


BMJ Open Residential area and screening venue location features associated with spatial variation in breast cancer screening invitation response rates: an observational study in Greater Sydney, Australia

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To cite: Khan JR, Carroll SJ, Warner-Smith M, *et al.* Residential area and screening venue location features associated with spatial variation in breast cancer screening invitation response rates: an observational study in Greater Sydney, Australia. *BMJ Open* 2021;**11**:e043853. doi:10.1136/bmjopen-2020-043853

► Prepublication history and additional material for this paper are available online. To view these files, please visit the journal online (<http://dx.doi.org/10.1136/bmjopen-2020-043853>).

Received 18 August 2020
Revised 15 March 2021
Accepted 26 March 2021



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ABSTRACT

Objectives Participation in breast cancer screening (BCS) varies at the small-area level, which may reflect environmental influences. This study assessed small-area variation in BCS invitation response rates (IRRs) and associations between small-area BCS IRR, sociodemographic factors, BCS venue distance and venue location features in Greater Sydney, Australia.

Methods BCS IRR data for 2011–2012 were compiled for 9528 Australian Bureau of Statistics Statistical Area Level 1 (SA1) units (n=227 474 women). A geographical information system was used to extract SA1-level sociodemographic features (proportions of women speaking English at home, full-time employed and university educated, and proportion of dwellings with motor vehicles), SA1-level distance to closest venue(s) (expressed as quartiles), and closest venue(s) collocated with bus stops, train station, hospital, general practitioner and shops. Associations between area-level features, BCS venue distance, venue location features and IRR were estimated using ordinary least square-type spatial lag models including area education as a covariate.

Results BCS IRR varied across SA1s (mean=59.8%, range: 0%–100%), with notable spatial autocorrelation (Moran's I=0.803). BCS IRR was positively associated with greater SA1-level proportion of women speaking English at home ($\beta=2.283$, 95% CI 2.024 to 2.543), women's education (in the model including speaking English at home $\beta=0.454$, 95% CI 0.211 to 0.697), dwellings with motor vehicles ($\beta=1.836$, 95% CI 1.594 to 2.078), greater distance to venue (eg, most distant quartile compared with closest: $\beta=6.249$, 95% CI 5.489 to 7.008), and BCS venue collocated with shops ($\beta=0.762$, 95% CI 0.273 to 1.251). Greater SA1-level women employment ($\beta=-0.613$, 95% CI -0.898 to -0.328) and venue collocated with train station ($\beta=-1.889$, 95% CI -2.376 to -1.402) or hospital ($\beta=-0.677$, 95% CI -1.164 to -0.189) were inversely related to BCS IRR.

Conclusions Small-area variation in BCS IRR exists for Greater Sydney and is strongly related to sociodemographic factors that, together with BCS venue

Strengths and limitations of this study

- This study documents, for the first time, substantial small-area variation in breast cancer screening (BCS) invitation response rate (IRR) for Greater Sydney, Australia.
- For the smallest unit at which Census data are released, this study shows not only that IRR is related to favourable sociodemographic conditions but also that rates vary with built environmental features of screening venue sites.
- Results indicating spatial variability and small-area correlates of IRR can be used by policymakers and service providers to design targeted interventions specific to the features of local-area resident populations to boost screening participation, reduce disparities and monitor progress in service use.
- This study is ecological; therefore, area-level relationships found do not necessarily reflect individual-level relationships but do have relevance to area-level intervention.
- Potentially relevant covariates, including public information campaigns, private BCS rates, and within-venue features and availability of appointments were unavailable.

location features, could inform targeted attempts to improve IRR.

INTRODUCTION

Worldwide, breast cancer (BC) is the most prevalent cancer among women.¹ Among Australian women, BC is the most commonly diagnosed cancer and the second leading cause of cancer mortality.² *BreastScreen Australia* is an organised population-based breast cancer screening (BCS) programme, aiming to reduce women's BC morbidity and

mortality through early cancer detection.² *BreastScreen Australia* provides mammograms every 2 years free of charge to asymptomatic women aged over 40 years.² The programme targeted women aged 50–69 years through invitation letters until July 2013, when *BreastScreen Australia* expanded this target age range (and therefore those women being sent invitation letters) from 50–69 years to 50–74 years.² The programme aims to screen at least 70% of women targeted across any given 2-year period.² While BCS among Australian women has increased over time, from 51.7% in 1996–97 to 54.6% in 2015–2016 among women aged 50–69 years, it continues to remain below the target rate of 70%.²

Australia's most populous city, Greater Sydney (20.9% of Australia's population³), had a BCS participation rate of 47.3% among women aged 50–69 years in 2013–2014, lower than the national average and well below target.^{4,5} However, this rate varies within Greater Sydney (from 38.5% to 58.2%) for local government areas (LGAs)—a very large spatial unit.⁴ A notable marker of BCS participation rate variation for Greater Sydney is area-level socioeconomic status (SES) for which LGA-based rates vary from 50.3% for the least disadvantaged to 43.7% for the most disadvantaged areas.⁴

