce inequalities in cancer screening and avoidable deaths, and encourage implementation of targeted interventions in communities residing within districts identified as having atypically low coverage.

ABBREVIATIONS

CI	Confidence Interval
FTE	Full-Time Equivalent
GP	General Practitioner
GVIF	Generalized Variance-Inflation Factor
HSCIC	Health and Social Care Information Centre
IMD	Indices of Multiple Deprivation
IQR	Interquartile Range
LSOA	Lower Super Output Area
PCT	Primary Care Trust
SD	Standard Deviation
SHA	Strategic Health Authority

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COMPETING INTERESTS

None

AUTHOR'S CONTRIBUTION

NJM performed the statistical analysis, interpreted the results and wrote the manuscript. ED carried out the data informatics and data checks, and co-wrote the manuscript. JW & JW provided general expert guidance. SWD provided general statistical guidance. All authors reviewed and approved the final manuscript.

DATA SHARING STATEMENT

Data are freely available from the HSCIC:

Cervical screening: <http://www.hscic.gov.uk/catalogue/PUB10339/bres-scre-prog-eng-2011-12-tab.xls>

Breast screening: <http://www.hscic.gov.uk/catalogue/PUB07990/cerv-scre-prog-eng-2011-12-tab.xls>

No additional data available.

ETHICS APPROVAL

None

LIST OF FIGURES

Figure 1. Funnel plots of screening coverage and list of PCTs lying outside the 95% control limits prior to and after risk adjustment

Top left panel. Funnel plots of screening coverage prior to any adjustment

- (a) Cervical screening in women aged 25-49.
- (b) Cervical screening in women aged 50-64.
- (c) Breast screening in women aged 50-64.

Top right panel. Funnel plots of screening coverage after adjustment for population and general practice factors

- (a') Cervical screening in women aged 25-49.
- (b') Cervical screening in women aged 50-64.
- (c') Breast screening in women aged 50-64.

----- 95.0% control limits
..... 99.8% control limits
SHA, Strategic Health Authority; Q30, North East; Q31, North West ;Q33, East Midlands; Q34, West Midlands; Q35, East of England; Q36, London; Q37, South East Coast; Q38, South Central; Q39, South West.

Table. Number of PCTS lying outside the 95% control limits prior to and after risk adjustment. The number of PCTs within London SHA (Q36) is shown in brackets.

Figure 2. Geographical location of atypical PCTs

Map. Map of PCT 2006 boundaries with PCTs lying below the 95% lower control limits after risk adjustment coloured in red and PCTs lying above the 95% upper control limits after risk adjustment coloured in green.

Table. PCTs lying outside the control limits are listed with corresponding percentile given in brackets. PCTs with coverage ranking among the 15 lowest- (rank ≤ 15) or 15 highest (rank ≥ 137) are specified. All PCTs lying outside the control limits had relative coverage rankings ≤ 15 for lower 95% limit and ≥ 137 for upper 95% limit.

SHA, Strategic Health Authority; Q30, North East; Q31, North West ;Q33, East Midlands; Q34, West Midlands; Q35, East of England; Q36, London; Q37, South East Coast; Q38, South Central; Q39, South West.

Figure 3. Correlations between population factors overall, and among the 15 highest- and 15 lowest-ranking PCTs after risk adjustment

a-c. Correlation coefficients are displayed in each cell. a, All PCTs; b, 15-lowest ranking PCTs; c, 15 highest ranking PCTs.

For the 15 lowest and 15 highest-ranking PCTs, correlation coefficients which are significantly different from zero at the 1% level are highlighted in green for positive correlations, and in red for negative correlations.

d. Fisher's z test for significant differences in correlation coefficients between two independent groups.

Bold, p-values < 0.05. Italic, p-values not significant at the 10% level.

1, % Deprivation; 2, % Urbanisation; 3, % Asian, Black or Mixed ethnic minority groups; 4, % Other ethnic minority groups; 5, % No higher education.

For peer review only

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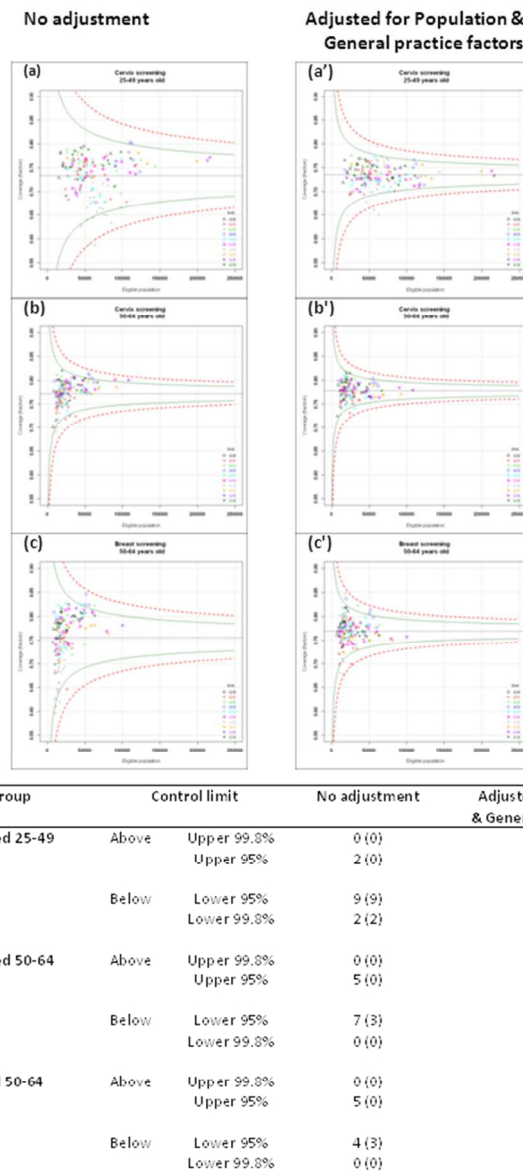
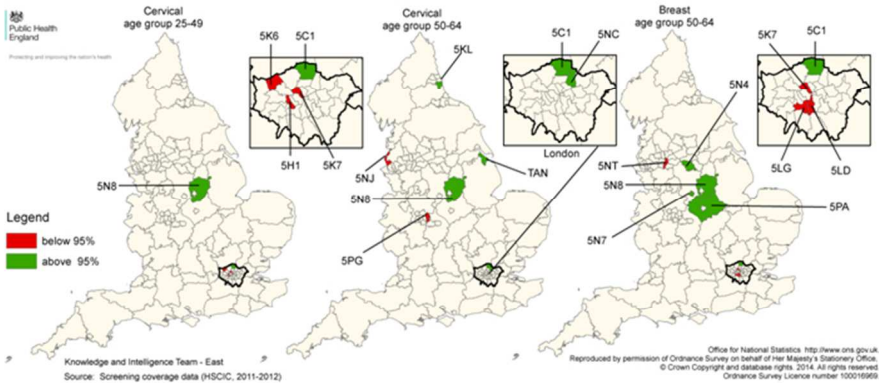


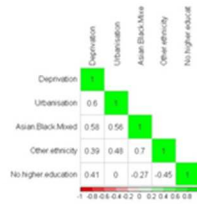
Figure1
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PCT name	SHA	Screening group		
		Cervical age group 25-49	Cervical age group 50-64	Breast Age group 50-64
Below lower 95% control limit				
SH1 / Hammersmith and Fulham	036	Below 99.8% (0.01%)	Rank ≥137	Rank ≥137
SH6 / Harrow	036	Below 95% (0.2%)	Rank ≥137	—
SH7 / Camden	036	Below 99.8% (0.001%)	Rank ≥137	Below 95% (0.02%)
SHJ / Sefton	031	Rank ≥137	Below 95% (0.3%)	—
SPG / Birmingham East & North	034	Rank ≥137	Below 95% (1.2%)	—
SLD / Lambeth	036	—	Rank ≥137	Below 95% (0.01%)
SLG / Wandsworth	036	—	Rank ≥137	Below 95% (0.4%)
SNT / Manchester	031	—	Rank ≥137	Below 95% (0.2%)
Above upper 95% control limit				
SC1 / Enfield	036	Above 95% (99.8%)	Above 95% (99.9%)	Above 95% (99.9%)
SNS / Nottinghamshire County Teaching	033	Above 95% (93.9%)	Above 95% (93.9%)	Above 95% (93.5%)
SKL / Sunderland Teaching	030	Rank ≤15	Above 95% (98.6%)	Rank ≤15
SNC / Waltham Forest	036	—	Above 95% (99.3%)	Rank ≤15
TAN / North East Lincolnshire Care Trust Plus	032	Rank ≤15	Above 95% (99.8%)	—
SH4 / Sheffield	032	—	—	Above 95% (98.5%)
SH7 / Derby City	033	—	Rank ≤15	Above 95% (99.7%)
SPA / Leicestershire County & Rutland	033	—	—	Above 95% (96.5%)

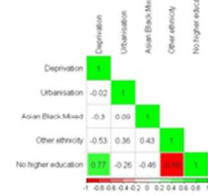
Figure2
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a. All PCTs (N = 151)

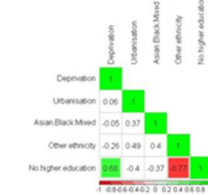


b. 15 lowest-ranking PCTs

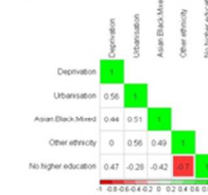
Cervical age group 25-49



Cervical age group 50-64

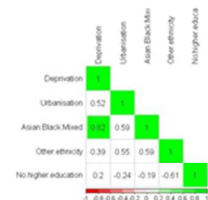


Breast age group 50-64

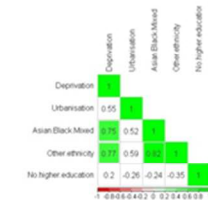


c. 15 highest-ranking PCTs

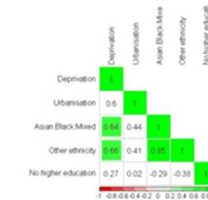
Cervical age group 25-49



Cervical age group 50-64

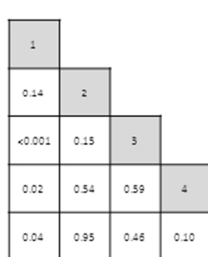


Breast age group 50-64

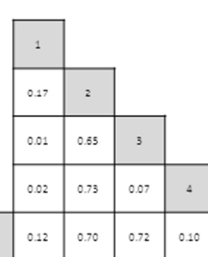


d. Differences in correlates between the 15 lowest- and the 15 highest-ranking PCTs

Cervical age group 25-49



Cervical age group 50-64



Breast age group 50-64

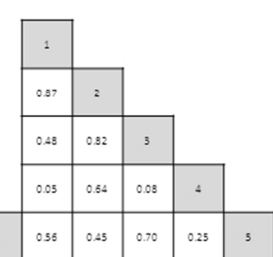


Figure3
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SUPPLEMENTARY FILE (MASSAT, DOUGLAS ET AL.)

