ORIGINAL ARTICLE

Lung Screen Uptake Trial (LSUT): Randomized Controlled Clinical Trial Testing Targeted Invitation Materials

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Abstract

Rationale: Low uptake of low-dose computed tomography (LDCT) lung cancer screening, particularly by current smokers of a low socioeconomic position, compromises effectiveness and equity.

Objectives: To compare the effect of a targeted, low-burden, and stepped invitation strategy versus control on uptake of hospital-based Lung Health Check appointments offering LDCT screening.

Methods: In a two-arm, blinded, between-subjects, randomized controlled trial, 2,012 participants were selected from 16 primary care practices using these criteria: *1*) aged 60 to 75 years, *2*) recorded as a current smoker within the last 7 years, and *3*) no prespecified exclusion criteria contraindicating LDCT screening. Both groups received a stepped sequence of preinvitation, invitation, and reminder letters from their primary care practitioner offering prescheduled appointments. The key manipulation was the accompanying leaflet. The intervention group's leaflet targeted psychological barriers and provided low-burden information, mimicking the concept of the U.K. Ministry of Transport's annual vehicle test ("M.O.T. For Your Lungs").

Measurements and Main Results: Uptake was 52.6%, with no difference between intervention (52.3%) and control (52.9%) groups in unadjusted (odds ratio [OR], 0.98; 95% confidence interval [CI], 0.82–1.16) or adjusted (OR, 0.98; 95% CI, 0.82–1.17) analyses. Current smokers were less likely to attend (adjusted OR, 0.70; 95% CI, 0.56–0.86) than former smokers. Socioeconomic deprivation was significantly associated with lower uptake for the control group only ($P < 0.01$).

Conclusions: The intervention did not improve uptake. Regardless of trial arm, uptake was considerably higher than previous clinical and real-world studies, particularly given that the samples were predominantly lower socioeconomic position smokers. Strategies common to both groups, including a Lung Health Check approach, could represent a minimum standard.

Clinical trial registered with www.clinicaltrials.gov (NCT02558101) and registered prospectively with the International Standard Registered Clinical/Social Study (N21774741).

Keywords: lung neoplasms; early detection of cancer; behavioral sciences; socioeconomic factors

At a Glance Commentary

Scientific Knowledge on the Subject: Consistently low uptake of low-dose computed tomography lung cancer screening by high-risk groups compromises its effectiveness, limiting the population impact on lung cancer mortality and potentially widening existing inequalities. To date, enrollment in trials has been <5% and only 1.9% of the eligible U.S. population have been screened.

What This Study Adds to the Field: This trial is the first to use behavioral science to design and test a low-cost, primary care practice–based, postal invitation strategy in a real-world demonstration setting. Across both trial arms, uptake was higher than has ever been observed previously at 53%, suggesting the behavioral science strategies common to both trial arms together optimize uptake. These strategies included a "Lung Health Check/M.O.T. For Your Lungs" approach to the screening offer (the latter mimicking the concept of the UK Ministry of Transport annual vehicle test), primary care practitioner endorsement, preinvitations, postal reminders, and scheduled appointments. The targeted, stepped, and low-burden intervention invitation approach did not improve uptake overall but importantly was the more equitable, reducing the social gradient by better engaging those living in areas of highest deprivation and lung cancer incidence.

Lung cancer leads cancer mortality globally (1). Although tobacco control strategies are the primary means to reduce incidence, early diagnosis markedly increases 5-year survival from 6% to 82% (stage IV vs. 1A non-small cell) (2). Currently though, most (66%) diagnoses in the United Kingdom are made at an advanced stage (3). The U.S. National Lung Screening Trial ($n = 53,454$) demonstrated that screening asymptomatic high-risk adults using low-dose computed tomography (LDCT) reduced the risk of mortality from lung cancer by 20% compared with chest X-ray (4). Consequently, the U.S. Preventive Services Task Force recommended screening for high-risk adults. The U.K. National Screening Committee is awaiting the Dutch-Belgian trial NELSON's (Nederlands-Leuvens Longkanker Screenings Onderzoek) findings ($n = 15,822$), but early data suggest a mortality benefit (5).

Engaging those at high risk improves the risk/benefit ratio of screening. However, enrollment into lung screening trials has been low (<5%) (6) and skewed toward those at lower risk. Long-term smokers are overrepresented within lower socioeconomic position (SEP) communities, yet both current smoking status and low SEP are negatively associated with uptake (7, 8) and positively associated with risk (9). Indeed, despite the U.S. Preventive Services Task Force's recommendation, just 1.9% of eligible, high-risk individuals have been screened in the United States (10). Attendance of the pilot Lung Health Check services in England has been relatively higher at 27% (Nottingham), 26% (Manchester), and 40% (Liverpool). Due to the ineligibility of some attenders, this translated to LDCT uptake by 13%, 14%, and 9%, respectively (11, 12).

Psychological barriers to participation were identified by research (13) that we undertook to inform the present intervention. Together with existing studies, findings suggested smokers (compared with non-smokers) are more fatalistic about lung cancer, perceive treatment efficacy as lower (13–17), feel stigmatized (13, 18), hold higher affective risk perceptions, and fear diagnosis (13, 19). Previous studies in colorectal cancer screening suggest tailoring leaflets to modify attitudinal barriers (20) may improve uptake (20–22). From a translational perspective, leaflets provide a low-cost and scalable intervention.

