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Pragmatic Interventions to Boost Surveillance Mammogram Uptake Among an Overdue Population
A Randomized Clinical Trial

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IMPORTANCE Suboptimal adherence to recommended surveillance mammography remains a challenge even in countries with organized screening programs. Scalable strategies to re-engage overdue repeat screeners are urgently needed.

OBJECTIVE To evaluate the effectiveness of pragmatic behavioral interventions in increasing mammogram uptake among overdue repeat screeners.

DESIGN, SETTING, AND PARTICIPANTS This 5-group randomized clinical trial was conducted from September to December 2024 in Singapore's integrated tertiary hospital system. Eligible participants were women aged 50 to 69 years who were overdue for a repeat screening (with ≥1 prior mammogram not conducted in the past 2 years), eligible for a free biennial screening as recommended for this age group, and registrants of the hospital's mobile health application.

INTERVENTIONS Participants were randomly allocated (2:1:1:1:1) into 5 groups: group 1 received personalized mailed reminder (MR); 2, MR plus US$7.50 conditional voucher; 3, MR plus conditional chance to win US$3750 lottery; 4, MR plus motivational videos; and 5, MR plus dedicated scheduling hotline. All groups also received 3 mobile-app push notification reminders, spaced 3 weeks apart.

MAIN OUTCOMES AND MEASURES Mammogram uptake in groups 2 through 5 compared to group 1 in 3 months.

RESULTS The analysis included 9000 women (median [IQR] age, 62 [58-66]) years. The 5872 (65.2%) who were aged 60 to 69 years had longer screening lapses (mean [SD], 7.7 [5.4] years) than those aged 50 to 59 years (mean [SD], 5.4 [3.5] years; $P < .001$). Mammogram uptake was 11.2% in group 1 and highest in group 5 (13.8%), but not significantly different. Groups 2 through 4 showed no significant increase over group 1. Participants who were more than 10 years overdue in groups 2 and 5 had slightly higher mammogram uptake (8.8%; relative risk [RR], 1.84; 95% CI, 1.13-3.00; and 8.9%; RR, 1.87; 95% CI, 1.14-3.07, compared to group 1 (4.8%), but not significant ($P = .06$ and .07, respectively). Engagement with digital interventions was low (<5% webpage views). Group 1 achieved a modest uptake relative to cost per additional mammogram, outperforming all other interventions in efficiency.

CONCLUSIONS AND RELEVANCE This randomized clinical trial found that a simple 1-time MR among overdue repeat screeners in Singapore's no-reminder, opt-in system may prompt repeat mammography, and additional behavioral interventions offered no incremental increase in mammogram uptake over MR alone.

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Visual Abstract

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Supplemental content

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Breast cancer is the most frequently diagnosed malignant neoplasm among women worldwide, with 2.3 million cases in 2022.[1] Surveillance mammography is a cornerstone of early detection, reducing breast cancer mortality by 14% to 33%[2] and easing the health care burden associated with late-stage disease. Despite organized screening programs in many high- and middle-income countries, adherence to recommended screening guidelines remains suboptimal, often falling below the 70% participation benchmark,[3] particularly among women with a history of screening (repeat screeners).

A meta-analysis of 37 studies[4] reported a weighted average repeat mammogram screening rate of 46.1%, with subsequent studies showing wide variability (6.0%-84.5%)[5-8] due to differences in populations, methods, and definitions used. Repeat screening adherence tends to be especially poor across several Asian countries, with rates as low as 3.0% to 25.0%.[9-12] This distinct and relatively understudied population of overdue repeat screeners faces unique barriers to continued participation, including low perceived risk, fear of the procedure or diagnosis, logistical hurdles, modesty concerns, and misconceptions, such as the belief that 1 mammogram is sufficient when asymptomatic.[13-15] Evidence suggests that although prior participation increases future uptake,[16] long-term disengagement is common and often requires proactive intervention.[17]

Numerous randomized clinical trials have assessed various interventions to boost mammogram uptake including mailed reminders,[18,19] telephone outreach,[20,21] text messaging,[22] financial incentives,[23-25] educational materials,[26,27] and multicomponent strategies incorporating prescheduled appointments[17] and counseling.[28,29] However, most of these have focused on first-time or recently screened populations. Evidence on effective approaches for reengaging women who are substantially overdue for mammography remains limited.

This study sought to address a critical evidence gap by evaluating scalable interventions to boost mammogram uptake among overdue women in Singapore where routine reminders are uncommon. This lack of systemic prompts places the onus on women to proactively schedule mammograms, likely contributing to persistently low biennial screening adherence—the most recent national estimate was 34.7% in 2023.[30] The proportion of overdue repeat screeners adhering to the guidelines is likely even smaller, although unquantified. In Singapore, women aged 50 to 69 years have access to subsidized biennial mammograms through a national screening program established more than 2 decades ago.