Table A1. Correlations between population and general practice factors, and screening coverage (all PCTS)
Upper diagonal: Correlation coefficient; Lower diagonal: p-value of test for significant correlation between paired samples

	Population factors						General practice factors					Coverage		
	% Urbanization	% Deprivation	% Asian, Black, or Mixed ethnicity	% Other minor ethnicity	% No higher education	% Registered women aged 25-29	Average practice list size	% Single-handed practices	Practitioner headcount per 10 ⁵ population	Practice staff FTE	% Practitioners qualified outside UK	Cervical group aged 25-49	Cervical group aged 50-64	Breast group aged 50-64
Population factors														
% Urbanization	1	0.61	0.56	0.48	-0.002	0.63	-0.50	0.49	0.02	-0.51	0.42	-0.60	-0.49	-0.66
% Deprivation	< 0.001	1	0.58	0.39	0.41	0.64	-0.58	0.46	0.23	-0.36	0.54	-0.56	-0.47	-0.58
% Asian, Black, or Mixed ethnicity	< 0.001	< 0.001	1	0.70	-0.27	0.62	-0.35	0.39	0.14	-0.25	0.43	-0.78	-0.24	-0.68
% Other minor ethnicity	< 0.001	< 0.001	< 0.001	1	-0.45	0.60	-0.40	0.38	0.14	-0.25	0.22	-0.78	-0.45	-0.74
% No higher education	NS (0.9)	< 0.001	0.001	< 0.001	1	-0.11	-0.26	0.21	-0.25	-0.04	0.37	0.31	0.02	0.31
% Registered women aged 25-29	< 0.001	< 0.001	< 0.001	< 0.001	NS (0.2)	1	-0.33	0.30	0.26	-0.24	0.21	-0.71	-0.43	-0.69
General practice factors														
Average practice list size	< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001	1	-0.75	0.06	0.36	-0.52	0.42	0.39	0.49
% Single-handed practices	< 0.001	< 0.001	< 0.001	< 0.001	0.01	< 0.001	< 0.001	1	-0.35	-0.27	0.61	-0.41	-0.28	-0.43
Practitioner headcount per 10 ⁵ population	NS (0.8)	0.006	NS (0.1)	NS (0.08)	0.002	0.001	NS (0.5)	< 0.001	1	0.06	-0.35	-0.19	-0.14	-0.22
Practice staff FTE	< 0.001	< 0.001	0.002	0.002	NS (0.7)	0.004	< 0.001	0.001	NS (0.4)	1	-0.36	0.34	0.37	0.35
% Practitioners qualified outside UK	< 0.001	< 0.001	< 0.001	0.006	< 0.001	0.009	< 0.001	< 0.001	< 0.001	< 0.001	1	-0.29	-0.18	-0.32
Coverage														
Cervical group aged 25-49	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.02	< 0.001	< 0.001	1	0.68	0.84
Cervical group aged 50-64	< 0.001	< 0.001	0.004	< 0.001	NS (0.8)	< 0.001	< 0.001	< 0.001	NS (0.09)	< 0.001	0.03	< 0.001	1	0.65
Breast group aged 50-64	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.006	< 0.001	< 0.001	< 0.001	< 0.001	1

NS: not significant at the 5% level; FTE: Full Time Equivalent

Table A2.1. Regression modelling for cervical screening coverage among women aged 25-49, including % registered women aged 25-29.

Model	Univariate			Population		General practice		Population & General practice	
Deviance explained by model	–			79.5%		46.4%		80.9%	
Population factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
% Urbanization	0.993 (0.992, 0.995)	< 0.001	41.9%	0.999 (0.998, 1.000)	NS (0.3)	–	–	0.999 (0.998, 1.001)	0.8
London SHA	0.696 (0.653, 0.741)	< 0.001	46.2%	0.972 (0.901, 1.048)	NS (0.5)	–	–	–	–
% Deprivation	0.977 (0.973, 0.981)	< 0.001	41.1%	0.992 (0.986, 0.999)	0.03	–	–	1.0017 (0.996, 1.007)	0.5 ^s
% Asian, Black, or Mixed ethnicity	0.989 (0.988, 0.990)	< 0.001	63.3%	0.997 (0.995, 0.999)	0.004	–	–	0.995 (0.993, 0.997)	< 0.001
% Other minor ethnicity	0.901 (0.889, 0.912)	< 0.001	62.4%	0.963 (0.946, 0.980)	< 0.001	–	–	0.958 (0.943, 0.973)	< 0.001
% No higher education	1.012 (1.005, 1.020)	0.001	7.3%	1.007 (1.000, 1.013)	NS (0.06)	–	–	–	–
% Registered women aged 25-29	0.965 (0.959, 0.970)	< 0.001	52.9%	0.990 (0.984, 0.996)	0.002	–	–	0.987 (0.981, 0.994)	< 0.001
General practice factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
Average practice list size	1.00008 (1.00005, 1.00010)	< 0.001	23.3%	–	–	0.99999 (0.99996, 1.00002)	NS (0.6)	–	–
% Single-handed practices	0.990 (0.987, 0.993)	< 0.001	20.6%	–	–	0.990 (0.985, 0.995)	< 0.001	0.998 (0.995 – 1.000)	0.06
Practitioner headcount per 10 ⁵ population	0.993 (0.989, 0.997)	0.001	6.5%	–	–	0.989 (0.985, 0.992)	< 0.001	0.998 (0.995 – 1.000)	0.06
Practice staff FTE	1.0003 (1.0002, 1.0004)	< 0.001	22.8%	–	–	1.0002 (1.0001, 1.0003)	< 0.001	1.00007 (1.00002, 1.00013)	0.01
% Practitioners qualified outside UK	0.994 (0.992, 0.997)	< 0.001	13.7%	–	–	0.998 (0.996, 1.001)	NS (0.2)	–	–

CI: Confidence Interval; FTE: Full-Time Equivalent; NS: Considered non-significant (see Methods for details); SHA: Strategic Health Authority

^s The variance of the coefficient estimate is being inflated by multicollinearity with other factors ($\sqrt{\text{GVIF}} = 2.8$).

Table A3.1. 15 lowest-ranking PCTs prior to and after adjustment for population and general practice factors

	Rank (/151)	No adjustment (percentile)	Adjustment for Population & General practice factors (percentile)
Cervical group aged 25-49	137	5MX	5A9*
	138	5LD*	5LA*
	139	5AT*	5HY*
	140	5C3*	5PN
	141	5K5*	5PG
	142	5C4*	5NL
	143	5C5* [§] (2.79%)	TAP
	144	5A9* [§] (2.65%)	5FE
	145	5HY* [§] (2.04%)	5AT*
	146	5LC* [§] (1.56%)	5KM
	147	5HX* [§] (1.11%)	5NJ
	148	5K6* [§] (0.86%)	5HP
	149	5LA* [§] (0.69%)	5K6* [§] (0.22%)
	150	5H1* ^{§§} (0.04%)	5H1* ^{§§} (0.01%)
	151	5K7* ^{§§} (0.04%)	5K7* ^{§§} (0.001%)
Cervical group aged 50-64	137	5LG*	5LD*
	138	5J4	5M7*
	139	5M1	5HY*
	140	5C3*	5NT
	141	5HP	5K6*
	142	5PG [§] (2.70%)	5M1
	143	5NT [§] (2.09%)	5LG
	144	5NL [§] (1.92%)	TAM
	145	5K7*	5KM
	146	5NJ [§] (0.98%)	5K7*
	147	5KM	5LA*
	148	5LC* [§] (0.31%)	5PG [§] (1.20%)
	149	5D9	5NJ [§] (0.30%)
	150	5LA* [§] (0.08%)	5H1*
	151	5H1* [§] (0.02%)	5D9
Breast group aged 50-64	137	5K5*	5F5
	138	5A8*	5FL
	139	5HP	5NH
	140	5C4*	5NG
	141	5LF*	5LF*
	142	5LG*	5LQ
	143	5C3*	5H1*
	144	5NT [§] (0.89%)	TAP
	145	5C9*	5LE*
	146	5LE*	5LG* [§] (0.42%)
	147	5H1*	5HP
	148	5LC*	5NT [§] (0.22%)
	149	5LD* [§] (0.17%)	5LA*
	150	5K7* [§] (0.09%)	5K7* [§] (0.02%)
	151	5LA* [§] (0.03%)	5LD* [§] (0.01%)

PCT: Primary Care Trust; SHA: Strategic Health Authority

Dark red: PCTs lying below the 95% lower control limits using full model (atypical PCTs).