Environmental influences including SES shape behaviour and are thus relevant to BCS.⁶ While behavioural interventions seek to raise participation in cancer screening programmes by targeting individual factors predisposing and reinforcing screening,^{7,8} research indicates that screening responses are enhanced by attention to environmental conditions that enable individuals to enact behavioural intentions.^{7,8} Grounded to social cognitive theory (SCT), such screening promotion interventions conceive behaviour as an interaction between the person, behaviour and environment.^{9,10} SCT recognises that people and their environments are reciprocal determinants of each other, that the limits of self-direction coexist with opportunities for influencing destiny. Given it is important that cancer screening promotion strategies emphasise environmental as much as individual influences,¹¹ there is a need to better assess environmental factors that contribute to BCS uptake.

In industrialised countries, individuals residing in areas having greater education and/or income, and proportionately fewer non-English speakers, are more likely to participate in BCS.^{12–14} BCS participation has also been shown to be inversely related to distance to screening venue and less likely when the closest venue was collocated with a health facility.^{12,15} Another study suggested that women in an area served by multiple screening venues may attend a venue collocated with a shopping centre, recognising the convenience of other collocated services (ie, shops) which they might use before or after their screening appointment ('trip chaining').¹⁶ A study in England reported lesser BCS uptake associated with greater area-level deprivation and proportion of people commuting to work by public transport, and greater uptake associated with greater area-level car ownership.¹⁷

One German study reported lesser BCS uptake associated with greater area-level unemployed migrants or long-term unemployed residents.¹⁸ A second German study reported lesser BCS uptake related to greater area-level education and income, the discrepancy between studies potentially reflecting different research designs, definitions and measures.¹⁹ While the literature does attest environmental features influence BCS participation, aligning with the postulates of SCT, the direction of these influences remains unclear.²⁰

Assessing spatial variation in environmental phenomena related to health requires, ideally, small-area rather than large-area units.²¹ Small-area analyses assist the detection of localised variations otherwise masked by large-area averages. Previous studies have attested a need for small-area assessment of environmental predictors in relation to BCS uptake; however, few studies have undertaken and reported small-area analyses.^{17,19} Small-area research on social and built environmental factors shaping BCS use has not previously been reported for Greater Sydney. Information on spatial variability in BCS uptake and environmental correlates of uptake are required so that policymakers and service providers can design targeted interventions specific to the features of local-area resident populations and the settings in which they live to boost screening participation, reduce disparities and monitor progress in service use. This study sought, for Greater Sydney, first, to assess small-area variation in BCS uptake and, second, to estimate associations between BCS uptake and small-area sociodemographic factors, BCS venue distance and venue location features.

METHODS

Population, setting and BCS data

This observational study was set in the Greater Sydney region of New South Wales (NSW). The target population was all women invited to screen (ages 50–69 years) during 2011–2012 through the state-wide *BreastScreen NSW* programme. The Cancer Institute of NSW provided population-wide BCS invitation and invitation response data for this time period.

Invitation records included residential address geocodes which enabled spatial linkage with Australian Bureau of Statistics (ABS) Statistical Area Level 1 (SA1) spatial unit information. The SA1 is the smallest unit at which ABS data are reported. Invitation data were aggregated within SA1s to express SA1-level BCS invitation response rates (IRRs). ABS 2011 Census data²² were used to characterise SA1-level sociodemographic information.

Table 1 summarises the steps used to prepare the analytical dataset. From an initial base of 458 940 records across 2011–2012, 424 802 records remained after applying individual-level record exclusions. These individual records were linked to 17 453 SA1s and further exclusions then applied based on SA1-level information (see table 1); notably, SA1s with fewer than 10 invited women were excluded to ensure a defensible denominator by

Table 1 Data extraction steps and data loss in constructing IRR and creating an analytical BCS dataset for Greater Sydney

| Data | Individuals | Exclusion | Reason for exclusion |
|--|----------------|-----------|--|
| Individuals | 458940 | – | Individuals invited to screen by <i>BreastScreen NSW</i> during the invitation period (2011–2012). Invitations are based on the electoral role (a reliable population information source within Australia) ⁴² ; therefore, this is a population not a sample. |
| Individuals | 440299 | 18641 | Individuals excluded owing to address not being successfully geocoded (13 903), residing in the island location (48) and residing outside of NSW (4690). |
| Individuals | 438318 | 1981 | Excluded individuals who screened before their earliest invitation date. |
| Individuals | 424802 | 13516 | Individuals aged <50 and >69 years during invitation were excluded because individuals of this age group would not be invited to participate. |
| Individuals are spatially joined to SA1s | SA1* 17 453 | – | |
| SA1s | 10535 | 6918 | Excluded SA1s located outside of study area (eg, Greater Sydney). |
| SA1s | 10309 | 226 | SA1s with fewer than 10 women aged 50–69 years (n=226) were excluded due to low count at small-area level and to reduce randomisation bias because ABS Census data cells containing small values had been adjusted randomly to protect confidentiality. ⁴³ |
| SA1s | 9531 | 778 | SA1s with fewer than 10 invited women were excluded to ensure a defensible denominator by which to express IRR. |
| SA1s | 9528 | 3 | SA1s for which it appeared that the number of women speaking only English at home was greater than the total number of women listed as residing within that SA1 were excluded as the numerator could not reasonably be greater than the denominator. These unlikely numbers can arise due to ABS procedures to randomise small cell values in order to maintain confidentiality. |

*ABS SA1, a total of 227 474 women invited for screening resided in 9528 SA1s.