In addition to targeting psychological barriers, behavioral science theory, such as the Precaution Adoption Process Model (23), proposes that different types of information are needed depending on an individual's state of engagement, decision-making, and behavior. A first-time invitation might primarily focus on engaging individuals in considering the offer using a low-burden approach, with subsequent communication promoting informed choice and reducing practical barriers. This stepped approach may be particularly important if the offer is anticipated to provoke fear, which can reduce receptivity (24, 25), and for those with lower literacy, because information burden can reduce comprehension and promote distrust (23–26). However, to date, recruitment methods for trials have been cognitively and practically demanding.

Therefore, this trial primarily aimed to test the effect of targeted, stepped, and low-burden invitation materials on uptake of Lung Health Check appointments offered in a real-world context. The secondary aims were to explore whether the intervention

materials affected informed decision-making outcomes, to gauge likely uptake of a national program, and to examine the feasibility of invitation via primary care. Some results have been reported as an abstract (26).

Methods

Design
A two-arm, blinded, between-subjects, randomized controlled trial design tested the effect of intervention invitation materials on uptake of a prescheduled Lung Health Check appointment at which LDCT screening might be offered. A protocol has been published (27) with potential overlap. Eligible individuals were identified from primary care practices in London using electronic searches performed between October 2015 and March 2017.

Eligibility Criteria
The searches ($n = 147,015$) extracted individuals aged 60 to 75 years who had been recorded as smokers since April 2010 (within 7 years of invitation). This was the date smoking status became a Quality and Outcomes Framework indicator to ensure completeness and identify current and recent ex-smokers. The searches excluded individuals who had an active lung cancer diagnosis or metastatic cancer, were on the palliative care register, had undergone a recent computed tomography thorax ($\leqslant 12$ mo), lacked capacity, or had insufficient English or a comorbidity contraindicating screening or treatment. Lists were then screened by primary care practitioners. To avoid contamination, only one eligible individual per household was invited.

Randomization
A web-based program individually randomized participants (1:1) using permuted blocks to balance group allocation by practice. Identifiable details were concealed during assignment, which was performed by a blinded researcher. Invited individuals were blind to the research nature at the invitation stage to avoid undermining the primary outcome.

Intervention and Control Invitation Materials
Our invitation methods and evidence are published (13, 27) and appended (see File E1 in the online supplement). Briefly, evidence-based methods were used for both invitation groups, including primary care endorsement (21, 28), prenotification (29), reminders (30, 31), and prescheduled appointments (32, 33). The screening offer was framed within a Lung Health Check. All participants received the same postal invitation letters from their primary care practice: preinvitation letter, invitation letter with scheduled appointment, and reminder reinvitation letter with a second scheduled appointment (sent to nonresponders $\geqslant 4$ wk after missed appointment). The letters were identical with two exceptions: 1) the intervention group's letters referred to "ever smokers" whereas the control group's referred to "current and former smokers" and 2) the intervention group's invitation letter included a bullet-pointed summary of the Lung Health Check, including LDCT scan offer, on the reverse side.

The key manipulation was the accompanying leaflet. The control group received an information booklet mimicking the facts booklets of NHS (National Health Service) cancer screening programs. The intervention group received an "M.O.T. For Your Lungs" leaflet, designed to target psychological barriers to attendance (fear, fatalism, and stigma), to be low-burden (sufficient for deciding to attend and consider the screening offer), and stepped (full information given at the appointment using the control group's booklet or available before via a website, phone, or post). An M.O.T. is an annual roadworthy test for vehicles and was a lay concept perceived to be analogous to a medical checkup and preferred by patient and public involvement groups.

Lung Health Check Appointment
The appointments were run by research nurses and clinical trial practitioners at two London hospital outpatient clinics. The appointment included a medical and smoking history to determine risk-based eligibility for the LDCT scan according to one of three criteria: 1) U.S. National Lung Screening Trial $\geqslant 30$-pack-year smoking history and still smoking or quit $\leqslant 15$ years; 2) Prostate, Lung, Colorectal, and Ovarian score $\geqslant 1.51\%$; or 3) Liverpool Lung Project score $\geqslant 2.5\%$. Full information about the risks and benefits of screening was provided to all using the control group's leaflet and supported by the nurse consultation. A spirometry test and a carbon monoxide

reading were also performed. Participants self-reporting as current smokers or with a carbon monoxide reading $\geqslant 10$ ppm were given the accredited "Very Brief Advice" on smoking (National Centre for Smoking Cessation and Training [34]) and randomized to an opt-out or opt-in referral intervention.

Ethics
Approval was granted by an NHS Research Ethics Committee (reference: 15/LO/1186).

Primary Outcome Measure
Attendance of the Lung Health Check appointment (percentage of those invited) was used to measure whether individuals could be engaged in considering a screening offer.

Secondary Outcome Measures
The prespecified secondary endpoints in our statistical analysis plan included comparison of uptake by demographic and smoking status subgroups, uptake of LDCT screening for those eligible (and willingness among those ineligible), and informed decision-making outcomes. Data on participants' engagement with the invitation materials were also collected. Further prespecified endpoints are LDCT scan results, resource use, and psychological outcomes.

Demographic data. Pseudonymized data on age, sex, ethnicity, and area-level socioeconomic deprivation (Index of Multiple Deprivation [IMD] score and rank) were collected from the primary care records of all those invited and again from attenders using self-report measures. Attenders also reported their education level and marital status. Hospital site of the screening offer was recorded.