Orange: Atypical PCTs found among PCTs with lowest relative coverage prior to adjustment.

Percentile is given for those PCTs lying below the 95% lower control limits prior to and after full adjustment.

* PCT in London SHA (Q36)

[§] PCT lying between the 95% and 99.8% lower control limits

^{§§} PCT lying below the 99.8% lower control limits

Table A3.2. 15 highest-ranking PCTs prior to and after adjustment for population and general practice factors

	Rank (/151)	No adjustment (percentile)	Adjustment for Population & General practice factors (percentile)
Cervical group aged 25-49	1	5N8 [§] (94.4%)	5C1* ^{§§} (99.8%)
	2	5N6 [§] (93.9%)	TAN
	3	TAC	5C9*
	4	5A3	5MX
	5	5NW	5D8
	6	TAN	5K5*
	7	5QM	TAK*
	8	5D8	5A3
	9	5J6	5N8 [§] (93.9%)
	10	5ET	5A7*
	11	5QH	5J6
	12	5PA	5C5*
	13	5EF	5J9
	14	5JE	5LC*
	15	5P9	5KL
Cervical group aged 50-64	1	5A3	5C1* ^{§§} (99.9%)
	2	5N8 [§] (96.4%)	TAN [§] (99.8%)
	3	5PA [§] (95.8%)	5NC* [§] (99.3%)
	4	TAN	5A3
	5	5NA*	5KL [§] (98.6%)
	6	5P2	5MX
	7	5QF	5JE
	8	5N2	5C9*
	9	5QH	5NA*
	10	5N6 [§] (91.8%)	5N7
	11	5QM	5J6
	12	5J6	5N8 [§] (93.9%)
	13	5P9	5QN
	14	5QV [§] (89.8%)	5N2
	15 [#]	5FL	5F1
Breast group aged 50-64	1	5PA [§] (97.4%)	5C1* ^{§§} (99.9%)
	2	5M2	5N7 [§] (99.7%)
	3	TAC	5N4 [§] (98.5%)
	4	5PL [§] (93.1%)	5A4*
	5	5N8 [§] (93.0%)	5F1
	6	5N6 [§] (92.9%)	5PC
	7	5CN	5NC*
	8	5NV [§] (92.5%)	5JE
	9	5JE	5H8
	10	5QD	5PA [§] (96.5%)
	11	5PX	5KL
	12	5N7	5PJ
	13	5PT	5N8 [§] (93.5%)
	14	5PW	TAK*
	15	5H8	5MK

PCT: Primary Care Trust; SHA: Strategic Health Authority

Dark green: PCTs lying above the 95% upper control limits using full model (atypical PCTs).**Light green:** Atypical PCTs found among PCTs with highest relative coverage prior to adjustment.

Percentile is given for those PCTs lying above the 95% upper control limits prior to and after full adjustment.

* PCT in London SHA (Q36)

§ PCT lying between the 95% and 99.8% upper control limits

§§ PCT lying above the 99.8% upper control limits

The 17th highest-ranking PCT (5QC) also laid above the 95% upper control limit (percentile 89.1%)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	Present key elements of study design early in the paper
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	(a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants (b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed Case-control study—For matched studies, give matching criteria and the number of controls per case
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) Cohort study—If applicable, explain how loss to follow-up was addressed Case-control study—If applicable, explain how matching of cases and controls was addressed Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses

Continued on next page

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time <i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure <i>Cross-sectional study</i> —Report numbers of outcome events or summary measures
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses

Discussion

Key results	18	Summarise key results with reference to study objectives
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	Discuss the generalisability (external validity) of the study results

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based
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*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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VARIATION IN CERVICAL AND BREAST CANCER SCREENING COVERAGE IN ENGLAND: A CROSS-SECTIONAL ANALYSIS TO CHARACTERISE DISTRICTS WITH ATYPICAL BEHAVIOUR

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VARIATION IN CERVICAL AND BREAST CANCER SCREENING COVERAGE IN ENGLAND: A CROSS-SECTIONAL ANALYSIS TO CHARACTERISE DISTRICTS WITH ATYPICAL BEHAVIOUR

Running title: Atypical Screening coverage in England

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STRENGTHS AND LIMITATIONS OF THIS STUDY

- This study reports on an analysis of breast and cervical screening coverage rates to identify area-level factors associated with high and low coverage.
- This is the first study to characterise English districts with atypically high or low cervical or breast screening coverage using a risk-adjustment approach.
- At district level, high rates of deprivation, urbanisation, and ethnic minority groups other than Asian, Black, or Mixed remain independent predictors of lower coverage for both programmes, and explain most of the lower cervical screening coverage seen in London.
- Districts with atypically low screening coverage displayed distinct correlation patterns between their population characteristics, in particular with regard to deprivation: these districts may benefit from the development of new approaches to target the low-attending communities living within their boundaries.
- This study deals only with area-level rather than individual-level factors. However, this is often the only data available on participation in public health interventions; the method used is fairly simple and could easily be applied to other settings.

ABSTRACT

Objectives. Reducing cancer screening inequalities in England is a major focus of the 2011 Department of Health cancer outcome strategy. Screening coverage requires regular monitoring in order to implement targeted interventions where coverage is low. This study aimed to characterise districts with atypical coverage levels for cervical or breast screening.

Design. Observational study of district-level coverage in the English Cervical and Breast screening programmes in 2012.

Setting. England, UK.

Participants. All English women invited to participate to the Cervical (age group 25-49 and 50-64) and Breast (age group 50-64) screening programmes.

Outcomes. Risk adjustment models for coverage were developed based on district-level characteristics. Funnel plots of adjusted coverage were constructed and atypical districts examined by correlation analysis.

Results. Variability in coverage was primarily explained by population factors, whereas general practice characteristics had little independent effect. Deprivation and ethnicity other than White, Asian, Black, or Mixed were independently associated with poorer coverage in both screening programmes, with ethnicity having the strongest effect; in comparison the influence of Asian, Black, or Mixed ethnic minority was limited. Deprivation, ethnicity and urbanisation largely accounted for the lower cervical screening coverage in London. However, for breast screening, being located in London remained a strong negative predictor. A subset of districts was identified as having atypical coverage across

programmes. Correlates of deprivation in districts with relatively low adjusted coverage were substantially different from overall correlates of deprivation.

Discussion. These results inform the continuing drive to reduce avoidable cancer deaths in England, and encourage implementation of targeted interventions in communities residing in districts identified as having atypically low coverage. Sequential implementation to monitor the impact of local interventions would help accrue evidence on 'what works'.

INTRODUCTION

The English National Cervical and Breast Screening Programmes aim either to prevent cancer by treating pre-cancerous changes or diagnose cancer at earlier stages when treatment outcomes are more successful^{1,2}. Their success is dependent upon high levels of participation³.

Reducing cancer screening inequalities in England is a major focus of the 2011 Department of Health cancer outcome strategy to promote early diagnosis and save lives^{4,5}. There is a need to characterise districts that require most support in reducing inequalities or those which could be used as leading examples.

Funnel plots overlapped with control limits have been shown to be a useful tool for comparing proportional outcomes between centres or districts⁶⁻⁸. The outcome is plotted against a measure of precision for each district, and control limits are set around the target value. Districts lying outside the limits are subject to ‘special-cause variation’ and may repay further investigation. Control limits can be adjusted to incorporate sources of variation such as demographic and socio-economic factors in order to identify districts with atypically high or low outcomes, given their known characteristics^{8,9}.

Identification of atypical districts might be expected to be a simple matter. It is, however, challenging due to the necessarily incomplete nature of aggregate data, the possible collinearities in such data, and the multiplicity of model choices, even with relatively small numbers of potential risk factors.

Factors associated with variation in screening coverage in England have previously been identified: deprivation, non-Caucasian ethnicity and poorer primary care-level service have

been found linked with lower attendance at both cervical^{10,11} and breast^{12,13} screening. In addition, coverage in London has generally been observed to be lower than the national average^{1,2}.

We constructed funnel plots to display the scatter of cervical and breast screening coverage around the national average in areas defined by former English Primary Care Trusts (PCTs), the commissioning groups for GPs at the time of data collection. We developed risk adjustment models based on demographic, socio-economic and primary care-level characteristics, and control limits were adjusted accordingly. Districts with atypically high or low coverage were identified, and associations among district characteristics were investigated in an attempt to highlight those districts where further investigation may be beneficial in informing policy to improve coverage.

METHODS

Data source

Coverage data were available in 152 geographical areas (referred to in this paper as districts) defined by the commissioning groups for GPs at the time the data were collected, i.e. the English Primary Care Trusts (PCTs). Data from April 2011 to March 2012 were sourced from the Health & Social Care Information Centre (HSCIC)^{1,2}. *Cervical screening coverage* was defined as the percentage of eligible women registered with a general practice, who had an adequate screening test within the last 3.5 years for 25-49 year-olds, and the last 5 years for 50-64 year-olds. District-level data were obtained for the two age groups separately. *Breast screening coverage* was defined as the percentage of eligible

women registered with a general practice, who had an adequate screening mammogram within the last 3 years. Data for 50-64 year-olds were obtained to match the older cervical screening group.

The percentage urbanisation within each PCT was derived from the urban-rural classification¹⁴. For two PCTs with missing data (Stockton-on-Tees, Isle of Wight), the Local Authority urbanisation score was used instead.