ABS, Australian Bureau of Statistics; BCS, breast cancer screening; IRR, invitation response rate; SA1, Statistical Area Level 1.

which to express IRR. This yielded an analytical dataset of 227 474 records accounting for 9528 SAIs. Sensitivity analyses (see online supplemental file) based on setting different thresholds for minimum target population numbers (ie, invitees) per SAI (n of SAIs=5776, ≥ 20 invitees, and n of SAIs=2370, ≥ 30 invitees) were performed to assess the impact of different thresholds.

MEASURES

Outcome measure

BCS IRR was defined for each SAI as the number of women who screened within 6 months of receipt of a screening invitation, relative to the total number of women who received a screening invitation.

Exposure measures

Exposure measures focused on the sociodemographic features of invitees' residential SAIs, venue distance and built environmental features of venue locations (specifically, venue colocation with bus stops, train stations, hospitals, general practitioners (GPs) and shops).

SA1-level sociodemographic features

Residential SA1-level sociodemographic measures included women's education, women's employment, women speaking English at home and household motor vehicle ownership. These measures were constructed from ABS 2011 Census data.²² *Women's education* was defined as the SA1 proportion of women with a bachelor's degree or higher qualification (n women with a Bachelor degree or higher/n total women aged ≥ 15 years), *women's employment* as the proportion of full-time employed women (n employed women aged ≥ 15 years/n total women aged ≥ 15 years) and *women speaking English at home* as the proportion of women who did not identify as speaking a language other than English at home (n women speaking English at home/n total women). *Motor vehicle ownership* was defined as the proportion of dwellings with one or more motor vehicles (n dwellings with motor vehicles/n all dwellings).

Venue distance

There were two types of breast screening venues: fixed (n=20) and mobile (n=43), where a fixed venue was defined as a permanent centre and a mobile venue was defined as a location at which a mobile BCS vehicle (truck, bus or van) provided screening for a (variable) period of time. Variation in days of venue access was accounted for, applying an exposure-time weighting factor adapted from occupational epidemiology.²³ This factor quantified for the observation period 2011–2012, the proportion of time that a given venue was the closest venue to a given SA1 centroid (ranging from 0 being never closest to one always closest). Straight line distances (in kilometre (km)) from each residential SA1 centroid to all screening venue locations were calculated using the 'haversine' formula²⁴ in R V.3.6.1. Research has shown

that straight line distances between area centroids and precise healthcare locations provide reasonable estimates of driving distance,²⁵ especially within urban areas, since area centroids are likely to be close enough to participant residences to provide sufficient spatial resolution for such estimates.²⁵ For each SAI, distances to each venue were multiplied by the venue exposure-time weighting factor (number of days for each closest venue divided by the length of study, ie, 912 days) and summed to provide an SA1-level venue distance measure then categorised according to quartiles.

Built environmental features of venue locations

Screening venue locational features included venue colocation with bus stops, train stations, hospitals, GPs and shops. For each venue location, buffers based on road network distances were constructed at either 500 or 800 metres (m) using ArcGIS Desktop V.10.5 Network Analyst extension (generalised option) and 2011 NSW road network data (source: StreetPro, 2011, Pitney Bowes). Public transportation data were extracted from the General Transit Feed Specification transit database (3 November 2013).²⁶ Venue colocation with a bus stop or a train station was defined as the presence of one or more bus stops within a 500 m buffer or for a train station within an 800 m buffer. These 500 and 800 m buffers are likely to reflect a standard walking distance for individuals using transit services. Different buffer sizes for bus stops and train stations were used to align with public transport catchment distances.²⁷

Hospital, GP and shop data were extracted from the 2011 MapInfo Business Points Australia Index using 2006 Australian and New Zealand Standard Industrial Classification codes. Colocation was defined as the presence of the feature (eg, hospital) within a 500 m buffer. These service and commercial features were coded as mutually exclusive with a prioritised sequence of hospital, GP and then, lastly, shop (as hospital, GP and shop can be located at the same place).