Smoking data. Last-recorded smoking status was extracted from primary care records (recoded as current/occasional, former, and never). Self-reported smoking status and smoking history were collected from attenders. Smoking duration and pack-years were calculated by the research nurse in combination with participants' quit histories. For current smokers, the number of previous serious quit attempts, tobacco dependence (35), and perceived chances of quitting (36) were measured.

Uptake data. Secondary outcomes included uptake of LDCT screening for those eligible and willingness to be screened for those ineligible.

Decision-making outcomes. A self-completed paper questionnaire given at the appointment included adapted items from the Satisfaction with Decision scale (37) and the low-literacy version of the Decisional Conflict scale (38, 39). A further nine items measured conceptual and numerical knowledge of lung cancer screening, including original and adapted items (40). Responses were dichotomized as correct versus incorrect/not sure and summed.

Engagement with the invitation leaflets. Participants were asked whether they remembered, read, and understood their respective leaflet, and whether they had been "useful," "difficult to understand," "informative," "too complicated," or had "too little information." Research nurses rated participants' background knowledge of screening subjectively as "none," "very little," "moderate," "fairly good," and "very comprehensive/near perfect."

Statistical Analyses

Sample size. Uptake for the control group was estimated to be 35% based on first-time uptake of the fecal occult blood test (FOBT) colorectal cancer screening program in London within the two most deprived quintiles (41). With a target sample size of 2,000 participants randomized evenly into two arms, the study was statistically powered (at 90%) to detect a 7% increase in uptake using two-sided tests at the 5% significance threshold. The 7% figure was based on studies testing targeted "psycho-educational" invitations in colorectal screening (20, 21) and considered a clinically meaningful benefit.

Primary analyses. Data were analyzed using IBM SPSS (v. 25). Analyses followed a prospectively registered statistical analysis plan (DOI: 10.17605/OSF.IO/HKEMM) and the trial protocol (27). The primary outcome was analyzed using an intention-to-treat approach ($N = 2,012$). Attendance was compared by invitation group using logistic regression and a deviance chi-squared test for statistical significance.

Secondary analyses. Analyses tested for associations between demographic characteristics, smoking status, and attendance, using bivariate and then multivariable logistic regression models to calculate adjusted odds ratios (aOR) ($n = 1,970$). Study-specific quintiles for IMD rank were calculated because the

Table 1. Sample Characteristics of All Those Invited, Overall and by Invitation Group

	All ($N = 2,012$)	Intervention ($n = 1,006$)	Control ($n = 1,006$)
Sex, % (n)			
F	46.3 (931)	44.7 (450)	47.8 (481)
M	53.7 (1,081)	55.3 (556)	52.2 (525)
Age, mean (SD)	66.0 (4.3)	66.1 (4.3)	65.9 (4.3)
Ethnicity, % (n)			
Asian	2.1 (42)	2.3 (23)	1.9 (19)
Black	9.6 (193)	9.4 (95)	9.7 (98)
Mixed	1.7 (34)	1.4 (14)	2.0 (20)
White	79.7 (1,604)	79.6 (801)	79.8 (803)
Other	2.9 (59)	3.1 (31)	2.8 (28)
Not stated	4.0 (80)	4.2 (42)	3.8 (38)
National Index of Multiple Deprivation quintile, % (n)			
Quintile 1 (1–6,496) most deprived	60.9 (1,226)	60.5 (609)	61.3 (617)
Quintile 2 (6,497–12,993)	35.3 (711)	35.4 (356)	35.3 (355)
Quintile 3 (12,994–19,489)	2.3 (47)	2.5 (25)	2.2 (22)
Quintile 4 (19,490–25,986)	0.1 (2)	0.1 (1)	0.1 (1)
Quintile 5 (25,987–32,482) least deprived	—	—	—
Missing	1.3 (26)	1.5 (15)	1.1 (11)
Smoking status, % (n)			
Current smoker	74.5 (1,499)	76.2 (767)	72.8 (732)
Former smoker	24.7 (497)	23.0 (231)	26.4 (266)
Never smoked tobacco	0.6 (13)	0.8 (8)	0.5 (5)
Refused/not stated	0.1 (2)	—	0.2 (2)
Missing	0.0 (1)	—	0.1 (1)
Attendance from all invited, % (n)			
Overall	52.6 (1,058)	52.3 (526)	52.9 (532)
Attended first appointment	40.3 (811)	39.7 (399)	41.0 (412)
Cancelled first appointment	5.0 (100)	4.6 (46)	5.4 (54)
Sent reminder (no response to first invitation)	54.7 (1,101)	55.8 (561)	53.7 (540)
Attended second (reminder) appointment	9.6 (194)	9.4 (95)	9.8 (99)
Cancelled second (reminder) appointment	2.9 (59)	3.4 (34)	2.5 (25)
No response to reminder invitation	42.1 (848)	42.9 (432)	41.4 (416)

sample was skewed toward above-average deprivation.

Logistic regression analyses then explored correlates of LDCT uptake among eligible participants. The decision-making outcomes were compared by invitation group, using chi-squared tests or *t* tests. For data collected after attendance, "prefer not to say," "not stated," or "don't know" responses were treated as missing.

Results

Characteristics of the Invited Sample

The average age was 66.0 years (SD, 4.3), 53.7% were male, and the majority (79.7%) were from a white ethnic group (Table 1). Overall, there was higher

representation of ethnic minority groups compared with the general population (14%) but lower than in London (40%), likely due to the younger age structure and differences in smoking prevalence (42). Nearly all those invited (96.2%) were categorized within the most deprived (60.9%) or second-most deprived (35.3%) IMD quintile. Three quarters (74.5%) were current smokers.

