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Measuring for change: A multi-centre pre-post trial of an air quality feedback intervention to promote smoke-free homes

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ABSTRACT

Introduction: Second-hand smoke exposure in the home is a serious cause of ill-health for children. Behaviour change interventions have been developed to encourage parents to keep homes smoke-free. This study evaluates a novel air quality feedback intervention using remote air quality monitoring with SMS and email messaging to promote smoke-free homes among families from deprived areas.
Methods: This paper presents a pre-post study of this intervention. Using internet connected monitors developed with the Dylos DC1700, daily SMS and weekly email feedback provided for 16 days to participants recruited in four European countries. Participants were recruited based on their stage of change, in order to target those most able to achieve smoke-free homes. The primary outcome measure was median change in mean fine particulate matter ($PM_{2.5}$) concentration between baseline and follow-up periods, while secondary outcome measures included change in time over the World Health Organisation (WHO) guideline limit for $PM_{2.5}$ exposure over 24 h (25 μg/m^3) in those periods and the number of homes where $PM_{2.5}$ concentrations reduced. Telephone interviews were conducted with participants in Scotland post-intervention to explore intervention experience and perceived effectiveness.
Results: Of 86 homes that completed the intervention study, 57 (66%) experienced pre-post reductions in measured $PM_{2.5}$. The median reduction experienced was 4.1 μg/m^3 (a reduction of 19% from baseline, p = 0.008). Eight homes where concentrations were higher than the WHO guideline limit at baseline fell below that level at follow-up. In follow-up interviews, participants expressed positive views on the usefulness of air quality feedback.
Discussion: Household air quality monitoring with SMS and email feedback can lead to behaviour change and

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consequent reductions in SHS in homes, but within the context of our study few homes became totally smoke-free.

1. Introduction

Second-hand smoke (SHS) is a risk factor for a range of childhood illnesses, including otitis media, meningitis and asthma exacerbations (US Surgeon General, 2006). In countries with comprehensive smoke-free indoor places legislation, the home is the primary remaining location of childhood exposure to SHS (Akhtar et al., 2007). A wide range of behaviour change interventions have been designed and trialled to encourage parents who smoke not to do so indoors. Techniques such as counselling (Abdullah et al., 2015; Chellini et al., 2013), smoking cessation support for parents (Jiménez-Muro et al., 2013) and feedback of children's biomarkers of SHS exposure (McIntosh et al., 1994) have been used in some interventions, but the evidence does not clearly indicate a best-practice strategy to reduce SHS exposure and improve children's health (Behbod et al., 2018).

One promising technique for promoting smoke-free homes is air quality feedback – giving parents objective information about the impact of their smoking on indoor air, and thereby on their children's health. Of five randomised controlled intervention trials using this technique, four led to significant reductions in the intervention arm (Emmons et al., 2001; Ratschen et al., 2017; Hughes et al., 2018; Harutyunyan et al., 2013) with one leading to no change at follow-up (Semple et al., 2018).

Previous studies have often used feedback provided days or weeks after air quality measurements were taken (Emmons et al., 2001; Ratschen et al., 2017; Wilson et al., 2013; Dobson et al., 2017;3.), which could reduce the effectiveness of feedback if participants have forgotten their behaviours during the measurement period.

In order to build on these previous intervention studies in a lower-cost intervention, it was decided to develop an intervention which used remote feedback, providing information from internet-based air quality monitoring. This intervention would employ both immediate and delayed feedback techniques to communicate information about SHS in the home using SMS, email messaging and phone calls.

This intervention incorporates the remote delivery of objective feedback on SHS levels in the home using both air quality feedback and mobile health techniques. This study aims to evaluate the effectiveness of that intervention.

2. Methods

2.1. Study design and overall intervention

This paper describes a pre-post study of the Measuring for Change intervention to promote smoke-free homes. The intervention had several components: 1) $PM_{2.5}$ monitoring: participants were provided with particle counting instruments to measure in real time particulate matter concentration ($PM_{2.5}$) installed in their homes for a period of 30 days. These devices allow data acquisition in real-time with a 3G internet connection but no information is directly displayed on the device; 2) Personalised feedback: during the intervention, personalised feedback was provided via SMS and email to the smoker, and was discussed with the smoker along with goal-setting and exploration of suitable methods of behaviour change by telephone; 3) A final home visit gathered data on changes made. Intervention components over time are shown in Fig. 1.