The income deprivation domain score from the English Indices of Multiple Deprivation (IMD) 2010 was obtained and the percentage deprivation calculated as a population-weighted average of Lower Super Output Area (LSOA) income deprivation score¹⁵.

Ethnicity data and the percentage of the total population without any higher education were sourced from the Office of National Statistics (ONS) 2011 Census^{16,17}. For ethnicity, two explanatory variables were derived: the percentage of Asian, Black, or Mixed ethnic minority groups, and the percentage of 'other' ethnic minority groups, which includes Asian and African Arabs and any other ethnic minority groups (e.g. Polynesians, Melanesians and Micronesians).

General practice characteristics data were sourced from the HSCIC¹⁸, and included average list size, percentage of single-handed practices (only 1 working provider or salaried/other general practitioner (GP) with possible additional GP registrar/retainer), practitioner headcount (excluding retainers and registrars) per 10⁵ population, practice staff (excluding GPs and registrars) full-time equivalent (FTE), and percentage of GPs who attained their primary medical qualification outside the UK.

Statistical analysis

Grouped logistic regression was applied to coverage data aggregated at district level¹⁹. A generalized linear model with quasibinomial error distribution was used to account for within-district extra-binomial variation²⁰. For the purpose of the analysis, variables were classified as "population" and "general practice" risk factors (Table 1). Continuous covariates were mean-centred. Covariates found to be significant at the 1% level using Wald tests in univariate analyses²¹ were considered for inclusion in two multiple regression sub-models, the first including population factors only and the second including general practice factors only. Correlation and collinearity were evaluated based on Pearson correlation coefficients (Supplementary file Table A1 & Figure 3a) and generalized variance-inflation factors (GVIF) for covariate coefficients, respectively²². Differences between correlation coefficients in two independent groups were assessed for significance by applying Fisher's z test on z-transformed correlations²³.

The full regression model was built by including both population and general practice factors that were significant at the 5% level in the sub-models. Percent of deviance (-2 log-likelihood statistic) explained by the adjusted model compared to the null (unadjusted) model was used as a descriptive measure of attribution of variation¹⁹.

Funnel plots of coverage against eligible population in each district were constructed⁹. The covariate-adjusted coverage proportion for each district was calculated as the product of the national average by the ratio of observed to expected values from the full regression model. The national average for coverage was used as a target value, and the 95% and 99.8% control limits were plotted around it using the asymptotic normal approximation, with a variance inflation factor for extra-binomial variation (²⁴ details available from NJM).

All statistical analyses were performed in R version 3.0.2.

RESULTS

Data description

District-level data on cervical (age groups 25-49 and 50-64) and breast (age group 50-64) screening coverage are summarized in [Table 1](#); overall, and separately for London and the rest of England. Between-district variability was more pronounced for breast screening (median 76.9, IQR 6.5) and the younger cervical screening group aged 25-49 (median 74.6, IQR 5.9) than for the cervical screening group aged 50-64 (median 77.5, IQR 3.5, [Table 1](#)). The difference in coverage level between London and the rest of England was also larger for the breast and younger cervical screenings groups; with median coverage 7-8% lower in London.

[\[Table 1 here\]](#)

Table 1. District-level summary of population factors, general practice factors, and screening coverage in England in 2012 (n = 151)

Population factors	Min-Max	Mean (SD)	Median (IQR)
% Urbanisation	31.0 - 100.0	81.2 (21.5)	91.0 (35.03)
% Deprivation	6.8 - 33.8	16.2 (5.8)	15.3 (8.4)
% Asian, Black, or Mixed ethnicity	1.3 - 67.6	15.1 (15.4)	8.9 (20.5)
% 'Other' ethnicity	0.1 - 11.1	1.2 (1.6)	0.6 (1.3)
% No higher education	10.1 - 35.2	23.0 (5.1)	23.0 (6.8)
% Registered women aged 25-29	12.2 - 32.2	19.5 (4.2)	18.3 (5.2)
General practice factors	Min-Max	Mean (SD)	Median (IQR)
Average practice list size	4026.4 - 9566.2	6656.2 (1371.2)	6537.1 (2236.0)
% Single-handed practices	0.0 - 41.0	13.45 (10.2)	11.0 (16.0)
Practitioner headcount per 10 ⁵ population	50.9 - 95.3	68.7 (8.3)	67.7 (10.8)
Practice staff FTE	146.3 - 1884.2	513.7 (296.7)	424.0 (283.7)
% Practitioners qualified outside UK	3.0 - 70.0	26.4 (14.7)	25.0 (19.2)
Screening coverage (%)	Min-Max	Mean (SD)	Median (IQR)
Cervical group aged 25-49			
Overall	58.7 - 80.4	73.4 (4.4)	74.6 (5.9)
London SHA (Q36)	58.7 - 77.7	67.8 (4.6)	67.8 (5.7)
Rest of England	67.4 - 80.4	74.8 (3.0)	75.4 (3.8)
Cervical group aged 50-64			
Overall	69.1 - 82.0	77.2 (2.5)	77.5 (3.5)
London SHA (Q36)	69.1 - 80.9	75.7 (2.8)	75.6 (3.1)
Rest of England	70.1 - 82.0	77.6 (2.3)	77.9 (2.8)
Breast group aged 50-64			
Overall	59.5 - 84.7	75.6 (5.1)	76.9 (6.5)
London SHA (Q36)	59.5 - 78.8	69.0 (4.9)	68.8 (8.6)
Rest of England	64.6 - 84.7	77.3 (3.6)	78.1 (5.5)

FTE, Full-Time Equivalent; IQR: Inter Quartile Range; SD, Standard Deviation; SHA, Strategic Health Authority

Relationships between population, general practice factors, and coverage

Tables 2.1, 2.2 and 2.3 show the unadjusted and adjusted odds ratios of the associations between population and general practice risk factors with coverage. Each factor was found to be univariately associated with coverage in all screening groups, except for the percentage of population with no higher education and the practitioner headcount, which were only significant for the cervical screening group aged 25-49.

Variability in coverage was primarily explained by population factors with general practice characteristics only accounting for a small fraction of the residual variability (< 2% of total deviance after adjustment for population factors). Population covariates explained a lesser percentage of the total deviance among the cervical screening group aged 50-64 (45%, Table 2.2) than the cervical screening group aged 25-49 (78%, Table 2.1) or the breast screening group (72%, Table 2.3); overall variability was also lowest among the former group (IQR 3.5 versus IQR 5.9 and 6.5, respectively, Table 1).

With regard to general practice factors, only staff FTE remained positively associated with cervical screening coverage after accounting for population factors (Table 2.2).

After adjusting for deprivation, ethnicity and education, residing in London and urbanisation were no longer significantly associated with lower cervical screening coverage, but both remained associated with lower breast screening coverage.

Deprivation remained inversely associated with coverage in all screening groups, but displayed some collinearity with other factors for the cervical screening group aged 25-49 (Tables 2.1).

Absence of higher education remained associated with higher coverage in the cervical screening group aged 25-49 after adjusting for other population factors ([Table 2.1](#)). In this latter group, the effect of deprivation and education were no longer significant when the model accounted for the percentage of registered women aged 25-29 ([Supplementary file Table A2.1](#)).

After adjusting for other population factors, the percentage of 'other' ethnic minority groups remained negatively correlated with coverage in all screening groups, whereas the percentage of Asian, Black, or Mixed ethnic minority groups was no longer associated with lower breast screening coverage ([Tables 2.2-2.3](#)).

[\[Tables 2.1-2.3 here\]](#)

Table 2.1 Regression modelling for cervical screening coverage among women aged 25-49

Model	Univariate			Population		General practice		Population & General practice	
Deviance explained by model	–			78.2%		46.4%		79.1%	
Population factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
% Urbanisation	0.993 (0.992, 0.995)	< 0.001	41.9%	0.999 (0.998, 1.000)	0.03	–	–	0.999 (0.998, 1.000)	0.3
London SHA (Q36)	0.696 (0.653, 0.741)	< 0.001	46.2%	1.011 (0.939, 1.088)	NS (0.8)	–	–	–	–
% Deprivation	0.977 (0.973, 0.981)	< 0.001	41.1%	0.987 (0.981, 0.993)	< 0.001	–	–	0.989 (0.981, 0.996)	0.004 [§]
% Asian, Black, or Mixed ethnicity	0.989 (0.988, 0.990)	< 0.001	63.3%	0.997 (0.995, 0.999)	0.005	–	–	0.997 (0.995, 0.999)	0.005
% ‘Other’ ethnicity	0.901 (0.889, 0.912)	< 0.001	62.4%	0.958 (0.941, 0.975)	< 0.001	–	–	0.963 (0.946, 0.980)	< 0.001
% No higher education	1.012 (1.005, 1.020)	0.001	7.3%	1.011 (1.004, 1.017)	0.001	–	–	1.011 (1.004, 1.018)	0.003
General practice factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
Average practice list size	1.00008 (1.00005, 1.00010)	< 0.001	23.3%	–	–	0.99999 (0.99996, 1.00002)	NS (0.6)	–	–
% Single-handed practices	0.990 (0.987, 0.993)	< 0.001	20.6%	–	–	0.990 (0.985, 0.995)	< 0.001	0.998 (0.996, 1.000)	0.1
Practitioners headcount per 10 ⁵ population	0.993 (0.989, 0.997)	= 0.001	6.5%	–	–	0.989 (0.985, 0.992)	< 0.001	0.9993 (0.9963, 1.0022)	0.6
Practice staff FTE	1.0003 (1.0002, 1.0004)	< 0.001	22.8%	–	–	1.0002 (1.0001, 1.0003)	< 0.001	1.00005 (0.99999, 1.00011)	0.06
% Practitioners qualified outside UK	0.994 (0.992, 0.997)	< 0.001	13.7%	–	–	0.998 (0.996, 1.001)	NS (0.2)	–	–

CI, Confidence Interval; FTE, Full-Time Equivalent; NS, Considered non-significant (see Methods for details); SHA, Strategic Health Authority

[§] The variance of the coefficient estimate is being inflated by multicollinearity with other factors ($\sqrt{\text{GVIF}} = 2.7$).