Primary Analyses

Uptake of the Lung Health Check. Sixteen primary care practices participated with a combined population of 147,015 patients (Figure 1). Of these, 2,012 individuals were randomized in equal numbers ($n = 1,006$) to the
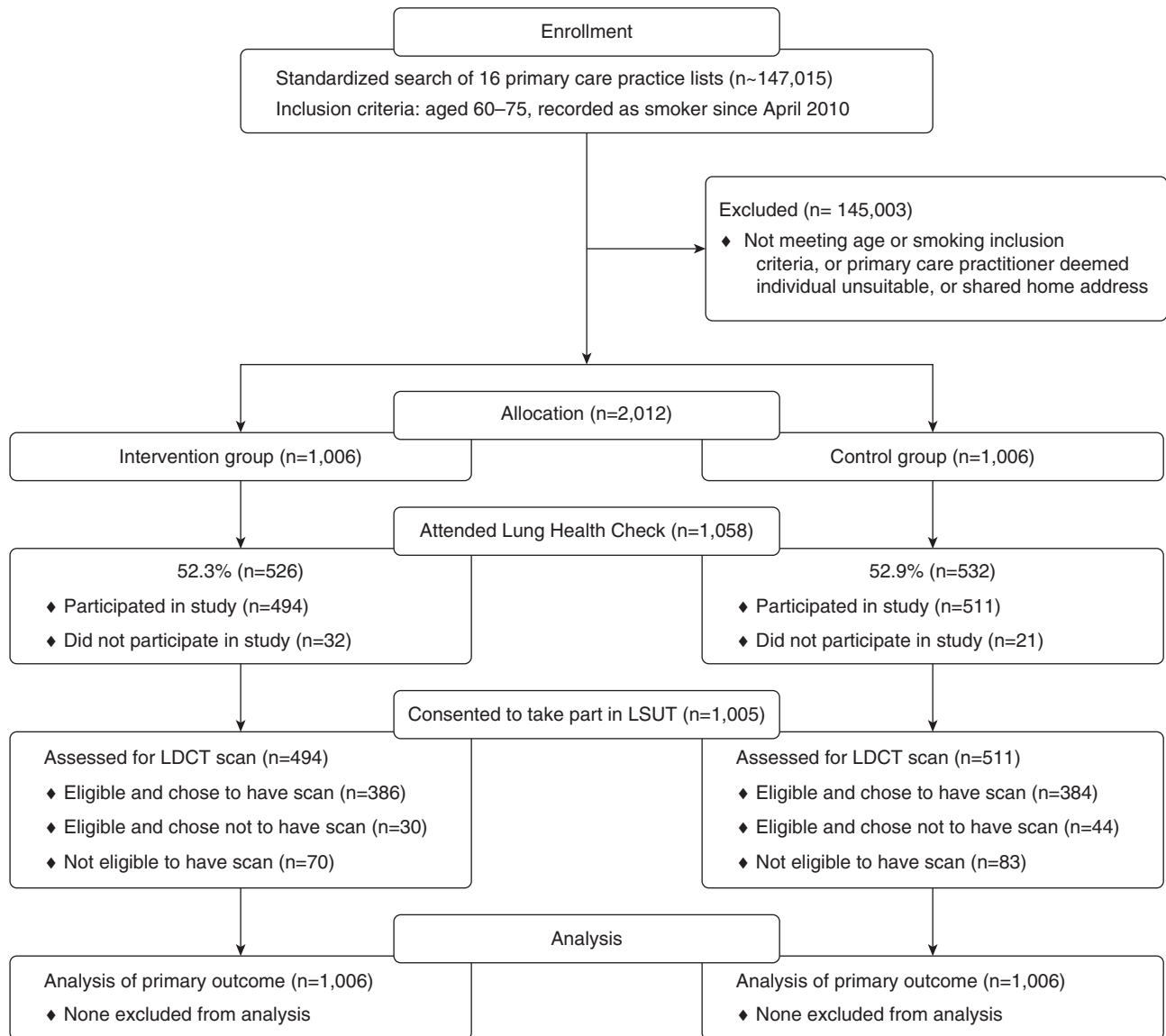
Figure 1. CONSORT (Consolidated Standards of Reporting Trials) trial flow diagram. LDCT = low-dose computed tomography.

invitation groups. Over half, 52.6% (*n* = 1,058), attended their appointment (*see* Table 1).

Individuals predominantly attended the first appointment offered (40.3%), but 9.6% attended the second appointment offered with their reminder. There was no response from 42.1%. There was no statistically significant difference in uptake by hospital site (53.0% vs. 50.8%). Most (94.9%) attenders enrolled.

Near equal numbers from the intervention (52.3%) and control groups (52.9%; 526 vs. 532, respectively) attended. In unadjusted analyses, there was no association between invitation group and uptake (OR, 0.98; 95% confidence interval [CI], 0.82–1.16; Table 2).

Secondary Analyses

Correlates of uptake of the Lung Health Check. Neither sex nor age were associated with uptake (*see* Table 2). Ethnicity was associated with uptake across groups (*P* < 0.001). Compared with those of a white ethnic background, individuals of other ethnic background were more likely to attend (aOR, 2.34; 95% CI, 1.30–4.20) and those with no recorded ethnic group were less likely to attend (aOR, 0.09; 95% CI, 0.04–0.19). Higher deprivation was associated with lower uptake across study-specific IMD quintiles (*P* < 0.01). Individuals categorized within the three least deprived study-specific quintiles

had higher odds of attendance compared with those in the most deprived quintile (aOR, 1.62; 95% CI, 1.21–2.15 and aOR, 1.68; 95% CI, 1.26–2.25, respectively). Current smokers were significantly less likely to attend than former smokers (aOR, 0.70; 95% CI, 0.56–0.86).