As a high-income city-state with strong health literacy and excellent digital and transport connectivity, favorable conditions exist; yet uptake remains suboptimal. This suggests that structural access and affordability alone are insufficient and approaches effective in Western populations may not translate directly to this context. To our knowledge, no large prospective studies in Asia have systematically evaluated interventions to boost uptake. Therefore, we hypothesized that behavioral nudges previously effective elsewhere, would differ in their effectiveness in Singapore, and that identifying the most impactful ones would address a critical evidence gap and inform strategies to improve mammogram uptake. The interventions considered are grounded in behavioral science: (1) a 1-time personalized mailed reminder (MR) alone; or MR combined with (2) conditional vouchers, offering guaranteed, tangible rewards reinforcing action, (3) conditional lottery-based incentive leveraging anticipated regret and optimism bias to motivate behavior under uncertainty, (4) motivational video messaging aimed at shifting perceived risk and benefit through social norming, and (5) a dedicated scheduling hotline (DSH) to reduce challenges in appointment scheduling, addressing logistical inertia. These strategies were designed to overcome psychological and logistical barriers, such as low perceived urgency, limited perceived benefit, low motivation, and scheduling challenges. The aim of this study was to evaluate the effectiveness of these 5 pragmatic behavioral interventions in increasing mammogram uptake among overdue repeat screeners.

Key Points

Question Can mailed reminder with or without additional behavioral interventions improve mammogram uptake among women previously screened but overdue for a recommended biennial screening?

Findings In this 5-group randomized clinical trial including 9000 participants, adding 4 different behavioral interventions to a mailed reminder offered no additional benefits in mammogram uptake in a setting that lacks systematic reminders.

Meaning Mailed reminders are similarly effective compared to other interventions in supporting mammogram uptake, suggesting that more complex approaches to patient engagement are not superior to a simple, 1-time mailed reminder.

Methods

Ethics approval was granted by the National Healthcare Group Domain Specific Review Board, with a waiver of informed consent because the study involved minimal risk, did not affect participants' rights or welfare, and because obtaining consent was impractical given the large sample size and potential for bias.[31] We followed the Consolidated Standards of Reporting Trials (CONSORT) reporting guideline. The trial protocol is available in Supplement 1.

Study Design

A 5-group, parallel, prospective randomized clinical trial (RCT) evaluated behavioral interventions to improve mammogram uptake among women overdue for biennial screening. The specific interventions were: group 1 received MR alone; group 2, MR plus US$7.50 conditional voucher for completion of screening within 3 months; group 3, MR plus conditional chance of winning US$3750 lottery when screening within 3 months; group 4, MR plus access to motivational videos in Singapore's 4 official languages (English, Malay, Mandarin, and Tamil); and group 5, MR plus facilitated appointment scheduling via an exclusive DSH within 9 weeks. All randomized participants also

received 3 push notifications (PNs), spaced 3 weeks apart, through the hospital-linked mobile health application (NUHS app). The PN were linked to webpages with group-specific messages as in the MR.

Study Population

Participants were identified from the electronic medical records (EMR) of National University Health System (NUHS), a tertiary hospital health system serving approximately one-third of Singapore's population, from August 1 to 16, 2024. Eligible participants were women aged 50 to 69 years; residents of Singapore; had at least 1 prior mammogram, but none in the past 2 years; were active NUHS app users during the past 12 months; and were due for a fully subsidized mammogram screening. Women with a prior breast cancer diagnosis or incomplete mailing address were excluded. Demographic characteristics, including ethnicity, were self-reported and documented in EMR.

Interventions

Participants were randomly allocated in a 2:1:1:1:1 ratio using a random number generator and assigned to the 5 groups by the same research staff. The MR was a personalized 1-page letter printed on hospital letterhead to ensure the message's credibility. Both MR and PN contained identical messaging, emphasizing the importance of screening, participant's overdue status, access to a free mammogram screening, and intervention-specific details. Mailers were dispatched 6 days before trial commencement, and the first PN was sent on the start date. Participants scheduled a mammogram by calling the central radiology appointment hotline or via the Health Appointment System (HAS) website. Group 5 participants received exclusive access to a DSH staffed by trained personnel who assisted with appointment scheduling, addressed common procedural concerns, and provided guidance on logistics and expectations. Participants were informed that this was a research study, and they could opt out via email. The trial period was from September 16 to December 31, 2024, with mammogram data extracted from the EMR at conclusion.