Particulate matter monitoring was conducted in the participant's home for 30 days. Monitoring with no feedback took place during the first seven days (the pre-intervention period). Between days 8 and 23 (inclusive), one SMS message giving information about the air quality in the home along with a semi-randomly generated advice to encourage parents to make their home smoke-free was sent to the participant's mobile phone each day. On days 8, 16 and 22 emails containing a graph of air quality over the past seven days and a graphical representation of the mean air quality in that time were sent. On days 9 & 23, participants received a 15-minute phone call from a member of the local research team to discuss the information they received the day before, asking additional questions about their progress and offering them the chance to ask questions about the intervention process.

2.2. Recruitment

An overall recruitment target of 160 individuals was set across four countries/five study centres. Centres in Scotland, Greece and Catalonia were set targets of 40 recruits, while the two Italian centres (Milan and Florence) were each set a target of 20. Although inclusion and exclusion criteria remained the same in each centre, specific recruitment strategies varied to take account of different circumstances in each country. Among the strategies used were advertisements displayed on social networks (including Facebook), primary health care centres, universities and libraries.

Monitoring took place from November 2017 – September 2018 in Scotland, April 2018 – July 2018 in Florence, April 2018 – November 2018 in Greece, April 2018 – December 2018 in Milan and September 2018 – April 2019 in Catalonia.

2.3. Inclusion and exclusion criteria

To be eligible to participate, individuals had to smoke in their home indoors or live with someone who smoked indoors, take care of a child aged 16 or under at least once a week, have regular access to the internet and have no plans to move home for two months from first contact with the research team.

Following a previous air quality intervention study conducted in

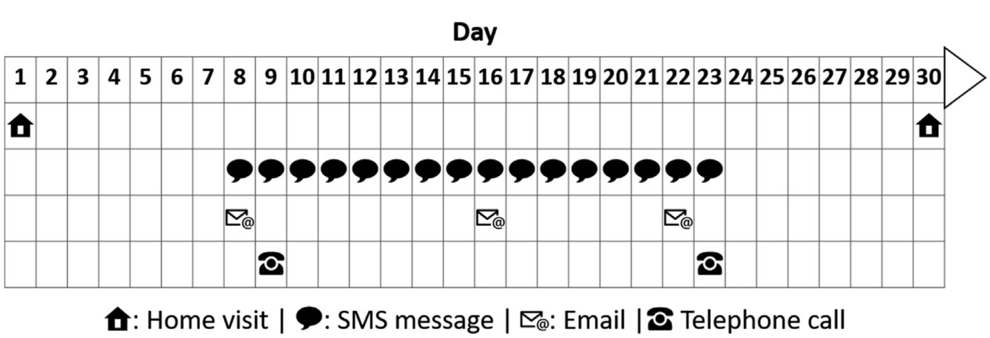

Fig. 1. Intervention components over the course of an intervention.

Scotland in which many participants were unable to make a substantial change to their smoking behaviours (Semple et al., 2018) this intervention was designed to target those who were motivated and capable of making their homes smoke-free. For this reason, a stage of change assessment questionnaire was designed to assess participants' capacity to change. This questionnaire incorporated an assessment of stage of change pre-intervention, based on the five sequential stages of change outlined in the transtheoretical model of behaviour change (Prochaska and Velicer, 1997), in order to identify potential participants who were in the contemplation (thinking about change), preparation (taking steps toward changing) and maintenance (changing) stages of change who may be more likely to engage with the intervention. Also included were two questions to assess feasibility of change towards creating a smoke-free home, based on previous research that has identified a number of barriers associated with successful behaviour change in this context (Passey et al., 2016).

Potential participants were asked to assess whether smoking in the home was a problem for themselves or anyone living in their home, asked when they might change their behaviour, and asked how realistic it would be to make their home smoke-free, and how realistic it would be to reduce the amount of SHS in the home (on a Likert scale where 0 represented "not realistic at all" and 10 represented "extremely realistic"). A further free-form question asked about barriers and facilitators to making the home smoke-free, focusing on practical issues such as other smokers living there and access to outdoor space.

Participants were ineligible to participate if they indicated that smoking was not a problem in the home, or if their answer to how realistic making the home smoke-free would be was less than or equal to 3.