As with venue distance, an exposure-time weighting factor was applied to colocation measures to account for time duration variations in the availability of mobile venues. Given that a more distant venue would likely have a lesser influence, the weighting factor was extended to incorporate distance (ie, a gravity model approach²⁸) as well as exposure time (see online supplemental file). In this approach, the exposure value (eg, colocation) for the closest venue was multiplied by the total number of days that the given venue was the closest, divided by the duration of the study and the distance from SA1 centroid to venue, which enabled summarising information about built environmental features at the SA1 level.

Residential SA1 accessibility to venue-level built environmental features (bus stops, train stations, hospitals, GPs and shops) was defined as follows: >median of weighted scores as 'yes', otherwise 'no'.

Patient and public involvement statement

This study accessed data collected by the state-wide *Breast-Screen NSW* programme provided by the Cancer Institute of NSW. Neither patients nor the public was involved in the planning, design, conduct or reporting of this study.

Statistical analyses

SA1-level BCS IRRs were mapped (ArcGIS Pro²⁹) to visualise the spatial pattern across Greater Sydney. Descriptive statistics were computed for all variables.

Before initiating analyses, the spatial correlation of BCS IRR was assessed. A binary contiguity matrix based on the k nearest-neighbour spatial weights matrix of four was specified to calculate Moran's I . A spatial weight matrix of four was selected as research suggests that while four to six neighbours is optimal, underspecifying for four rather than six is preferential to overspecifying.³⁰ The Moran's I pseudo p value was estimated using Monte Carlo simulations for a series of random replications ($n=999$).³⁰ Moran's I for IRR was 0.803 (p value=0.001), indicating substantial positive spatial autocorrelation.

To examine the associations between predictors and IRR, an ordinary least squares (OLS) model was fitted and spatial autocorrelation for residuals was tested. Substantial spatial autocorrelation in residuals indicated the need to account for spatial dependence in the modelling strategy. Ignoring this spatial dependency, the estimated OLS model parameters may provide inconsistent and biased estimates.³¹ The robust Lagrange Multiplier test indicated that the spatial lag model (SLM) performed best, among spatial lag and error models. Therefore, SLMs were used. SLMs are widely used to account for spatial autocorrelation in area-level analyses in health service research.^{17 19} If we let y be the BCS IRR, then the SLM can be written as

$$y = \rho W y + X \beta + \varepsilon,$$

where W represents the spatial weight matrix, ρ the spatial lag parameter, X the explanatory variables, β a vector of coefficients and ε the error term. The spatial lag term $W y$ is the spatially lagged dependent variable (y). This is a multiplicative term, the spatial weights matrix multiplied by the vector of the dependent variable.³¹ Intuitively, it states that the IRR for each area is related to the average IRRs from neighbouring areas. The maximum likelihood approach was used to estimate the SLM, and goodness-of-fit was assessed using the pseudo R^2 and Akaike information criteria (AIC).³¹

All sociodemographic measures were standardised (z -scores with a mean of 0 and an SD of 1) before inclusion in models. Standardisation assists comparative interpretation of effects (eg, effects of sociodemographic variables on IRR).

Ten separate sets of models constructed as follows: (1) three SA1-level sociodemographic variables separately, adjusting for SA1-level women's education; (2) all SA1-level sociodemographic together; and (3) distance to venue and five venue location built environmental variables separately, adjusting for SA1-level women's education.

Models were constructed pragmatically, based on theory and previous literature. We aimed to assess, in separate models each accounting for an SES-based covariate, the impact of three different sociodemographic predictors on the outcome. An omnibus model including all three predictors, together with the SES-based covariate, was fitted for transparency and to demonstrate consistency in the predictor–outcome associations across models. Model fit statistics (such as model R^2 and AIC) were not used to guide model selection but are reported to enable the reader to compare models. SLMs estimating the associations between environmental exposures and IRR were adjusted for SA1-level women's education. Analyses were conducted using *R* V.3.6.1. Statistical significance was set at p value < 0.010.

RESULTS

Figure 1 illustrates the spatial variability in SA1-level BCS IRR in Greater Sydney with an average IRR of 59.8% (SD 23.4%) (table 2). For SA1-level proportions of sociodemographic features, the mean women's education (proportion having a bachelor's degree or greater) was 23.9% (SD 13.1%); the mean women's employment (full-time) was 27.9% (SD 9.0%); and the mean women speaking English at home was 63.6% (SD 23.9%). SA1-level motor vehicle ownership (as proportion of dwellings) was 87.0% (SD 11.0%). The mean SA1-level exposure-time weighted distance to the closest BCS venue(s) was 9.4 km (SD 8.7 km). Proportions of venues colocated with built environmental features included bus stop (76.2%), train station (41.3%), hospital (17.5%), GP (55.6%) and shops (20.6%).