When analyses of uptake were stratified by invitation group, there were again no associations with sex, age, or hospital site. For the control group, the same associations with other (vs. white) ethnicity (aOR, 3.23; 95% CI, 1.28–8.14) and not-stated ethnicity (aOR, 0.03; 95% CI, 0.00–0.19) were observed. Deprivation was significantly associated with

Table 2. Frequencies and Logistic Regression Analyses Examining the Correlates of Uptake

	Attended [% (n)] (N=2,012)	All		Intervention		Control	
		Unadjusted OR (95% CI) (N=2,012)	Adjusted OR (95% CI) (n=1,970)	Unadjusted OR (95% CI) (n=1,006)	Adjusted OR (95% CI) (n=983)	Unadjusted OR (95% CI) (n=1,006)	Adjusted OR (95% CI) (n=987)
Sex		P=0.557	P=0.433	P=0.828	P=0.944	P=0.290	P=0.237
F	52.0 (479)	1.00	1.00	1.00	1.00	1.00	1.00
M	53.4 (574)	1.05 (0.88–1.26)	1.08 (0.90–1.29)	0.97 (0.76–1.25)	0.99 (0.76–1.29)	1.14 (0.89–1.47)	1.17 (0.90–1.52)
Age		P=0.857	P=0.879	P=0.484	P=0.365	P=0.331	P=0.188
		1.00 (0.98–1.02)	1.00 (0.98–1.02)	0.99 (0.96–1.02)	0.99 (0.96–1.02)	1.02 (0.99–1.05)	1.02 (0.99–1.05)
Ethnicity		P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
White	54.1 (864)	1.00	1.00	1.00	1.00	1.00	1.00
Asian	52.6 (20)	0.85 (0.46–1.57)	0.87 (0.45–1.69)	1.13 (0.49–2.60)	1.44 (0.56–3.75)	0.61 (0.24–1.53)	0.52 (0.20–1.37)
Black	56.0 (107)	1.11 (0.82–1.49)	1.11 (0.82–1.51)	1.09 (0.71–1.68)	1.06 (0.68–1.65)	1.12 (0.73–1.71)	1.17 (0.76–1.81)
Mixed	36.2 (12)	**0.47 (0.23–0.95)**	0.48 (0.24–1.00)	0.35 (0.11–1.12)	0.37 (0.11–1.23)	0.56 (0.23–1.38)	0.57 (0.23–1.43)
Other	72.9 (43)	**2.29 (1.28–4.10)**	**2.34 (1.30–4.20)**	1.82 (0.85–3.92)	1.92 (0.89–4.15)	**3.07 (1.23–7.66)**	**3.23 (1.28–8.14)**
Not stated*	8.9 (7)	**0.08 (0.04–0.18)**	**0.09 (0.04–0.19)**	**0.15 (0.06–0.35)**	**0.15 (0.06–0.35)**	**0.02 (0.00–0.17)**	**0.03 (0.00–0.19)**
Study-specific deprivation quintile†		P<0.01‡	P<0.01	P=0.154‡	P=0.100	P<0.01‡	P<0.05
Quintile 1 (most deprived)	45.2 (179)	1.00	1.00	1.00	1.00	1.00	1.00
Quintile 2	51.6 (205)	1.29 (0.97–1.70)	1.28 (0.96–1.71)	1.25 (0.84–1.86)	1.28 (0.85–1.92)	1.31 (0.89–1.93)	1.31 (0.87–1.96)
Quintile 3	57.5 (234)	**1.63 (1.23–2.15)**	**1.62 (1.21–2.15)**	1.49 (1.00–2.21)	1.49 (0.99–2.24)	**1.77 (1.20–2.62)**	**1.74 (1.16–2.61)**
Quintile 4	51.3 (195)	1.27 (0.96–1.68)	1.23 (0.92–1.64)	0.98 (0.66–1.47)	0.96 (0.64–1.45)	**1.63 (1.10–2.42)**	**1.60 (1.06–2.41)**
Quintile 5 (least deprived)	58.2 (227)	**1.65 (1.25–2.19)**	**1.68 (1.26–2.25)**	1.36 (0.91–2.02)	1.44 (0.96–2.17)	**2.01 (1.35–2.99)**	**1.93 (1.28–2.93)**
Smoking status		P<0.001§	P<0.01	P<0.05§	P<0.05	P<0.05§	P<0.05
Former smoker	60.2 (299)	1.00	1.00	1.00	1.00	1.00	1.00
Current smoker	50.3 (754)	**0.67 (0.55–0.82)**	**0.70 (0.56–0.86)**	**0.70 (0.52–0.94)**	**0.72 (0.53–0.97)**	**0.65 (0.49–0.86)**	**0.68 (0.51–0.92)**
Invitation group		P=0.789	P=0.843	—	—	—	—
Control	53.0 (529)	1.00	1.00	—	—	—	—
Intervention	52.5 (524)	0.98 (0.82–1.16)	0.98 (0.82–1.18)	—	—	—	—