Recruits could be eligible to take part in the study if they lived with an adult smoker but did not smoke themselves. In this case, the intervention was delivered as with a smoking participant with researchers using elements of the AFRESH Programme (Dobson et al., 2017;3.; O'Donnell et al., 2019) to provide assistance on communicating messages about SHS in homes to other householders.

2.4. Monitoring strategy

Dylos DC1700 monitors, low-cost optical particle counters which have been used to detect SHS-related $PM_{2.5}$ in previous studies (Hughes et al., 2018; Semple et al., 2018; Semple et al., 2013), were converted into internet-connected RAPID monitors as described in a previous paper (Dobson et al., 2019;17.). These monitors were used to provide continuous internet-connected air quality monitoring in each intervention household for 30 days. Monitors were installed in the main living area of the house to provide a representation of personal exposure at home, at a height of at least one metre from the floor to avoid low-level dust, and away from any open windows (to avoid air currents) or obvious sources of PM (such as cookers).

Each monitor used in the study was individually calibrated to improve the accuracy of the device's measurements. Calibration was conducted in Milan by researchers at the National Cancer Institute of Italy (INT). Calibration of 29 Dylos devices took place against a BAM-1020 continuous particle monitor (Met One Instruments, Inc., Grants Pass, Oregon), a high-precision instrument frequently used for regulatory purposes. Dylos devices were collocated with the BAM-1020 and three fans in an office owned by INT. Volunteer smokers were asked to smoke in this room for one hour, with the monitors left running for six hours.

Instrument-specific calibration factors were generated by dividing the mean BAM-1020 $PM_{2.5}$ concentration by each Dylos' estimated $PM_{2.5}$ concentration (as derived from a previously developed equation designed to estimate SHS-related $PM_{2.5}$ mass concentration from Dylos small particle number concentration data) (Semple et al., 2015). The calibration factors for the Dylos devices ranged between 1.39 and 3.18.

In order to provide a general point of comparison in SMS and email communications between smoking-permitted and smoke-free homes in SMS messages, an estimated value for $PM_{2.5}$ in homes where smoking is not allowed was required. Ambient air pollution varies in locations around the world. As this study was conducted in five cities across Europe with variable levels of air pollution specific comparison values were generated for each study centre.

Each centre conducted five-day measurements in five smoke-free homes within their study area to determine a smoke-free homes value. In addition to the generation of smoke-free homes values, these measurements were used as an opportunity to train researchers in the operation of the RAPID monitors.

2.5. SMS and email messages

Messages were generated automatically using custom software developed for this study following pre-defined templates. SMS messages were made up of a selection of components, some based on the air quality of the participant's home, others randomly selected. A message would first give the estimated $PM_{2.5}$ concentration in the home over the 24 h before the message was generated. It would then provide a comparison to the estimated concentration over the previous seven days (higher, similar or lower) followed by a comparison to $PM_{2.5}$ concentrations in smoke-free homes as measured in an urban area relevant to the participant (Edinburgh, Milan, Florence, Athens or Barcelona). Finally, a short piece of advice on keeping a smoke-free home derived from the Scottish Government's Right Outside campaign (Inform, 2018) was appended. Example messages can be seen in Supplementary file 1. These components were translated into Italian, Greek and Spanish.

2.6. Telephone feedback

Participants were telephoned on two occasions (at day 9 and day 23). These days were chosen to allow participants to receive and read emails on days 8 and 22, and consider questions and thoughts during that time. These calls were semi-structured, including a questionnaire mirroring elements of the initial stage of change questionnaire given at recruitment (to track changes in motivation to change). Participants were asked about the status of previously identified barriers and facilitators, with guidance given on overcoming barriers.

2.7. Follow-up interviews

In Scotland, participants who had completed the intervention were invited to take part in a 20-minute follow-up telephone interview, which explored participant experience of the intervention process and participant views on its effectiveness, using a mix of open-ended and closed questions (see Supplementary file 2 for interview schedule).

2.8. Questionnaires

In addition to stage of change questionnaires given at recruitment, day 9 and day 23 (Supplementary file 2), participants were given baseline and follow-up questionnaires at first and last home visits. Questions asked for information about the home, smoking rules indoors and knowledge about the health effects of SHS.