Table 2.2 Regression modelling for cervical screening coverage among women aged 50-64

Model	Univariate			Population		General practice		Population & General practice	
Deviance explained	–			44.6%		26.7%		45.3%	
Population factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
% Urbanisation	0.997 (0.996, 0.998)	< 0.001	25.5%	0.999 (0.998, 0.999)	0.004	–	–	0.999 (0.998 – 0.999)	0.02
London SHA (Q36)	0.886 (0.837, 0.937)	< 0.001	10.6%	0.940 (0.875, 1.010)	NS (0.09)	–	–	–	–
% Deprivation	0.987 (0.984, 0.990)	< 0.001	31.1%	0.989 (0.985, 0.992)	< 0.001	–	–	0.990 (0.985, 0.994)	< 0.001
% Asian, Black, or Mixed ethnicity	0.997 (0.996, 0.998)	< 0.001	9.9%	1.005 (1.003, 1.007)	< 0.001	–	–	1.004 (1.002, 1.006)	< 0.001
% 'Other' ethnicity	0.959 (0.947, 0.972)	< 0.001	19.6%	0.970 (0.952, 0.988)	0.001	–	–	0.963 (0.946, 0.980)	< 0.001
% No higher education	0.997 (0.993, 1.002)	NS (0.3)	0.9%	–	–	–	–	–	–
General practice factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
Average practice list size	1.00004 (1.00003, 1.00006)	< 0.001	20.2%	–	–	1.000025 (1.000003, 1.000047)	0.02	0.999996 (0.999979, 1.000012)	0.6
% Single-handed practices	0.995 (0.993, 0.997)	< 0.001	13.1%	–	–	0.999 (0.995, 1.002)	NS (0.4)	–	–
Practitioner headcount per 10 ⁵ population	0.998 (0.996, 1.001)	NS (0.2)	1.2%	–	–	–	–	–	–
Practice staff FTE	1.00015 (1.00010, 1.00020)	< 0.001	19.5%	–	–	1.00010 (1.00005, 1.00016)	< 0.001	1.000058 (1.000007, 1.000109)	0.03
% Practitioners qualified outside UK	0.997 (0.996, 0.999)	< 0.001	7.8%	–	–	1.001 (0.998, 1.002)	NS (0.5)	–	–

CI, Confidence Interval; FTE, Full-Time Equivalent; NS, Considered non-significant (see Methods for details); SHA, Strategic Health Authority

Table 2.3 Regression modelling for breast screening coverage among women aged 50-64

Model	Univariate			Population		General practice		Population & General practice	
Deviance explained by model	–			70.7%		31.0%		70.6%	
Population factors	OR (95% CI)	p-value (Wald, χ2)	Deviance explained	OR (95% CI)	p-value (Wald, χ2)	OR (95% CI)	p-value (Wald, χ2)	OR (95% CI)	p-value (Wald, χ2)
% Urbanisation	0.992 (0.991, 0.993)	< 0.001	50.5%	0.996 (0.995, 0.998)	< 0.001	–	–	0.996 (0.995, 0.998)	< 0.001
London SHA (Q36)	0.642 (0.587, 0.703)	< 0.001	37.7%	0.896 (0.811, 0.990)	0.03	–	–	0.885 (0.806, 0.970)	0.009
% Deprivation	0.972 (0.967, 0.978)	< 0.001	38.8%	0.991 (0.986, 0.997)	0.002	–	–	0.991 (0.985, 0.997)	0.004
% Asian, Black, or Mixed ethnicity	0.987 (0.985, 0.989)	< 0.001	49.1%	0.999 (0.996, 1.002)	NS (0.5)	–	–	–	–
% ‘Other’ ethnicity	0.880 (0.863, 0.898)	< 0.001	50.8%	0.948 (0.923, 0.973)	< 0.001	–	–	0.945 (0.922, 0.969)	< 0.001
% No higher education	1.010 (1.001, 1.019)	NS (0.03)	3.1%	–	–	–	–	–	–
General practice factors	OR (95% CI)	p-value (Wald, χ2)	Deviance explained	OR (95% CI)	p-value (Wald, χ2)	OR (95% CI)	p-value (Wald, χ2)	OR (95% CI)	p-value (Wald, χ2)
Average practice list size	1.00010 (1.00007, 1.00012)	< 0.001	26.5%	–	–	1.000046 (1.000006, 1.000087)	0.03	1.00001 (0.99998, 1.00003)	0.6
% Single-handed practices	0.988 (0.984, 0.991)	< 0.001	24.2%	–	–	0.9945 (0.9886, 1.0004)	NS (0.07)	–	–
Practitioner headcount per 10 ⁵ population	0.996 (0.991, 1.001)	NS (0.1)	1.7%	–	–	–	–	–	–
Practice staff FTE	1.00025 (1.00015, 1.00035)	< 0.001	14.1%	–	–	1.000099 (0.999990, 1.000209)	NS (0.07)	–	–
% Practitioners qualified outside UK	0.993 (0.990, 0.995)	< 0.001	16.0%	–	–	0.9992 (0.9957, 1.0027)	NS (0.6)	–	–

CI, Confidence Interval; FTE, Full-Time Equivalent; NS, Considered non-significant (see Methods for details); SHA, Strategic Health Authority

Identification of districts with atypical coverage

Figure 1 illustrates the districts with coverage estimates lying outside the control limits prior to (Figure 1a-c) and after full covariate adjustment (Figure 1a'-c'). The geographical location of districts with atypical coverage is shown in Figure 2.

Over two-thirds of the districts initially lying below limits for cervical screening - for most, located within London - no longer lay *below* limits after adjustment. For the breast screening group, only one out of the four initial outliers (Kensington & Chelsea in London – data not shown) was found to lie within limits after adjustment, while a new London district was uncovered as atypically low (Wandsworth, London). For two London districts, the adjusted coverage remained below the 99.8% lower limit for the cervical screening group aged 25-49, and ranked among the 15 lowest districts for the other two screening groups (Hammersmith and Fulham, and Camden, Figure 2).

In contrast to what was observed for the districts lying below limits, the districts lying above the 95% upper limits *after* adjustment were mostly different from those identified prior to adjustment: only 1 in 2 districts for the cervical screening group aged 25-49, 1 in 5 for the cervical screening group aged 50-64, and 2 in 5 for the breast screening group would have been identified as atypically high performers without adjustment (Figure 1 & data not shown). Two districts displayed atypically high coverage in all screening groups irrespective of age (Enfield, London and Nottinghamshire County Teaching, East Midlands).

Characteristics of districts with relatively high and low adjusted coverage

Districts were ranked according to their adjusted coverage values ([Supplementary file Tables A3.1 & A3.2](#)). Associations between population factors were investigated among the 15 lowest- ([Figure 3b](#)) and the 15 highest-ranking districts ([Figure 3c](#)).

For all screening groups, we noted strong positive associations between deprivation and non-white ethnicities among the highest-ranking districts, which differed significantly from the associations seen among lowest-ranking districts (Fisher’s z test $p<0.05$ for cervical screening and $p=0.05$ for breast screening group among ethnic minorities groups only, [Figure 3d](#)).

For cervical screening, a strong positive correlation between deprivation and absence of higher education was observed among lowest-ranking districts ($\rho=0.77$ and 0.68 for age group 25-49 and 50-64, respectively), which tended to not be as strong overall or among highest-ranking districts, in particular for the younger age group (Fisher’s z test $p=0.04$).

Lowest-ranking districts tended to have populations of ethnicity other than Asian, Black, or Mixed with a higher level of education ($\rho=-0.88$, -0.77 and -0.70 for cervical age groups 25-49 and 50-64, and breast age group 50-64 respectively) compared with overall or high-ranking districts, in particular for cervical screening (Fisher’s z test $p=0.1$ for both cervical age groups).

DISCUSSION

This aim of this analysis was to identify and characterise districts that displayed atypically high or low cervical or breast screening coverage given population and general practice risk factors at district level. We found that a subset of districts with atypical coverage levels was common to both programmes, while other sets were more specific to the programme or age group.

Our risk adjustment results confirm the importance of demographic and socio-economic characteristics for coverage levels, and highlight the comparatively minor impact of various aspects of primary care. This suggests that strategies targeted at raising awareness or addressing barriers among socially- and culturally-diverse populations are likely to be the most effective at increasing coverage.

The number of practice staff FTE remained positively associated with cervical screening coverage but not breast screening coverage after adjusting for population factors. The finding that cervical screening coverage is more likely to be influenced by general practice factors is unsurprising since many women are screened at their local practice²⁵, and previous studies have shown the number of nurses per practice to be associated with cervical screening coverage in deprived areas¹⁰.

Coverage in London has generally been observed to be lower than the national average^{1,2}, in spite of some other public health features (for example obesity rates) being better in London²⁶. We found that urbanisation, ethnicity, and deprivation, largely accounted for the lower cervical screening uptake in London. For breast screening however, being located in

London, remained a strong independent negative risk factor, which warrants further investigation.