Outcome Measures

The primary end point was EMR-verified mammogram uptake rate in group 1 compared with groups 2 through 5 by December 31, 2024. Secondary end points included the impact of ethnicity, age, housing type, and time overdue for mammogram on uptake rates. PN interactions were tracked using Google Analytics. Click-through rate (CTR) was defined as the proportion of participants who clicked the PN hyperlink to access the associated webpage. Video views were monitored using unique webpage tracking links. Additional engagement metrics included event counts (eg, link clicks, scrolling), engaged sessions (sessions lasting >10 seconds), and HAS link clicks. These data were analyzed post hoc by PN batch across study groups to assess trends. Intervention costs were estimated from a health care system perspective, accounting for operational and administrative costs. Costs were expressed per 1000 participants, and impact was measured as additional mammogram screenings performed compared with group 1.

Statistical Analysis

Sample size was estimated based on the primary outcome of mammogram uptake, comparing each intervention group to group 1. Assuming a 20% uptake in group 1, a total of 1650 participants in group 1 and 825 in each intervention group were required to detect a 5% absolute difference in uptake with 80% power at a 2-sided significance level of $P = .05$. Accounting for 5% attrition and 40% mailer nonengagement, 9000 participants were recruited (3000 in group 1 and 1500 per intervention group), yielding approximately 4950 evaluable participants. Mammogram uptake differences were evaluated by χ^2 tests, with effects reported as relative risk (RR) and 95% CIs. Subgroup analyses were conducted using log-binomial regression incorporating intervention effects, subgroup characteristics (age, ethnicity, housing type as a socioeconomic proxy, distance from mammogram facilities, and time interval from previous mammogram), and their interactions. Post hoc multiple comparisons were adjusted using the Benjamini-Yekutieli procedure. All analyses followed the intention-to-treat principle and were conducted using R, version 4.4.1 (R Foundation for Statistical Computing) from January 6 to 21, 2025.

Results

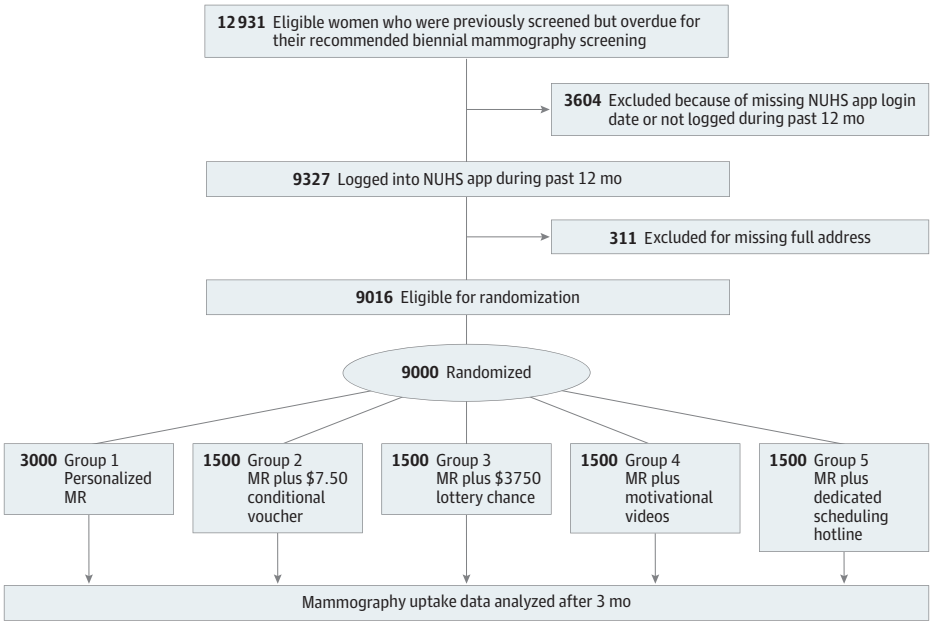
Patient Characteristics

From 12 931 potentially eligible participants, 9000 active mobile app users with complete mailing address records were randomly allocated to the 5 interventional groups in a 2:1:1:1:1 ratio (**Figure 1**) and included in the analysis. Baseline demographic and socioeconomic characteristics of the participants are shown in **Table 1**. The 5 randomized groups were well balanced at baseline, with median (IQR) participant age of 62 years (58-66) years, of whom 5872 (65.2%) were age 60 to 69 years. Consistent with Singapore's ethnic composition, 75.3% of participants were Chinese, 12.1% Malay, and 7.1% Indian. Approximately 88.1% of participants were residing in public housing, while approximately 99% resided within 5 km of a mammogram facility. Older women (age 60-69 years) had significantly longer mean (SD) screening intervals than those aged 50 to 59 (7.7 [5.4] vs 5.4 [3.5]; $P < .001$) years. Chinese participants had the longest mean (SD) interval since previous screening (7.0 [5.1] years); significantly longer than Indian participants (6.5 [4.6] years; $P = .02$), and women of other ethnicity, which included self-reported central Asian, Eurasian, Middle Eastern, South, and Southeast Asian (6.3 [4.5] years; $P = .007$). Participants living in public housing had longer overdue intervals since previous mammogram (7.0 [5.0] vs 6.6 [5.1] years; $P < .001$). Distance to mammogram facility had no significant impact on overdue time. Post-trial, all 9000 participants were included in the analysis.