Table 3 presents the associations between single sociodemographic predictors and IRR accounting for area education as well as the results of the full sociodemographic model. SA1 proportion of women speaking English at home was positively associated with IRR (model 1: $\beta=2.283$, 95% CI 2.024 to 2.543); that is, a 1 SD (=23.9%) increase in the proportion of women speaking English at home was associated with a 2.283 greater IRR, as all SA1-level sociodemographic variables were standardised. Women's employment rate was negatively associated with IRR (model 2: $\beta=-0.613$, 95% CI -0.898 to -0.328). Motor vehicle ownership (% dwellings with one or more motor vehicles) was positively related to IRR (model 3: $\beta=1.836$, 95% CI 1.594 to 2.078). The directions of associations of all sociodemographic variables with IRR were consistent in full sociodemographic model (model 4). Inclusion of all three sociodemographic variables within the same omnibus model improved model fit according to model R^2 and AIC, although this was not a large improvement. The patterns of association remained the same as in models 1–3: SA1 proportion of women speaking English at home ($\beta=1.949$, 95% CI 1.676 to 2.222) and motor vehicle ownership ($\beta=1.422$, 95% CI 1.168 to 1.677) were positively associated, and women's employment rate was

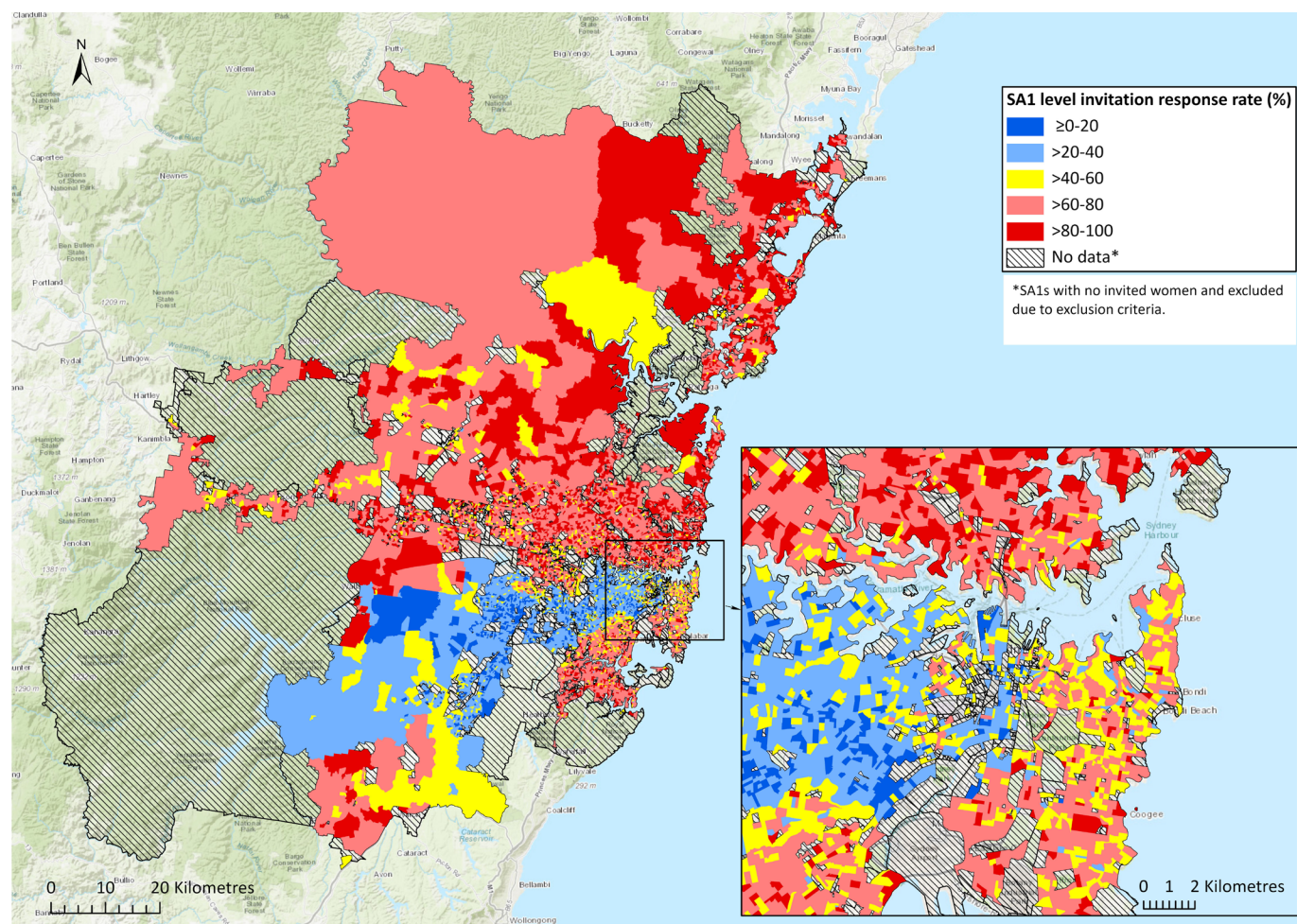


Figure 1 Map showing the distribution of breast cancer screening invitation response rate for Greater Sydney.

negatively associated with IRR ($\beta=-1.154$, 95% CI -1.437 to -0.870).