Definition of abbreviations: CI = confidence interval; OR = odds ratio.
Bold indicates ORs that are significant at P<0.01.
*No record of ethnic group in primary care.
†2010 Index of Multiple Deprivation rank quintile with cutoffs based on distribution in LSUT sample.
‡Cases with no Index of Multiple Deprivation rank and/or score were excluded (n = 26 in full sample).
§Never smokers (n = 13 in full sample) and refused/missing smoking status (n = 3 in full sample) were excluded.
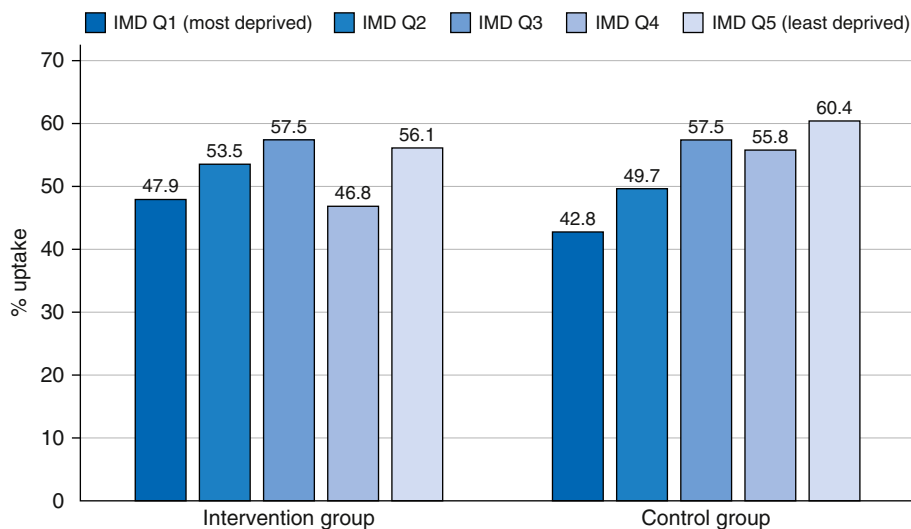
Figure 2. Uptake by study-specific deprivation quintile (Q) Index of Multiple Deprivation (IMD) for each invitation group (N = 2,012). Note that 2010 IMD rank quintile with cutoffs were based on distribution in the LSUT sample.

increasingly lower odds of attendance across quintiles (P < 0.05). For example, the odds of uptake for the least deprived quintile were nearly twice as high as those for the most deprived (aOR, 1.93; 95% CI, 1.28–2.93). Ethnicity was also associated with uptake for the intervention group (P < 0.001), with lower odds of uptake for those with no stated ethnic group (aOR, 0.15; 95% CI, 0.06–0.35). Conversely, deprivation did not significantly differentiate uptake in the intervention invitation group.

Figure 2 presents the absolute percent uptake by study-specific IMD quintile and invitation group. The gradient appears relatively less steep in the intervention group, with uptake relatively higher for the two most deprived quintiles in the intervention group (47.9% and 53.5%, respectively) compared with the control group (42.8% and 49.7%, respectively) and relatively lower for the two least deprived quintiles (46.8% and 56.1% vs. 55.8% and 60.4%, respectively).

Smoking characteristics and eligibility for screening. On average, attenders reported beginning smoking at age 17.9 years (SD, 5.8) and accumulated a 39.4 (SD, 25.0)-pack-year history (Table 3). Most current smokers had tried to quit previously (78.7%) and had low confidence in their chances of quitting (58.7%). The majority (84.5%) were eligible for LDCT screening. Among those ineligible (n = 160), willingness to be screened was high (81.9%).

Uptake of the LDCT scan. Most (91.2%) of those eligible chose to have the scan (Table 4). Sex, age, and marital status were not associated with LDCT uptake. For ethnicity, Asian ethnicity predicted lower odds of uptake compared with white ethnicity (aOR, 0.09; 95% CI, 0.02–0.31), but there were few Asian participants (n = 13). There was no association with black ethnicity and too few noncases within the other ethnic groups. Deprivation was not associated with LDCT uptake. In unadjusted analyses, current smokers were less likely to opt for the LDCT scan than former smokers, but the association was not statistically significant in adjusted analyses (aOR, 0.52; 95% CI, 0.27–1.01). Invitation group did not affect the likelihood of LDCT uptake.

Engagement with the invitation leaflets. A higher number of control participants (81.3%) remembered receiving their respective leaflet compared with the intervention group (64.1%; P < 0.001). Intervention participants understood more of their leaflet (P < 0.05) but there were no differences in background knowledge. File E2 presents further analyses.

Decision-making outcomes. There was no difference in mean scores for conceptual and numerical knowledge by invitation group (see File E2). Across both groups, endorsement of the Decisional Conflict Scale was high (≥76.2%), indicating low conflict. Most participants reported awareness of the benefits of screening, knew which they valued, felt supported, and were

clear about their choice (all ≥89.6%). The risks were less well-understood. Fewer control participants reported that they knew what the risks were compared with intervention participants (76.2% vs. 83.2%; P < 0.05), but similar numbers knew which they valued (84.6% and 84.2%, respectively). Decisional satisfaction was high across groups, both self-reported and nurse-rated (all ≥97.3%).

Discussion

Uptake of the Lung Health Check was 53%, which is an important finding in itself, considerably higher than previously observed. The population was high-risk, with the majority eligible for LDCT screening. The intervention made no difference to uptake overall or by smoking status, with uptake biased in favor of former (compared with current) smokers. However, there was evidence that the targeted, stepped, and low-burden materials were relatively more effective at engaging the most deprived individuals.