Impact of Interventions on Mammogram Uptake Rate

Mammogram uptake in group 1 was 337 (11.2%) compared to 182 (12.1%), 170 (11.3%), 162 (10.8%), and 207 (13.8%) in groups 2 to 5, respectively; **Table 2**). Uptake in group 5 was higher than group 1 (RR, 1.23; 95% CI, 1.07-1.38; $P = .01$); however, this did not meet the prespecified significance threshold of $P < .0125$

Figure 1. CONSORT Flow Diagram



MR indicates mailed reminder; NUHS, National University Health System.

Table 1. Baseline Characteristics of Participants

Characteristic	Study group, No. (%)					Total participants (groups 1-5)	Subgroup analysis of interval since previous mammogram	
	1	2	3	4	5		Mean (SD), y	*P* value
Participants, No.	3000	1500	1500	1500	1500	9000	NA	NA
Demographic characteristics								
Age, median (IQR), y	62 (58-66)	62 (58-66)	62 (58-65)	62 (58-66)	62 (57-66)	62 (58-66)	NA	NA
Age groups, y								
50-59	1023 (34.1)	514 (34.3)	544 (36.3)	518 (34.5)	529 (35.3)	3128 (34.8)	5.4 (3.5)	<.01
60-69	1977 (65.9)	986 (65.7)	956 (63.7)	982 (65.5)	971 (64.7)	5872 (65.2)	7.7 (5.4)	
Ethnicity								
Chinese	2236 (74.5)	1147 (76.5)	1112 (74.1)	1132 (75.5)	1154 (76.9)	6781 (75.3)	7.0 (5.1)	NA
Indian	220 (7.3)	109 (7.3)	111 (7.4)	96 (6.4)	103 (6.9)	1089 (12.1)	6.5 (4.6)	.02
Malay	379 (12.6)	171 (11.4)	181 (12.1)	182 (12.1)	176 (11.7)	639 (7.1)	6.8 (4.5)	.18
Other[a]	165 (5.5)	73 (4.9)	96 (6.4)	90 (6.0)	67 (4.5)	491 (5.5)	6.3 (4.5)	<.01
Housing type								
Public	2664 (88.8)	1325 (88.3)	1298 (86.5)	1323 (88.2)	1320 (88.0)	7930 (88.1)	7.0 (5.0)	<.01
Private	336 (11.2)	175 (11.7)	202 (13.5)	177 (11.8)	180 (12.0)	1070 (11.9)	6.6 (5.1)	
Proximity to primary clinic with mammography, km								
<5	2951 (98.4)	1473 (98.2)	1481 (98.7)	1484 (98.9)	1491 (99.4)	8880 (98.7)	6.9 (5.0)	.15
>5 to <10	49 (1.6)	27 (1.8)	19 (1.3)	16 (1.1)	9 (0.6)	120 (1.3)	6.3 (4.2)	
Time interval since previous mammogram, y								
Mean (SD)	7.0 (5.1)	6.9 (4.8)	7.0 (5.1)	6.8 (4.9)	6.9 (4.8)	6.9 (5.0)	NA	NA
Median (IQR)	5.3 (2.9-9.4)	5.3 (3.0-9.2)	5.3 (2.9-9.1)	5.4 (2.8-9.1)	5.6 (3.1-8.9)	5.3 (2.9-9.2)	NA	NA

Abbreviation: NA, not applicable.

[a] Includes self-declared Central Asian, Eurasian, Middle Eastern, and South and Southeast Asian ethnicity.

after accounting for multiple comparisons. No significant differences in uptake were observed among any of the post hoc pairwise comparisons between groups 2 to 5 (eTable 1 in Supplement 2). Among participants overdue more than 10 years, uptake was higher in group 2 (8.8%; RR, 1.84; 95% CI, 1.13-3.00; **Figure 2**) and group 5 (8.9%; RR, 1.87; 95% CI, 1.14-