Table 4 presents the associations of distance and single built environmental predictors with IRR, accounting for area education. Greater distance to screening venue was positively associated with IRR (model 5: distance $>3.679-6.816$ km: $\beta=1.823$, 95% CI 1.140 to 2.507; $>6.816-11.223$ km: $\beta=3.869$, 95% CI 3.162 to 4.576; $11.223+$ km: $\beta=6.249$, 95% CI 5.489 to 7.008). Venue colocation with a train station was inversely related to IRR (model 7: $\beta=-1.889$, 95% CI -2.376 to -1.402); colocation with a hospital was inversely related to IRR (model 8: $\beta=-0.677$, 95% CI -1.164 to -0.189); and colocation with a shop was positively related to IRR (model 10: $\beta=0.762$, 95% CI 0.273 to 1.251). Venue colocation with a bus stop or GP was not statistically significantly associated with IRR. SA1 women's education was positively associated with IRR in all models. Among models with distance and venue location built environmental measures, the model with distance as the predictor (model 5) performed best according to model R^2 and AIC.

Moran's I statistics for SLMs indicated no statistically significant spatial autocorrelation left in the residuals. A statistically significant positive spatial lag coefficient (ρ) in each model indicated IRR spillover effects (eg, model

1: $\rho=0.790$, $p<0.001$, indicating an increase of the IRRs in the neighbouring SA1s by 1.0 percentage point increases the expected IRR in the observed SA1 by 0.790 percentage points).

DISCUSSION

BCS IRR varied substantially across small areas (SA1s) for Greater Sydney. There was evidence of spatial autocorrelation in IRR. Area-level sociodemographic features (ie, women's education, employment, speaking English at home and dwellings with motor vehicles), distance to screening venue and venue built environmental features (ie, colocation with train station, hospital or shop) were each associated with IRR. Model fit performances were largely similar for all models constructed in this study. From the view of policy and programme planning, spatial variability and spatial autocorrelation in BCS IRR heralds a need for targeting the features of particular areas, in the design and delivery of interventions to improve BCS IRR.

Area-level proportions of women with university education, women speaking English at home, and of household motor vehicle ownership were each positively associated with IRR, consistent with expectations and other study findings.^{12 14 17 32} Motor vehicle ownership serves to

Table 2 Descriptive statistics for the analytical dataset and distribution of built environmental features of screening venue locations within Greater Sydney

| Variables | All SA1s (n=9528) | | |
|--|-------------------|---------------------|----------------------|
| Invitee residential SA1 measures | Average (SD) | Min | Max |
| IRR | 59.8 (23.4) | 0.0 | 100.0 |
| Area education for women* | 23.9 (13.1) | 0.0 | 66.7 |
| Women speaking English at home† | 63.6 (23.9) | 0.0 | 100.0 |
| Full-time employed women‡ | 27.9 (9.0) | 0.0 | 69.5 |
| Motor vehicle ownership§ | 87.0 (11.0) | 14.0 | 100.0 |
| Distance (km)¶ | 9.4 (8.7) | 0.2 | 76.6 |
| Venue built environmental measures (%) | All venues (n=63) | Fixed venues (n=20) | Mobile venues (n=43) |
| Colocated with bus stop | 76.2 | 85.0 | 72.1 |
| Colocated with train station | 41.3 | 60.0 | 32.6 |
| Colocated with hospital | 17.5 | 35.0 | 9.3 |
| Colocated with GP | 55.6 | 60.0 | 53.5 |
| Colocated with shop | 20.6 | 5.0 | 27.9 |

*Proportion of women with a bachelor's degree or higher.

†Proportion of women speaking English at home.

‡Proportion of full-time employed women.

§Proportion of dwellings with at least one motor vehicle.

¶Time-weighted distance to closest screening venue(s).

GP, general practitioner; IRR, invitation response rate; SA1, Statistical Area Level 1.

remove access-related barriers and reduces effort needed if using public transport to attend screening venues, while the association between education and health is well-established, education being positively related to health literacy.^{33 34} In contrast, non-English speakers may have distinct challenges including language barriers, less familiarity with the health-system and attitudes/beliefs about BC.³⁵ Emotional factors (fear and anxiety) and instrumental challenges (making appointments, accessing service and managing priorities) have also been reported as barriers to participation among culturally and linguistically diverse groups.^{36 37} Perhaps counterintuitively, our study found that the small-area proportion of full-time employed women was inversely associated with IRR. This result nevertheless aligns with a findings from a previous study in NSW, which reported that employed women were less likely to have recently been screened for BC.³⁸ Possibly, women may prioritise work and family commitments over self-health.