Deprivation was an independent negative risk factor for all screening groups, as also found for cervical screening by Bang and coll.²⁷. In the cervical screening group aged 25-49, this effect was in part explained by numbers of women under 30, as was the positive impact of lack of higher education on coverage. Cervical screening coverage has been reported to be lower in younger women²⁸, but younger women of lower socio-economic status or with fewer educational qualifications, regardless of ethnicity, have also been shown to be positively influenced by the 2009 Jade Goody's story with respect to cervical screening behaviour²⁹, giving hints as to potential strategies for improving uptake.

The impact of Asian, Black, or Mixed ethnic minority groups on coverage differed between programmes after controlling for other population factors. For breast screening, it was no longer significant. For cervical screening, we found it negatively influenced coverage in the age group 25-49, but was associated with greater coverage in the age group 50-64. Previously, only an overall negative overall association after adjustment for other population factors had been reported for cervical screening in women aged 25-64²⁷.

For both programmes, and regardless of age, 'other' ethnic minority groups were still associated with poorer coverage after accounting for deprivation and urbanisation, with a particularly strong effect in breast screening. In addition, our results suggest that women of 'other' ethnic minority background, who may be well educated and living in areas with smaller Asian, Black, or Mixed ethnic minority populations, are less likely to go for screening. Arabs communities account for a moderately large subset of the 'other' ethnic minority groups (40%), and uptake of cervical and breast screening has been shown to be low in

these populations for a number of reasons, including religious beliefs, emotional barriers (embarrassment/fear), language barriers or taboos surrounding sexual activity (for cervical screening) ³⁰⁻³². These communities may therefore require newly targeted interventions to promote screening.

Our correlation analyses suggest that districts with atypical coverage levels differ from one another not only in respect of a number of population- and general practice-level characteristics, but also in how these characteristics relate to each other. Correlates of deprivation in districts with relatively low adjusted coverage were substantially different from the general results, and even more so for cervical screening. In particular, the nature of the relationship between deprivation and non-White ethnicity differed, with an inverse relationship between deprivation and non-White ethnic groups among lowest-ranking districts.

Using funnel plots based on crude performance data to assess quality of care at area level may overestimate the number of "underperforming" districts, and overdispersion needs to be addressed *a priori*. We chose a risk adjustment approach to uncover districts with atypically high or low coverage given particular population and general practice characteristics. Districts with adjusted coverage values lying outside control limits display a behaviour which cannot solely be explained by the area-level risk factors investigated.

Districts with atypically high coverage were singled out and could be investigated to identify any local health interventions and policies that might help improve coverage in districts with similar characteristics but lower performance. Unfortunately, there is a general lack of

reporting in the research literature across districts on the impact of local interventions that have been implemented to improve screening uptake (ED, unpublished PhD thesis), so identifying ‘what works’ is challenging.

Simultaneously, districts with atypically low coverage were distinguished from those lying within bounds after accounting for urbanisation, deprivation and ethnicity, in particular for the London region. These districts may benefit from further investigation to uncover the features driving their atypically low coverage and help design population-specific strategies. Additional risk factors that may explain low coverage, as well as differences in district performance between programmes, include the percentage of women who are disabled³³, incarcerated³⁴, have greater difficulty in accessing services as indexed by time to screening centre¹³, and differential utilization behaviour as a result of socio-cultural factors, such as marital status³⁵, occupation³⁶, sexual orientation³⁷, and overseas birthplace or religious beliefs^{11,38} that might apply to particular programmes.

Our results are limited by the aggregated nature of the data, which may conceal ecological associations within districts. This could account for the weak association seen between coverage and general practice characteristics after adjustment for population factors. However, similar trends were observed when analysing general practice-level data for cervical screening coverage²⁷.

The districts boundaries used in this study (152 PCTs) are no longer in place; however, the findings may be applied to the newly defined boundaries (210 Clinical Commissioning Groups (CCGs)) by direct mapping³⁹.

The strength of the approach of combining risk adjustment modelling with funnel plots was to allow us to identify districts with unusual level of screening coverage after accounting for some of the important demographic and socio-economic characteristics of their populations and their primary care settings, known to affect coverage level. Such an approach could be implemented sequentially to monitor the impact of local interventions in a centralised fashion. This method could also be adapted for use with other health indicators.

Our results demonstrate that population factors largely explain the lower coverage in London. In addition, districts in London and other urban centres with specific population characteristics such as non-deprived ethnic minority groups were identified as requiring targeted intervention to improve coverage levels. Bilingual outreach and community-based advocacy, such as support from family and community leaders including GPs, has been found to be valuable in increasing uptake of cancer screening in ethnic minorities⁴⁰.

We hope these results will inform the continued drive to reduce inequalities in cancer screening and avoidable deaths, and encourage implementation of targeted interventions in communities residing within districts identified as having atypically low coverage.

ABBREVIATIONS

CCG	Clinical Commissioning Group
CI	Confidence Interval
FTE	Full-Time Equivalent
GP	General Practitioner
GVIF	Generalized Variance-Inflation Factor
HSCIC	Health and Social Care Information Centre
IMD	Indices of Multiple Deprivation
IQR	Interquartile Range
LSOA	Lower Super Output Area
PCT	Primary Care Trust
SD	Standard Deviation
SHA	Strategic Health Authority

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COMPETING INTERESTS

None

AUTHOR'S CONTRIBUTION

NJM performed the statistical analysis, interpreted the results and wrote the manuscript. ED carried out the data informatics and data checks, and co-wrote the manuscript. JW & JW provided general expert guidance. SWD provided general statistical guidance. All authors reviewed and approved the final manuscript.

DATA SHARING STATEMENT

Data are freely available from the HSCIC:

Cervical screening: <http://www.hscic.gov.uk/catalogue/PUB10339/bres-scre-prog-eng-2011-12-tab.xls>

Breast screening: <http://www.hscic.gov.uk/catalogue/PUB07990/cerv-scre-prog-eng-2011-12-tab.xls>

No additional data available.

ETHICS APPROVAL

None

LIST OF FIGURES

Figure 1. Funnel plots of screening coverage and list of districts lying outside the 95% control limits prior to and after risk adjustment

Top left panel. Funnel plots of screening coverage prior to any adjustment

- (a) Cervical screening in women aged 25-49.
- (b) Cervical screening in women aged 50-64.
- (c) Breast screening in women aged 50-64.

Top right panel. Funnel plots of screening coverage after adjustment for population and general practice factors

- (a') Cervical screening in women aged 25-49.
- (b') Cervical screening in women aged 50-64.
- (c') Breast screening in women aged 50-64.

----- 95.0% control limits
..... 99.8% control limits

SHA, Strategic Health Authority; Q30, North East; Q31, North West ;Q33, East Midlands; Q34, West Midlands; Q35, East of England; Q36, London; Q37, South East Coast; Q38, South Central; Q39, South West.

Table. Number of districts lying outside the 95% control limits prior to and after risk adjustment. The number of districts within London SHA (Q36) is shown in brackets.

Figure 2. Geographical location of atypical districts

Map. Map of PCT 2006 boundaries with districts lying below the 95% lower control limits after risk adjustment coloured in red and districts lying above the 95% upper control limits after risk adjustment coloured in green.

Table. Districts lying outside the control limits are listed with corresponding percentile given in brackets. Districts with coverage ranking among the 15 lowest- (rank ≤ 15) or 15 highest (rank ≥ 137) are specified. All districts lying outside the control limits had relative coverage rankings ≤ 15 for lower 95% limit and ≥ 137 for upper 95% limit.

SHA, Strategic Health Authority; Q30, North East; Q31, North West ;Q33, East Midlands; Q34, West Midlands; Q35, East of England; Q36, London; Q37, South East Coast; Q38, South Central; Q39, South West.

Figure 3. Correlations between population factors overall, and among the 15 highest- and 15 lowest-ranking districts after risk adjustment

a-c. Correlation coefficients are displayed in each cell. a, All districts; b, 15-lowest ranking districts; c, 15 highest ranking districts.

For the 15 lowest and 15 highest-ranking districts, correlation coefficients which are significantly different from zero at the 1% level are highlighted in green for positive correlations, and in red for negative correlations.

d. Fisher's z test for significant differences in correlation coefficients between two independent groups.

Bold, p-values < 0.05. Italic, p-values not significant at the 10% level.

1, % Deprivation; 2, % Urbanisation; 3, % Asian, Black or Mixed ethnic minority groups; 4, % 'Other' ethnic minority groups; 5, % No higher education.