A major strength of this study is its ecological validity. The design simulated a real-world service using practically feasible invitation methods via primary care, with the invited sample unaware their attendance was under study. Collecting individual-level demographic and smoking data provided a comprehensive understanding of nonresponders. A census-derived, area-based measure of deprivation allows national comparison but is less sensitive to individual variation. Moreover, the generalizability of these findings to affluent high-risk groups, a wider age range, and ethnic minority groups may be limited. We had complete data on most variables but there were 26 (1.3%) missing deprivation scores. Sensitivity analysis using multiple imputation made no difference to the findings.

Fifty-three percent uptake is an encouraging figure compared with trials and pilot services to-date (11, 12); especially given the invited sample was predominantly comprised of lower SEP current smokers. In UKLS (UK Lung Cancer Screening trial), interest from the most deprived quintile did not reach 20% (9). Indeed, attenders were high-risk, with 84% eligible for LDCT screening. Furthermore, this was a first-time invitation with no wider publicity or community engagement (11, 12). Uptake also compares favorably with first-time uptake of colorectal screening by FOBT in London

Table 3. Smoking Characteristics of Attenders Consenting to LSUT and Eligibility for LDCT

	All (n = 1,000)*	Intervention (n = 492)	Control (n = 508)
Age started smoking, mean (SD, range)	17.9 (5.8, 6–55)	17.9 (5.5, 7–55)	17.9 (6.1, 6–55)
Age stopped smoking†, mean (SD, range)	59.4 (10.7, 0–75)	59.8 (10.4, 21–75)	59.1 (11.0, 0–75)
Number of years smoked, mean (SD, range)	45.5 (9.5, 2–64)	45.6 (9.1, 2–64)	45.4 (9.9, 3–63)
Pack-years, mean (SD, range)	39.4 (25.0, 1–171)	38.0 (22.2, 1–128)	40.7 (27.5, 1–171)
Usual daily cigarette consumption‡,§, % (n)			
1–10	55.7 (395)	55.3 (199)	56.2 (196)
11–20	33.3 (236)	34.7 (125)	31.8 (111)
21–30	5.9 (42)	5.3 (19)	6.6 (23)
≥31	2.3 (16)	2.2 (8)	2.3 (8)
Missing	2.8 (20)	2.5 (9)	3.2 (11)
Time to first cigarette§, % (n)			
Within 5 min	16.5 (117)	16.9 (61)	16.0 (56)
6–30 min	33.4 (237)	33.9 (122)	33.0 (115)
31–60 min	16.8 (119)	17.2 (62)	16.3 (57)
>60 min	31.5 (223)	31.1 (112)	31.8 (111)
Missing	1.8 (13)	0.8 (3)	2.9 (10)
Nicotine dependence (HSI score)§, % (n)			
Low dependence	38.9 (276)	38.6 (139)	39.3 (137)
Moderate dependence	42.9 (304)	43.1 (155)	42.7 (149)
High dependence	14.5 (103)	15.3 (55)	13.8 (48)
Missing	3.7 (26)	3.1 (11)	4.3 (15)
Perceived chance of quitting§, % (n)			
Very low/low/not very high	58.7 (416)	56.9 (205)	60.5 (211)
Quite high/very high/extremely high	38.5 (273)	41.4 (149)	35.5 (124)
Missing	2.8 (20)	1.7 (6)	4.0 (14)
Previous quit attempts§, % (n)			
None	20.3 (144)	21.7 (78)	18.9 (66)
1–5	59.7 (423)	57.5 (207)	61.9 (216)
>5	19.0 (135)	20.0 (72)	18.1 (63)
Missing	1.0 (7)	0.8 (3)	1.1 (4)
Eligibility for LDCT scan, % (n)	84.5 (845)	84.6 (416)	83.4 (429)
LDCT scan willingness (of ineligible), % (n)			
Yes, definitely	66.9 (107)	71.8 (56)	62.2 (51)
Yes, probably	15.0 (24)	10.3 (8)	19.5 (16)
Probably not	3.8 (6)	1.3 (1)	6.1 (5)
Definitely not	3.8 (6)	5.1 (4)	2.4 (2)
Missing	10.3 (17)	11.5 (9)	9.8 (8)

Definition of abbreviations: LDCT = low-dose computed tomography; HSI = Heaviness of Smoking Index.
*Never smokers (n = 4) and missing smokers (n = 1) were excluded.
†Former smokers only (n = 269).
‡For participants reporting grams of tobacco per week, these were converted to number of cigarettes per day.
§Current smokers only (n = 709).

(41%) and is on a par with national FOBT uptake (54%) when launched in 2006 (41). However, uptake is lower than current national figures for breast (71%) and cervical (72%) cancer but seemingly not because men were less likely to attend.

Finding a reduced socioeconomic gradient in uptake for the intervention group suggests that targeted and low-burden invitation materials show promise for better engaging high-risk individuals living in the most socioeconomically

deprived areas. Nevertheless, it was the control invitation strategy that achieved the highest uptake for the least deprived quintile. These results suggest that the intervention invitation approach may be the more equitable, holding potential for reducing inequalities and achieving a greater reduction in lung cancer mortality by engaging those at highest risk. Future research should examine the feasibility and acceptability of stratifying invitation materials by area-level deprivation.