Table 2. Mammogram Uptake Rates Across Study Groups

Study group	No.	No. (%)		Compared with group 1		
		Did not complete mammogram	Mammogram completed	Absolute increase, %	Relative risk (95% CI)	*P* value[a]
1	3000	2663 (88.8)	337 (11.2)	NA	NA	NA
2	1500	1318 (87.9)	182 (12.1)	0.9	1.08 (0.91-1.28)	.37
3	1500	1330 (88.7)	170 (11.3)	0.1	1.01 (0.85-1.20)	.92
4	1500	1338 (89.2)	162 (10.8)	−0.4	0.96 (0.83-1.09)	.66
5	1500	1293 (86.2)	207 (13.8)	2.6	1.23 (1.07-1.38)	.01

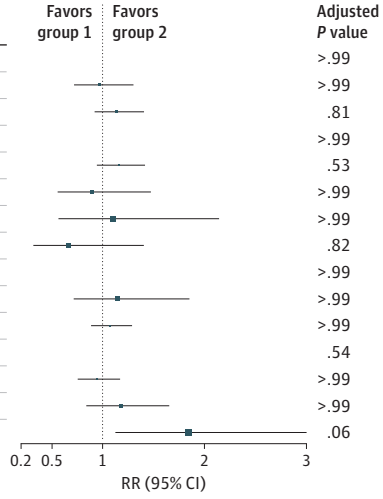
Abbreviation: NA, not applicable.

[a] The significance threshold ($P < .0125$) was prespecified during study design and factored into the sample size calculation to account for multiple comparisons. Results below the threshold were considered statistically significant.

Figure 2. Subgroup Analysis of Mammogram Uptake Rate by Age Group and Ethnicity, Housing Type, and Mammogram Overdue Times, Study Group 1 vs Groups 2 and 3

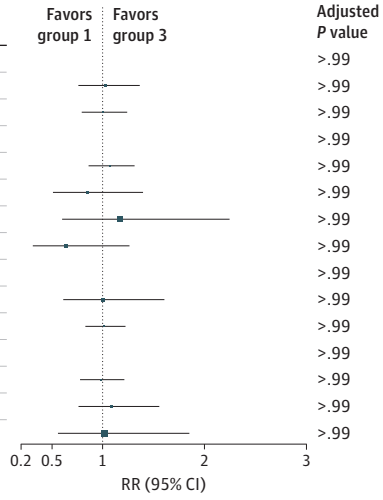
A Group 1 vs 2

Subgroup	Participants, No.		Completed mammogram, No.		RR (95% CI)	Adjusted *P* value
	Group 1	Group 2	Group 1	Group 2		
Age, y						>.99
50-59	1023	514	119	58	0.97 (0.72-1.30)	>.99
60-69	1977	986	218	124	1.14 (0.93-1.40)	.81
Ethnicity						>.99
Chinese	2236	1147	239	142	1.16 (0.95-1.41)	.53
Malay	379	171	49	20	0.90 (0.56-1.47)	>.99
Indian	220	109	22	12	1.10 (0.57-2.14)	>.99
Other[a]	165	73	27	8	0.67 (0.32-1.40)	.82
Housing type						>.99
Private	336	175	40	24	1.15 (0.72-1.85)	>.99
Public	2664	1325	297	158	1.07 (0.89-1.28)	>.99
Time of overdue mammogram, y						.54
>2 to <5	1436	701	226	104	0.94 (0.76-1.17)	>.99
>5 to <10	894	480	79	50	1.18 (0.84-1.65)	>.99
>10	670	319	32	28	1.84 (1.13-3.00)	.06



B Group 1 vs 3

Subgroup	Participants, No.		Completed mammogram, No.		RR (95% CI)	Adjusted *P* value
	Group 1	Group 3	Group 1	Group 3		
Age, y						>.99
50-59	1023	544	119	65	1.03 (0.77-1.36)	>.99
60-69	1977	956	218	105	1.00 (0.80-1.24)	>.99
Ethnicity						>.99
Chinese	2236	1112	239	127	1.07 (0.87-1.31)	>.99
Malay	379	181	49	20	0.85 (0.52-1.39)	>.99
Indian	220	111	22	13	1.17 (0.61-2.24)	>.99
Other[a]	165	96	27	10	0.64 (0.32-1.26)	>.99
Housing type						>.99
Private	336	202	40	24	1.00 (0.62-1.60)	>.99
Public	2664	1298	297	146	1.01 (0.84-1.22)	>.99
Time of overdue mammogram, y						>.99
>2 to <5	1436	708	226	109	0.98 (0.79-1.21)	>.99
>5 to <10	894	467	79	45	1.09 (0.77-1.55)	>.99
>10	670	325	32	16	1.03 (0.57-1.85)	>.99



RR indicates relative risk.