Greater area-level distance to venue(s) was associated with greater IRR, a result contrary to expectations. However, a US study observed distance did not predict BCS use, the interpretation being that screening venue proximity did not ensure greater use owing to constraints imposed by socioeconomic and cultural barriers.³⁹ Moreover, women may select venues based on other factors, for example, perceived venue quality, convenience to work or other services, appointment times/availability, parking availability and transport access. Our observation of greater residential distance to venue and greater IRR could also reflect knowledge of lesser access acting to

positively condition decisions to screen, as opposed to a potentially lesser sense of urgency to screen, given greater access.

Venue proximity to a train station was inversely related to IRR, while venue colocation with a bus-stop was not related to IRR. Despite public transport serving to enable access to a venue, it is unlikely that screening appointments would have been scheduled with consideration of available transportation services. A difference in associations between colocation with buses versus trains in relation to IRR was unexpected. Train routes tend to be direct to the city centre, while bus routes tend to wind through the streets. No previous studies have assessed venue colocation with bus stops and train stations in relation to IRR. Our findings suggest a need the further investigation of transport mode relationships.

Venue colocation with a hospital was inversely associated with BCS IRR, which may be due to limited parking available at hospitals.⁴⁰ Though colocation with a hospital was inversely associated with IRR, colocation with a GP clinic was not associated with IRR. No other studies have assessed colocation with hospital and GP separately in relation to screening behaviour; however, one study that assessed health facilities (hospital and other health facilities) reported individuals were less likely to visit any venue collocated with health facilities.¹⁵

BCS IRR was positively related to venue colocation with shops. Little research has been conducted on this relationship, but different characteristics of venue location (eg, ease of parking), or trip chaining to accomplish errands, may explain this result. A qualitative study

Table 3 Associations between SA1 sociodemographic features and IRR adjusting for area education for women in Greater Sydney (n=9528 SA1s).

| | Model 1 | Model 2 | Model 3 | Model 4 |
|---------------------------------|---|---|--|---------------------------------|
| Model specification | Women speaking English at home* + area education for women† | Full-time employed women‡ + area education for women‡ | Motor vehicle ownership§ + area education for women‡ | All sociodemographic |
| Predictors | β (95% CI) | β (95% CI) | β (95% CI) | β (95% CI) |
| Intercept | 12.646*** (11.980 to 13.312) | 10.676*** (10.075 to 11.277) | 11.610*** (10.991 to 12.229) | 13.262*** (12.585 to 13.938) |
| Women speaking English at home* | 2.283*** (2.024 to 2.543) | | | 1.949*** (1.676 to 2.222) |
| Full-time employed women‡ | | -0.613*** (-0.898 to -0.328) | | -1.154*** (-1.437 to -0.870) |
| Motor vehicle ownership§ | | | 1.836*** (1.594 to 2.078) | 1.422*** (1.168 to 1.677) |
| Area education for women† | 0.454*** (0.211 to 0.697) | 0.917*** (0.632 to 1.202) | 0.663*** (0.428 to 0.898) | 1.186*** (0.901 to 1.471) |
| ρ | 0.790*** | 0.823*** | 0.808*** | 0.780*** |
| Moran's I | -0.12506 | -0.13719 | -0.13212 | -0.12053 |
| R ² | 0.698 | 0.690 | 0.695 | 0.703 |
| AIC | 75 750 | 76 019 | 75 847 | 75 594 |

p value: ***<0.001.

*Proportion of women speaking English at home (standardised).

†Proportion of women with a bachelor's degree or higher (standardised).

‡Proportion of full-time employed women (standardised).

§Proportion of dwellings with at least one motor vehicle (standardised).

ρ, spatial lag coefficient; AIC, Akaike information criteria; IRR, invitation response rate; SA1, Statistical Area Level 1.

reported that women prefer BCS venues that are conveniently located, have free parking facilities and a non-clinical atmosphere.⁴¹

The statistically significant positive spatial lag estimate indicates that the BCS rates of neighbouring SA1s directly influence the rate in any given SA1. This finding aligns with results from previous research.¹⁹ The mechanism of this phenomenon may reflect informal communication, shared healthcare access and observational learning.

Associations of environmental features (residential area and venue-specific) with BCS uptake stand to be useful, following critical appraisal, for informing interventions to optimise service delivery and to minimise disparities in BCS use. Specifically, in areas with high proportions of culturally and linguistically diverse people and lower BCS uptake, potentially useful programmes of interventions to enhance uptake could take the form of cultural-specific health education messages and media campaigns, community engagement around the need for BCS and linguistic-cultural responsiveness training for healthcare professionals. More intensive service delivery (eg, more mobile vans, extended appointment periods and positioning of vans near shopping centres), peer education, need-based resource allocation and enhancing social support might also be useful for improving BCS use.

These study results are likely to be generalisable to other countries with similar and publicly funded BCS.