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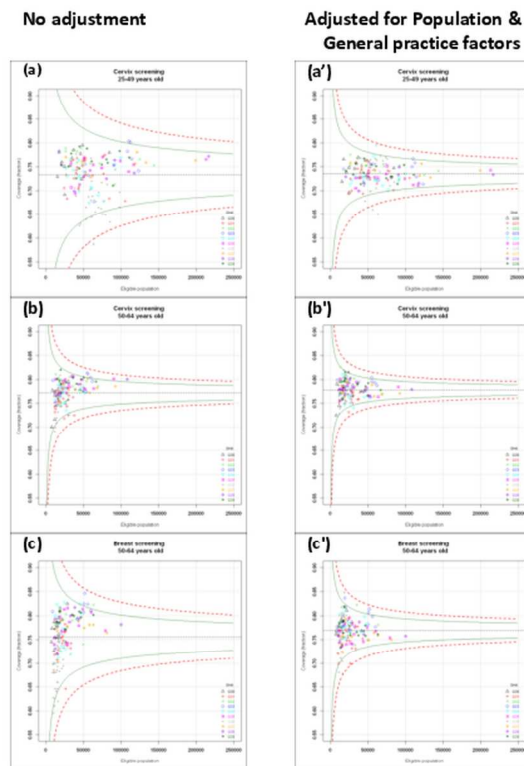
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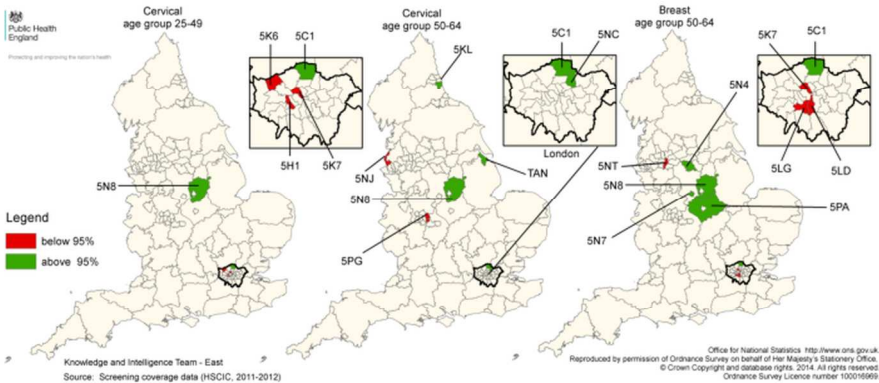
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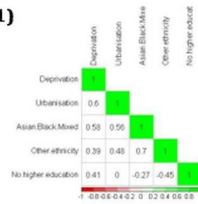
Screening group	Control limit		No adjustment	Adjusted for Population & General practice factors
Cervical aged 25-49	Above	Upper 99.8%	0 (0)	0 (0)
		Upper 95%	2 (0)	2 (1)
	Below	Lower 95%	9 (9)	3 (3)
		Lower 99.8%	2 (2)	2 (2)
Cervical aged 50-64	Above	Upper 99.8%	0 (0)	0 (0)
		Upper 95%	5 (0)	5 (2)
	Below	Lower 95%	7 (3)	2 (0)
		Lower 99.8%	0 (0)	0 (0)
Breast aged 50-64	Above	Upper 99.8%	0 (0)	0 (0)
		Upper 95%	5 (0)	5 (1)
	Below	Lower 95%	4 (3)	4 (3)
		Lower 99.8%	0 (0)	0 (0)

Figure1
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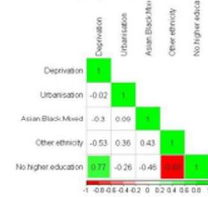


PCT name	SHA	Screening group		
		Cervical age group 25-49	Cervical age group 50-64	Breast Age group 50-64
Below lower				
95% control limit				
5H1 / Hammersmith and Fulham	Q36	Below 99.8% (0.01%)	Rank ≥ 137	Rank ≥ 137
5K6 / Harrow	Q36	Below 95% (0.2%)	Rank ≥ 137	—
5K7 / Camden	Q36	Below 99.8% (0.001%)	Rank ≥ 137	Below 95% (0.02%)
5NJ / Sefton	Q31	Rank ≥ 137	Below 95% (0.3%)	—
5PG / Birmingham East & North	Q34	Rank ≥ 137	Below 95% (1.2%)	—
5LD / Lambeth	Q36	—	Rank ≥ 137	Below 95% (0.01%)
5LG / Wandsworth	Q36	—	Rank ≥ 137	Below 95% (0.4%)
5NT / Manchester	Q31	—	Rank ≥ 137	Below 95% (0.2%)
Above upper				
95% control limit				
5C1 / Enfield	Q36	Above 95% (99.8%)	Above 95% (99.9%)	Above 95% (99.9%)
5N8 / Nottinghamshire County Teaching	Q33	Above 95% (93.9%)	Above 95% (93.9%)	Above 95% (93.5%)
5KL / Sunderland Teaching	Q30	Rank ≤ 15	Above 95% (98.6%)	Rank ≤ 15
5NC / Waltham Forest	Q36	—	Above 95% (99.3%)	Rank ≤ 15
TAN / North East Lincolnshire Care Trust Plus	Q32	Rank ≤ 15	Above 95% (99.8%)	—
5N4 / Sheffield	Q32	—	—	Above 95% (98.5%)
5N7 / Derby City	Q33	—	Rank ≤ 15	Above 95% (99.7%)
5PA / Leicestershire County & Rutland	Q33	—	—	Above 95% (96.5%)

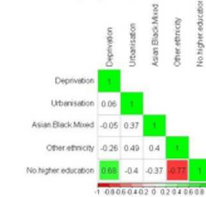
Figure2
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a. All districts (N = 151)**b. 15 lowest-ranking districts**

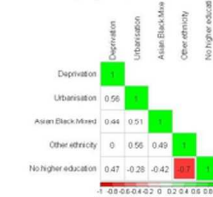
Cervical age group 25-49



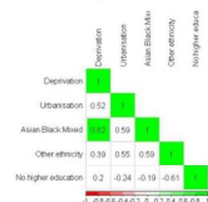
Cervical age group 50-64



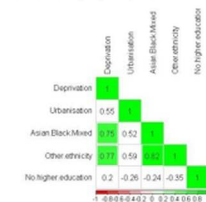
Breast age group 50-64

**c. 15 highest-ranking districts**

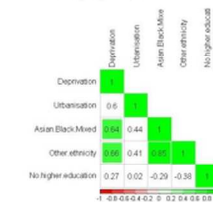
Cervical age group 25-49



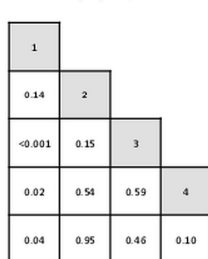
Cervical age group 50-64



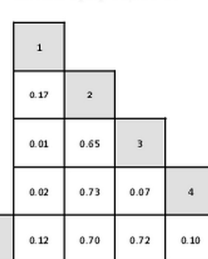
Breast age group 50-64

**d. Differences in correlates between the 15 lowest- and the 15 highest-ranking districts**

Cervical age group 25-49



Cervical age group 50-64



Breast age group 50-64

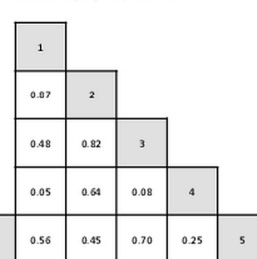


Figure 3 revised - TIFF version
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SUPPLEMENTARY FILE (MASSAT, DOUGLAS ET AL.)

Table A1. Correlations between population and general practice factors, and screening coverage (all districts)
Upper diagonal: Correlation coefficient; Lower diagonal: p-value of test for significant correlation between paired samples

	Population factors						General practice factors					Coverage		
	% Urbanization	% Deprivation	% Asian, Black, or Mixed ethnicity	% 'Other' ethnicity	% No higher education	% Registered women aged 25-29	Average practice list size	% Single-handed practices	Practitioner headcount per 10 ⁵ population	Practice staff FTE	% Practitioners qualified outside UK	Cervical group aged 25-49	Cervical group aged 50-64	Breast group aged 50-64
Population factors														
% Urbanization	1	0.61	0.56	0.48	-0.002	0.63	-0.50	0.49	0.02	-0.51	0.42	-0.60	-0.49	-0.66
% Deprivation	< 0.001	1	0.58	0.39	0.41	0.64	-0.58	0.46	0.23	-0.36	0.54	-0.56	-0.47	-0.58
% Asian, Black, or Mixed ethnicity	< 0.001	< 0.001	1	0.70	-0.27	0.62	-0.35	0.39	0.14	-0.25	0.43	-0.78	-0.24	-0.68
% 'Other' ethnicity	< 0.001	< 0.001	< 0.001	1	-0.45	0.60	-0.40	0.38	0.14	-0.25	0.22	-0.78	-0.45	-0.74
% No higher education	NS (0.9)	< 0.001	0.001	< 0.001	1	-0.11	-0.26	0.21	-0.25	-0.04	0.37	0.31	0.02	0.31
% Registered women aged 25-29	< 0.001	< 0.001	< 0.001	< 0.001	NS (0.2)	1	-0.33	0.30	0.26	-0.24	0.21	-0.71	-0.43	-0.69
General practice factors														
Average practice list size	< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001	1	-0.75	0.06	0.36	-0.52	0.42	0.39	0.49
% Single-handed practices	< 0.001	< 0.001	< 0.001	< 0.001	0.01	< 0.001	< 0.001	1	-0.35	-0.27	0.61	-0.41	-0.28	-0.43
Practitioner headcount per 10 ⁵ population	NS (0.8)	0.006	NS (0.1)	NS (0.08)	0.002	0.001	NS (0.5)	< 0.001	1	0.06	-0.35	-0.19	-0.14	-0.22
Practice staff FTE	< 0.001	< 0.001	0.002	0.002	NS (0.7)	0.004	< 0.001	0.001	NS (0.4)	1	-0.36	0.34	0.37	0.35
% Practitioners qualified outside UK	< 0.001	< 0.001	< 0.001	0.006	< 0.001	0.009	< 0.001	< 0.001	< 0.001	0.001	1	-0.29	-0.18	-0.32
Coverage														
Cervical group aged 25-49	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.02	< 0.001	< 0.001	1	0.68	0.84
Cervical group aged 50-64	< 0.001	< 0.001	0.004	< 0.001	NS (0.8)	< 0.001	< 0.001	< 0.001	NS (0.09)	< 0.001	0.03	< 0.001	1	0.65
Breast group aged 50-64	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.006	< 0.001	< 0.001	< 0.001	< 0.001	1

NS: not significant at the 5% level; FTE: Full Time Equivalent

Table A2.1. Regression modelling for cervical screening coverage among women aged 25-49, including % registered women aged 25-29.