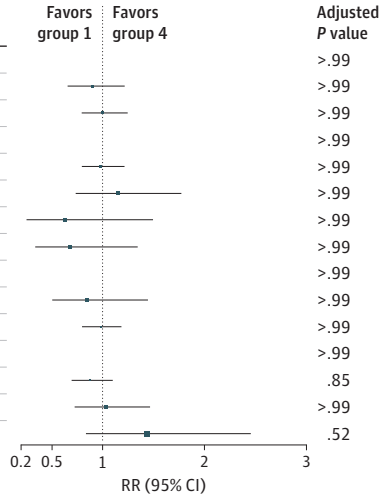
[a]Includes self-declared Central Asian, Eurasian, Middle Eastern, and South and Southeast Asian ethnicity.

3.07; **Figure 3**) compared to group 1 (4.8%), but these differences were also not significant after adjustment ($P = .06$ and $P = .07$, respectively). Similarly, uptake remained low among older women (60-69 years), with a modest increase in uptake in group 5 (13.9% vs 11.0% in group 1; RR, 1.26; 95% CI, 1.03-1.54; $P = .13$).

Figure 3. Subgroup Analysis of Mammogram Uptake Rate by Age Group, Ethnicity, Housing Type, and Mammogram Overdue Times, Study Group 1 vs Groups 4 and 5

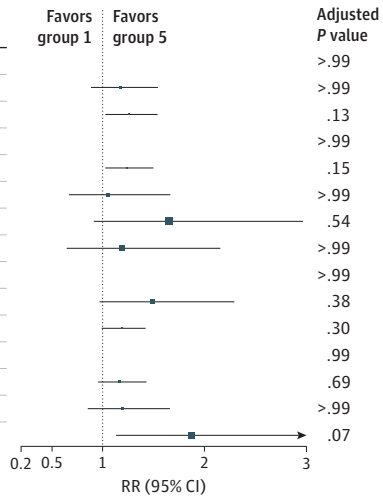
A Group 1 vs 4

Subgroup	Participants, No.		Completed mammogram, No.		RR (95% CI)	Adjusted *P* value
	Group 1	Group 4	Group 1	Group 4		
Age, y						>.99
50-59	1023	518	119	54	0.90 (0.66-1.21)	>.99
60-69	1977	982	218	108	1.00 (0.80-1.24)	>.99
Ethnicity						>.99
Chinese	2236	1132	239	119	0.98 (0.80-1.21)	>.99
Malay	379	182	49	27	1.15 (0.74-1.77)	>.99
Indian	220	96	22	6	0.63 (0.26-1.49)	>.99
Other	165	90	27	10	0.68 (0.34-1.34)	>.99
Housing type						>.99
Private	336	177	40	18	0.85 (0.51-1.44)	>.99
Public	2664	1323	297	144	0.98 (0.81-1.18)	>.99
Time of overdue mammogram, y						>.99
>2 to <5	1436	700	226	96	0.87 (0.70-1.09)	.85
>5 to <10	894	494	79	45	1.03 (0.73-1.46)	>.99
>10	670	306	32	21	1.44 (0.84-2.45)	.52



B Group 1 vs 5

Subgroup	Participants, No.		Completed mammogram, No.		RR (95% CI)	Adjusted *P* value
	Group 1	Group 5	Group 1	Group 5		
Age, y						>.99
50-59	1023	529	119	72	1.17 (0.89-1.54)	>.99
60-69	1977	971	218	135	1.26 (1.03-1.54)	.13
Ethnicity						>.99
Chinese	2236	1154	239	153	1.24 (1.03-1.50)	.15
Malay	379	176	49	24	1.05 (0.67-1.66)	>.99
Indian	220	103	22	17	1.65 (0.92-2.97)	.54
Other	165	67	27	13	1.19 (0.65-2.16)	>.99
Housing type						>.99
Private	336	180	40	32	1.49 (0.97-2.29)	.38
Public	2664	1320	297	175	1.19 (1.00-1.42)	.30
Time of overdue mammogram, y						.99
>2 to <5	1436	679	226	125	1.17 (0.96-1.43)	.69
>5 to <10	894	519	79	55	1.20 (0.86-1.66)	>.99
>10	670	302	32	27	1.87 (1.14-3.07)	.07



RR indicates relative risk.

[a]Includes self-declared Central Asian, Eurasian, Middle Eastern, and South and Southeast Asian ethnicity.