Strengths of this study include the large volume of BCS invitation data enabling small-area analysis of BCS uptake, appraisal of spatial variation, and examination of residential area sociodemographic, venue distance and venue locational features. These study findings can build on and support the evidence base for improving the targeting and uptake of BCS initiatives. Despite these specific strengths, this study has limitations. The first is this study is ecological and individual-level data (eg, socio-demographic and health belief) were unavailable. Relationships identified at the area level do not necessarily reflect individual-level relationships. Certain counterintuitive and null associations observed here could reflect the peculiarities of our ecological analysis. For instance, the counterintuitive result for distance to venue(s) does not reflect an association between individual-level distance to venue(s) and BCS participation, and interpretation as such is susceptible to the ecological fallacy. Unravelling such results requires regressing unit record BCS participation on area-level (multilevel model) or individual-level (unit record model) distance to venue(s). Second, potentially relevant variables including private BCS rates were unavailable. Thus, rates reported here will likely be lower

Table 4 Associations between distance, access to screening venue colocated with built environmental features and IRR adjusted for area education for women in Greater Sydney (n=9528 SA1s).

| | Model 5 | Model 6 | Model 7 | Model 8 | Model 9 | Model 10 |
|---------------------------------------|-------------------------------|---|--|---|---|---|
| Model specification | | | | | | |
| Predictors | | | | | | |
| Distance* + area education for women† | | Colocated with bus stop + area education for women† | Colocated with train station + area education for women† | Colocated with hospital + area education for women† | Colocated with GP + area education for women† | Colocated with shop + area education for women† |
| β (95% CI) | | β (95% CI) | β (95% CI) | β (95% CI) | β (95% CI) | β (95% CI) |
| Intercept | 9.867*** (9.185 to 10.549) | 10.482*** (9.853 to 11.111) | 12.029*** (11.323 to 12.735) | 11.042*** (10.375 to 11.708) | 10.282*** (9.660 to 10.905) | 10.282*** (9.660 to 10.905) |
| Distance* (≤3.679 km) | | | | | | |
| >3.679–6.816 km | 1.823*** (1.140 to 2.507) | | | | | |
| >6.816–11.223 km | 3.869*** (3.162 to 4.576) | | | | | |
| 11.223+ km | 6.249*** (5.489 to 7.008) | | | | | |
| Colocated with bus stop (yes) | | 0.388 (-0.041 to 0.817) | | | | |
| Colocated with train station (yes) | | | -1.889*** (-2.376 to -1.402) | | | |
| Colocated with hospital (yes) | | | | -0.677** (-1.164 to -0.189) | | |
| Colocated with GP (yes) | | | | | 0.154 (-0.242 to 0.551) | |
| Colocated with shop (yes) | | | | | | 0.762** (0.273 to 1.251) |
| Area education for women† | 1.273*** (1.020 to 1.526) | 0.567*** (0.329 to 0.805) | 0.536*** (0.298 to 0.774) | 0.605*** (0.370 to 0.840) | 0.572*** (0.333 to 0.810) | 0.618*** (0.371 to 0.866) |
| ρ | 0.787** | 0.823*** | 0.816*** | 0.823*** | 0.824*** | 0.824*** |
| Moran's I | -0.12632 | -0.13666 | -0.13449 | -0.13687 | -0.13675 | -0.13907 |
| R ² | 0.697 | 0.689 | 0.690 | 0.689 | 0.689 | 0.690 |
| AIC | 75 785 | 76 051 | 75 993 | 76 046 | 76 051 | 76 014 |

p value: ***<0.001, **<0.01.

*SA1 time-weighted distance to closest screening venue(s).

†Proportion of women with a bachelor's degree or higher (standardised).

ρ, spatial lag coefficient; AIC, Akaike information criteria; IRR, invitation response rate; SA1, Statistical Area Level 1.



than actual rates. This study was also unable to explore within-venue features (eg, number of machines and staff) that could further shape BCS uptake. Lastly, this research was unable to account for the impact of public information campaigns that may have operated in Greater Sydney across the study period.

CONCLUSIONS

This study assessed environmental factors associated with small-area variation in BCS IRR in Greater Sydney, Australia. Substantial small-area variation in BCS IRR exists for Greater Sydney and was strongly related to sociodemographic factors that, together with BCS venue location features, have the potential to inform targeted attempts to raise IRR through BCS service optimisation.

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Acknowledgements The authors thank the University of Canberra, Cancer Institute of NSW, and the University of South Australia. This research is part of the first author's PhD research, which is supported by the Australian Government Research Training Programme Scholarship.

Contributors JRK, SJC and MD conceptualised the study and planned the data analysis and drafted the manuscript. MW-S and DR acquired the data, offered intellectual input and provided critical revision. JRK performed the data analysis with input from SJC and MD. All authors approved the final version of the manuscript for publication.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

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Competing interests None declared.

Patient consent for publication Not required.

Ethics approval Ethical approval for this study was obtained from the NSW Population and Health Services Research Ethics Committee (CINSW reference: 2016/09/652 and AU RED reference: HREC/16/CIPHS/25), University of South Australia (protocol number: 0000036441) and the University of Canberra Human Research Ethics Committees (reference: 20181535). All Breast Screen NSW clients consented to their data being used for service improvement.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

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