Model	Univariate			Population		General practice		Population & General practice	
Deviance explained by model	–			79.5%		46.4%		80.9%	
Population factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
% Urbanization	0.993 (0.992, 0.995)	< 0.001	41.9%	0.999 (0.998, 1.000)	NS (0.3)	–	–	0.999 (0.998, 1.001)	0.8
London SHA	0.696 (0.653, 0.741)	< 0.001	46.2%	0.972 (0.901, 1.048)	NS (0.5)	–	–	–	–
% Deprivation	0.977 (0.973, 0.981)	< 0.001	41.1%	0.992 (0.986, 0.999)	0.03	–	–	1.0017 (0.996, 1.007)	0.5 ⁵
% Asian, Black, or Mixed ethnicity	0.989 (0.988, 0.990)	< 0.001	63.3%	0.997 (0.995, 0.999)	0.004	–	–	0.995 (0.993, 0.997)	< 0.001
% 'Other' ethnicity	0.901 (0.889, 0.912)	< 0.001	62.4%	0.963 (0.946, 0.980)	< 0.001	–	–	0.958 (0.943, 0.973)	< 0.001
% No higher education	1.012 (1.005, 1.020)	0.001	7.3%	1.007 (1.000, 1.013)	NS (0.06)	–	–	–	–
% Registered women aged 25-29	0.965 (0.959, 0.970)	< 0.001	52.9%	0.990 (0.984, 0.996)	0.002	–	–	0.987 (0.981, 0.994)	< 0.001
General practice factors	OR (95% CI)	p-value (Wald, χ^2)	Deviance explained	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)	OR (95% CI)	p-value (Wald, χ^2)
Average practice list size	1.00008 (1.00005, 1.00010)	< 0.001	23.3%	–	–	0.99999 (0.99996, 1.00002)	NS (0.6)	–	–
% Single-handed practices	0.990 (0.987, 0.993)	< 0.001	20.6%	–	–	0.990 (0.985, 0.995)	< 0.001	0.998 (0.995, 1.000)	0.06
Practitioner headcount per 10 ⁵ population	0.993 (0.989, 0.997)	0.001	6.5%	–	–	0.989 (0.985, 0.992)	< 0.001	0.998 (0.995, 1.000)	0.06
Practice staff FTE	1.0003 (1.0002, 1.0004)	< 0.001	22.8%	–	–	1.0002 (1.0001, 1.0003)	< 0.001	1.00007 (1.00002, 1.00013)	0.01
% Practitioners qualified outside UK	0.994 (0.992, 0.997)	< 0.001	13.7%	–	–	0.998 (0.996, 1.001)	NS (0.2)	–	–

CI: Confidence Interval; FTE: Full-Time Equivalent; NS: Considered non-significant (see Methods for details); SHA: Strategic Health Authority

⁵ The variance of the coefficient estimate is being inflated by multicollinearity with other factors ($\sqrt{\text{GVIF}} = 2.8$).

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Table A3.1. 15 lowest-ranking PCTs prior to and after adjustment for population and general practice factors

	Rank (/151)	No adjustment (percentile)	Adjustment for Population & General practice factors (percentile)
Cervical group aged 25-49	137	5MX	5A9*
	138	5LD*	5LA*
	139	5AT*	5HY*
	140	5C3*	5PN
	141	5K5*	5PG
	142	5C4*	5NL
	143	5C5* [§] (2.79%)	TAP
	144	5A9* [§] (2.65%)	5FE
	145	5HY* [§] (2.04%)	5AT*
	146	5LC* [§] (1.56%)	5KM
	147	5HX* [§] (1.11%)	5NJ
	148	5K6* [§] (0.86%)	5HP
	149	5LA* [§] (0.69%)	5K6* [§] (0.22%)
	150	5H1* ^{§§} (0.04%)	5H1* ^{§§} (0.01%)
	151	5K7* ^{§§} (0.04%)	5K7* ^{§§} (0.001%)
Cervical group aged 50-64	137	5LG*	5LD*
	138	5J4	5M7*
	139	5M1	5HY*
	140	5C3*	5NT
	141	5HP	5K6*
	142	5PG [§] (2.70%)	5M1
	143	5NT [§] (2.09%)	5LG
	144	5NL [§] (1.92%)	TAM
	145	5K7*	5KM
	146	5NJ [§] (0.98%)	5K7*
	147	5KM	5LA*
	148	5LC* [§] (0.31%)	5PG [§] (1.20%)
	149	5D9	5NJ [§] (0.30%)
	150	5LA* [§] (0.08%)	5H1*
	151	5H1* [§] (0.02%)	5D9
Breast group aged 50-64	137	5K5*	5F5
	138	5A8*	5FL
	139	5HP	5NH
	140	5C4*	5NG
	141	5LF*	5LF*
	142	5LG*	5LQ
	143	5C3*	5H1*
	144	5NT [§] (0.89%)	TAP
	145	5C9*	5LE*
	146	5LE*	5LG* [§] (0.42%)
	147	5H1*	5HP
	148	5LC*	5NT [§] (0.22%)
	149	5LD* [§] (0.17%)	5LA*
	150	5K7* [§] (0.09%)	5K7* [§] (0.02%)
	151	5LA* [§] (0.03%)	5LD* [§] (0.01%)

PCT: Primary Care Trust; SHA: Strategic Health Authority
Dark red: PCTs lying below the 95% lower control limits using full model (atypical PCTs).
Orange: Atypical PCTs found among PCTs with lowest relative coverage prior to adjustment.
Percentile is given for those PCTs lying below the 95% lower control limits prior to and after full adjustment.
* PCT in London SHA (Q36)
§ PCT lying between the 95% and 99.8% lower control limits
§§ PCT lying below the 99.8% lower control limits

Table A3.2. 15 highest-ranking PCTs prior to and after adjustment for population and general practice factors

	Rank (/151)	No adjustment (percentile)	Adjustment for Population & General practice factors (percentile)
Cervical group aged 25-49	1	5N8 [§] (94.4%)	5C1* [§] (99.8%)
	2	5N6 [§] (93.9%)	TAN
	3	TAC	5C9*
	4	5A3	5MX
	5	5NW	5D8
	6	TAN	5K5*
	7	5QM	TAK*
	8	5D8	5A3
	9	5J6	5N8 [§] (93.9%)
	10	5ET	5A7*
	11	5QH	5J6
	12	5PA	5C5*
	13	5EF	5J9
	14	5JE	5LC*
	15	5P9	5KL
Cervical group aged 50-64	1	5A3	5C1* [§] (99.9%)
	2	5N8 [§] (96.4%)	TAN [§] (99.8%)
	3	5PA [§] (95.8%)	5NC* [§] (99.3%)
	4	TAN	5A3
	5	5NA*	5KL [§] (98.6%)
	6	5P2	5MX
	7	5QF	5JE
	8	5N2	5C9*
	9	5QH	5NA*
	10	5N6 [§] (91.8%)	5N7
	11	5QM	5J6
	12	5J6	5N8 [§] (93.9%)
	13	5P9	5QN
	14	5QV [§] (89.8%)	5N2
	15 [#]	5FL	5F1
Breast group aged 50-64	1	5PA [§] (97.4%)	5C1* [§] (99.9%)
	2	5M2	5N7 [§] (99.7%)
	3	TAC	5N4 [§] (98.5%)
	4	5PL [§] (93.1%)	5A4*
	5	5N8 [§] (93.0%)	5F1
	6	5N6 [§] (92.9%)	5PC
	7	5CN	5NC*
	8	5NV [§] (92.5%)	5JE
	9	5JE	5H8
	10	5QD	5PA [§] (96.5%)
	11	5PX	5KL
	12	5N7	5PJ
	13	5PT	5N8 [§] (93.5%)
	14	5PW	TAK*
	15	5H8	5MK

PCT: Primary Care Trust; SHA: Strategic Health Authority

Dark green: PCTs lying above the 95% upper control limits using full model (atypical PCTs).**Light green:** Atypical PCTs found among PCTs with highest relative coverage prior to adjustment.

Percentile is given for those PCTs lying above the 95% upper control limits prior to and after full adjustment.

* PCT in London SHA (Q36)

[§] PCT lying between the 95% and 99.8% upper control limits^{§§} PCT lying above the 99.8% upper control limits[#] The 17th highest-ranking PCT (5QC) also lay above the 95% upper control limit (percentile 89.1%)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Checklist
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract	Yes
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	Yes
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	p.5-6
Objectives	3	State specific objectives, including any pre-specified hypotheses	p.6
Methods			
Study design	4	Present key elements of study design early in the paper	p.6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	p.6
Participants	6	(a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	p.6
		Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls	
		Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants	
		(b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed	
		Case-control study—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	p.6
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	p.6
Bias	9	Describe any efforts to address potential sources of bias	p.8
Study size	10	Explain how the study size was arrived at	p.6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	p.8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	p.8
		(b) Describe any methods used to examine subgroups and interactions	p.8
		(c) Explain how missing data were addressed	p.6-7
		(d) Cohort study—If applicable, explain how loss to follow-up was addressed	
		Case-control study—If applicable, explain how matching of cases and controls was addressed	
		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	p.12

Continued on next page

Results			Checklist
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	p.9 & Table 1
		(b) Indicate number of participants with missing data for each variable of interest	N/A
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	p.8
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	p.11-12 & Table 2.1-3
		(b) Report category boundaries when continuous variables were categorized	N/A
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Table A2.1
Discussion			
Key results	18	Summarise key results with reference to study objectives	p.18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	p.21
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	p.18-20
Generalisability	21	Discuss the generalisability (external validity) of the study results	p.20-22
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	p.23

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.