Related to this, intervention and control participants achieved similar decision-making outcomes, suggesting the low information burden component did not compromise decision-making. In fact, it was control participants who less frequently felt informed about the risks of screening despite receiving this information in advance. Our low-burden component was informed by evidence that information burden can deter individuals with low literacy (43–45) and that a third of nonparticipants in colorectal screening have not read the information booklet (46). Moreover, information receptivity and comprehension may be adversely affected by a fearful emotional state (24, 25), which a first-time lung screening invitation could provoke (13). Perhaps the appointment was a better environment to achieve comprehension, with the research nurse's support and time to mentally adjust to the offer. Alternatively, control participants may have paid less attention to the booklet at their appointment because the information was not novel. Nevertheless, these findings suggest that providing detailed information with screening invitations may neither be sufficient for supporting informed choice nor an equitable invitation approach. A low-burden approach that builds up information in steps to full information provision during the appointment could be further tested for decision-making and inequalities in participation.

The intervention had no effect on smoking-related inequalities, with uptake skewed in favor of former smokers, as in previous trials (7–9) and screening programs for other cancer types (47–50). Research suggests that fatalism, fear, and stigma are deep-rooted attitudes (13, 17), which may be particularly resistant to change among current smokers. Alternatively, perhaps addiction-specific factors are more instrumental. Because

Table 4. Frequencies and Logistic Regression Analyses Examining the Correlates of Uptake of the LDCT Scan among LDCT-Eligible Attenders

	Attenders Eligible for LDCT (n = 845)		
	LDCT Uptake [% (n)]	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Overall	91.2 (770)	—	—
Sex		$P = 0.846$	$P = 0.979$
F	91.4 (342)	1.00	1.00
M	91.1 (428)	0.95 (0.59–1.54)	1.01 (0.60–1.68)
Age	—	$P = 0.275$	$P = 0.267$
		0.97 (0.92–1.03)	0.97 (0.91–1.03)
Marital status		$P = 0.443$	$P = 0.394$
Married/cohabiting	92.2 (320)	1.00	1.00
Single/separated/divorced/widowed	90.7 (449)	0.82 (0.50–1.35)	0.79 (0.46–1.36)
Ethnicity		$P < 0.01$	$P < 0.01$
White	91.3 (642)	1.00	1.00
Asian	53.8 (7)	**0.11 (0.04–0.34)**	**0.09 (0.02–0.31)**
Black	92.7 (76)	1.20 (0.50–2.88)	1.28 (0.52–3.14)
Mixed	100.0 (8)	—	—
Other	97.1 (34)	—	—
Not stated	100.0 (3)	—	—
Study-specific deprivation quintile*		$P = 0.074$	$P = 0.072$
Quintile 1 (most deprived)	88.2 (134)	1.00	1.00
Quintile 2	91.7 (154)	1.48 (0.71–3.08)	1.82 (0.75–3.49)
Quintile 3	95.6 (172)	**2.89 (1.22–6.85)**	**2.82 (1.18–6.78)**
Quintile 4	87.7 (136)	0.96 (0.48–1.91)	0.94 (0.46–1.91)
Quintile 5 (least deprived)	92.7 (165)	1.71 (0.81–3.61)	1.74 (0.80–3.77)
Smoking status		$P < 0.05$	$P = 0.052$
Former	94.6 (211)	1.00	1.00
Current (incl. occasional)	90.0 (559)	**0.51 (0.27–0.97)**	0.52 (0.27–1.01)
Invitation group		$P = 0.177$	$P = 0.075$
Control	89.7 (384)	1.00	1.00
Intervention	92.8 (386)	1.47 (0.91–2.40)	0.63 (0.37–1.05)

Definition of abbreviations: CI = confidence interval; LDCT = low-dose computed tomography; OR = odds ratio.
Missing data were excluded. Bold indicates ORs that are significant at $P < 0.05$.
*2010 Index of Multiple Deprivation rank quintile with cutoffs based on distribution in LSUT sample.

this was a multifactorial intervention with no process evaluation, we cannot draw conclusions about individual components. It does, however, highlight there are both independent and shared barriers to participation associated with lower SEP and current smoking status.

A simple primary care record search effectively identified a largely screening-eligible population, suggesting invitation through primary care is feasible for a population-based program, as well as a strategy likely to improve uptake. Indeed, adopting the invitation methods common to both groups may optimize participation. This includes a Lung Health Check approach, primary care endorsement (21, 23), preinvitations (29), postal reminders

(30), and scheduled appointments (32, 34). The reminder reinvitations offering a second scheduled appointment prompted uptake by a further 10%, suggesting that lowering practical demands helps nonresponders overcome nonintentional barriers. Although offering scheduled appointments appears to have been effective, 47% of invited individuals did not attend, which has resource implications. We mitigated the impact by overbooking appointments, and other strategies might include asking invitees to confirm attendance. Lessons could be learned from the United Kingdom's NHS Breast Cancer Screening Program, which sends timed appointments (30). Overall, the likely effectiveness of the methods shared by both trial arms suggests that translating

intention into action may be easier to achieve than changing attitudes.

There remains a gap in knowledge of the most effective means of modifying psychological barriers to participation. More foundational and experimental research is needed to isolate and test different approaches. It is likely that a multipronged screening communication strategy would be needed, as well as interventions at the wider healthcare system level, to ensure that the screening pathway optimizes individuals' screening experience.

Conclusions
Uptake of LDCT screening is likely to increase if offered as an organized Lung Health Check program and individuals are invited via primary care. It is possible to engage a high-risk, screening-eligible sample of lower SEP current smokers using feasible, population-based, and low-cost methods. A targeted, stepped, and low-burden invitation approach shows promise for reducing the social gradient in uptake by engaging individuals living in areas of highest deprivation, without compromised decision-making. Further research is critical to understand how to further reduce inequalities, especially for current smokers. ∎

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