Participant Engagement With Various Interventions

In group 2, 50% (90 of 182 participants) who completed mammogram claimed conditional vouchers, whereas only 20.5% in group 3 (35 of 170) claimed the lottery chance. Among the motivational videos, the Mandarin version was most viewed (66% of clicks), followed by English (28%), Malay (5%), and Tamil (1%), with more than 70% of the views (276 of 377) occurring within the first week of notification. From September 16 to November 15, 2024, the DSH received 350 calls, with 331 answered (eFigure 1 in Supplement 2). Call volume peaked in the first 2 weeks (n = 194 [55%]) and declined to approximately 22 calls per week, with spikes in weeks 4 (32 calls) and 7 (30 calls), coinciding with the second and third batch deliveries of PN. Among the answered calls, 215 appointments were scheduled, and 207 participants (96.3%) completed mammogram screenings.

Participant Engagement Through the Mobile App

A total of 24 366 PNs were sent in 3 batches (excluding approximately 10% who had disabled PNs), yielding an overall CTR of 4.1%, indicating low engagement (eTable 2 in Supplement 2). Group 5 had a substantially lower CTR (3.1%) than group 1 (4.1%), but engagement metrics across groups 2 to 5 were comparable to group 1. Overall, the HAS link-click rate was approximately 0.9% across groups 1 to 4. While CTR remained consistent across PN batches (eTable 3 in Supplement 2), HAS click rate substantially rose after PN batches 2 and 3 in groups 1, 3, and 4.

Cost Analysis of the Interventions

The interventions' costs per 1000 participants ranged from $742 (group 1) to $5512 (group 5; eTable 4 in Supplement 2). When expressed as the number of additional mammograms

gained per 1000 participants, group 5 achieved the largest increase (26 additional mammograms), followed by group 2 (9 mammograms) and group 3 (1 mammogram) compared to group 1. Group 4 demonstrated a reduction in mammograms compared with group 1, and therefore, was considered less effective and dominated. Cost per additional mammogram screenings gained was lowest for group 2 ($182), followed by group 5 ($212). Group 3 achieved only 1 additional mammogram per 1000 participants compared to group 1, producing a markedly higher incremental cost per mammogram ($3209).

Discussion

To our knowledge, this is the largest RCT in Asia evaluating interventions to improve surveillance mammography uptake, with comparable large-scale trials (>10 000 participants) previously conducted only in Western populations.[17,23-25,32-34] This RCT targets a distinct population—women with a prior screening history but missed subsequent mammograms and an average interval of 6.9 years since the previous screening. Singapore's opt-in scheduling model, coupled with fear of procedural pain and cancer diagnosis, perceived low risk, cultural beliefs and modesty concerns, and cost apprehensions if cancer is diagnosed,[35] contributes to low mammogram uptake, despite the availability of free mammograms. Our study demonstrates that a 1-time personalized MR alone offers a simple, scalable, and effective strategy to nudge women overdue for repeat mammogram. However, additional behavioral interventions failed to outperform a basic 1-time MR alone. These findings offer actionable insights for policymakers seeking efficient and pragmatic strategies to address inertia in the current opt-in model and improve breast cancer screening uptake. It further challenges the assumption that layering behavioral interventions boosts screening uptake, even when those interventions target different behavioral mechanisms.

While mammogram uptake following MR alone was 11.0% among women aged 60 to 69 years and 4.8% among those long overdue (>10 years), MR with facilitated appointment scheduling (group 5) modestly boosted uptake by 1.26- and 1.87-fold, respectively. Although these findings were not statistically significant, point estimates suggest that facilitated scheduling may have value as a targeted strategy for these hard to reach, refractory cohorts. Compared to MR alone, group 5 achieved the largest increase in additional mammograms gained, but at a higher cost ($212 per additional mammogram). Hence, this strategy could be reserved for underserved populations and/or those who may benefit from additional behavioral reinforcement, such as older women or those long overdue for screening.

On the other hand, conditional voucher and lottery incentives produced only minor improvement in uptake with significantly higher costs ($182 and $3209 per additional mammogram, respectively), suggesting limited utility of financial incentives in populations with free mammogram access. Motivational videos (group 4) definitively underperformed, with higher costs, indicating that information-only strategies are insufficient to change screening behavior.

On comparing the financial incentives, only 50% of eligible participants in group 2 claimed the $7.50 voucher, and 20.5% in group 3 registered for the $3750 lottery. Vouchers were more popular perhaps due to their tangible, guaranteed nature, compared to the uncertainty of lottery-based incentives. It is unclear whether this reflects a general ineffectiveness of financial incentives or that the amounts offered were simply too small for a relatively high-income country such as Singapore given that a similar study in the US[23] found that a $25 incentive effectively promoted adherence. Despite the high initial viewership, engagement with motivational videos declined over time, likely due to lack of personalization, a passive format, competing distractions, and a low perceived benefit. In contrast, DSH offered continuous, personalized support that alleviated concerns and anxiety, likely improving appointment adherence; however, its high implementation cost limited scalability.

Despite targeting hospital-engaged mobile health app users, we were surprised to find low overall response to PNs, with CTRs ranging from 3.1% to 4.2% across groups. Although scalable and cost-effective, PNs alone may be insufficient to drive mammogram uptake. These findings suggest that digital cues require reinforcement through personalized and interactive strategies such as clearer and compelling messaging, multichannel reminders (eg, text, email, automated voice messaging), and simplified online scheduling. Additionally, segmenting notifications by user behavior, offering language-specific content, and conducting follow-up calls for nonresponders may further enhance the impact of digital outreach.

Strengths and Limitations

This is among the largest RCTs in Asia comparing behavioral interventions to increase uptake of surveillance mammography, providing robust evidence supporting mailer-based intervention as an affordable, scalable approach for the general population. In just over 1 month of implementation, 1054 of 9000 overdue women (approximately 11.7%) completed a mammogram who may have otherwise remained unscreened. This included 134 of 1922 women (7.0%) overdue for more than 1 decade, a group typically considered behaviorally resistant. These findings highlight the potential public health impact of a simple, low-cost nudge in reactivating lapsed screeners, including those with prolonged nonadherence. Although implemented in a Southeast Asian health system, the findings of this study will be broadly applicable to similarly structured health systems globally seeking pragmatic and scalable approaches to improve repeat mammography adherence.

The trial also has several limitations. First, low engagement with the mailers and digital outreach methods may have diluted the observed intervention effects in the intention-to-treat analysis. Second, the study was conducted within a single care delivery system offering free screening where participants were app users, which may restrict generalizability to settings with different health care structures with out-of-pocket cost or lower digital access or technological literacy. Additionally, although short-term uptake was evaluated, the sustainability of increased screening adherence remains unknown. Further longitudinal studies are warranted to assess the long-term impact of these interventions on subsequent screening

behavior and breast cancer detection rates. Lastly, our study did not have a control group, limiting our ability to draw conclusions regarding what would have happened in the absence of any intervention. However, given that time since last mammogram was quite long (mean, 6.9 years) in this study population, it is plausible that the uptake in mammography observed after the intervention was indeed due to the interventions tested.

Conclusions

This randomized clinical trial found that additional behavioral interventions did not further improve mammogram uptake over a single personalized MR—a low-cost, scalable, and effective strategy to increase screening participation among repeat screeners who do not receive routine reminders with usual care. Given persistently low repeat screening rates across diverse health systems globally, these findings provide evidence for adopting MR as a first-line, population-level intervention in similar settings and may help health systems avoid interventions that are more costly, yet no more effective. Low cost and minimal operational burden make this approach especially attractive for health systems with limited resources, opt-in screening models, digitally underserved populations, and those transitioning to organized screening, offering a low-barrier first step toward engagement. Although targeted enhancements, such as appointment facilitation, may aid subgroups with prolonged disengagement, their deployment should be weighed against cost. Future research should explore how to optimize the content, timing, frequency, and delivery of reminders, and assess their long-term impact on screening behavior and breast cancer outcomes across varied demographic and health system contexts.

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Invited Commentary

WOMEN'S HEALTH

A Global Perspective to Improving Mammogram Completion Among Women Overdue for Breast Cancer Screening

Steven J. Atlas, MD, MPH

In this issue of *JAMA Internal Medicine*, Lee and colleagues[1] report results of a randomized clinical trial evaluating reminder strategies for women overdue for breast cancer screening in Singapore. Screening mammography is widely recommended to reduce breast cancer morbidity and mortality,[2,3] but adherence to recommended screening guidelines remains suboptimal. To improve population screening rates, trials have shown that a variety of primary care-based interventions, including mailed reminders, behavioral interventions, and community health worker/patient navigator outreach, increase screening adherence.[4] However, almost all population-based cancer screening studies have been performed in high-income, Western countries in North America, Europe, and Australia.[5]

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This new trial examined population-based interventions among women overdue for screening in Singapore's integrated tertiary hospital system. This study is noteworthy for its large size, its location in a different region of the world, and its focus on women who were previously screened but are now overdue for a repeat mammogram. Most intervention trials include individuals who are overdue for screening, regardless of whether they have had a prior mammogram. In the study by Lee et al,[1] eligible women were 50 to 69 years and included only those who had at least 1 prior mammogram but none in the past 2 years. All participants received a mailed reminder along with 3 messages sent to their mobile device. The study then compared the mailed reminder alone to the mailed reminder with the addition of 1 of 4 different behavioral nudge interventions: economic incentives (conditional vouchers or a lottery-based incentive), a motivational video, or a dedicated phone scheduling hotline. Nine thousand women were randomized to one of these 5 arms, and completion of a mammogram at 3 months was the primary outcome.