2.9. Statistical analysis

2.9.1. Quantitative analysis

The primary outcome measure was change in mean $PM_{2.5}$ between baseline monitoring period (day 1 – day 7 inclusive) and follow-up monitoring period (day 24 – day 30). Secondary outcome measures included the time spent over the WHO guideline limit for $PM_{2.5}$ over 24 h (25 $\mu g/m^3$) at baseline and follow-up and the number of homes in which $PM_{2.5}$ concentrations fell.

Changes in paired home concentration data at baseline and follow-up, and home time over the WHO guideline limit, were tested for significance using the paired Wilcoxon signed-rank test. Pairs of baseline and follow-up values from each household were submitted to this test.

2.10. Qualitative analysis

Follow-up interviews were hand-recorded, with the interviewer [RO] taking intelligent verbatim notes on open-ended responses. Two researchers (RO and RD) independently reviewed the content of each interview, compared responses and identified preliminary themes. Additional analysis led to the agreement of key themes that reflected participant's experiences, quotes were extracted to illustrate each identified theme.

2.11. Ethics, trial registration and study consortium

Ethical approval for the overall study was provided in the first instance by the College Ethics Review Board of the College of Life Sciences & Medicine at the University of Aberdeen (CERB/2016/12/1412). Each research centre outside of Scotland applied for and received ethical approval from a local and applicable ethics board.

The study was registered on ClinicalTrials.gov (Identifier: NCT03151421).

3. Results

3.1. Recruitment

Recruitment involved an initial contact by telephone, during which potential participants were given information on the study, assessed against inclusion criteria and asked to complete a stage of change assessment to determine whether they were ready to change the smoking behaviour in their home. Due to an error, no stage of change assessments were conducted at first contact with participants in Milan. This could have resulted in participants unready to make behaviour changes taking part in the intervention study.

A total of 110 recruits passed the inclusion criteria while 86 completed the intervention. Of the 24 participants who initially agreed to take part but did not complete the intervention, 21 withdrew before the informed consent stage while 3 were withdrawn due to technical issues with air quality monitoring in their homes.

3.2. Intervention results

Overall, there was a small but statistically significant reduction in measured mean $PM_{2.5}$ concentrations in the follow-up periods compared to the baseline across all participants in the study (the primary outcome measure), with a median reduction of −19% (-4.1 μg/m^3). Full results by each centre and combined overall can be seen in Table 1.

Declines in measured $PM_{2.5}$ occurred at each centre and overall. In total, 57/86 homes (66%) had reduced $PM_{2.5}$ concentrations at follow-up compared to baseline. The percentage decline was similar across centres, ranging between 59% in Stirling and 72% in Milan. Overall, this suggests that the intervention resulted in the majority of homes in each centre reducing their smoking behaviour indoors.

A secondary outcome measure in this study was change in the percentage of time where measured $PM_{2.5}$ concentrations exceeded the WHO's guideline indoor limit for $PM_{2.5}$ over 24 h (25 μg/m^3). The percentage of time at follow-up where $PM_{2.5}$ was measured to be above this concentration was compared to the percentage of time at baseline where this was so.

Overall, time spent over 25 μg/m^3 fell by a median 3.3% from baseline to follow-up, representing around one hour per day in which the median home was below that level following the intervention ($p = 0.012$).

3.3. Telephone interview findings

Eight participants in Scotland took part in an interview. The key themes that reflected participant's experiences are outlined in Table 2. The data obtained supports the finding that the intervention was successful in reducing rather than eliminating SHS exposure in participating homes. Two of the eight participants interviewed had created a completely smoke-free home, others reduced their smoking consumption, or made changes to when/where smoking took place in the home (Fig. 3 quote a). Four participants attempted to raise the issue of smoking in the home with other adult household members who smoked, with varying levels of success (Fig. 3 quote b), highlighting the importance of facilitating and maintaining change in relation to smoking in the home as a collective responsibility. Participants noted several benefits associated with taking part in the intervention related to increased knowledge and awareness of the risks of SHS exposure (Fig. 3, quote c), but they raised a number of barriers associated with creating an entirely smoke-free home, including mental health status, sole caring responsibilities and poor weather conditions (Fig. 3, quote d).

All eight participants stated that they valued receiving objective, personalised feedback on their home air quality levels, which was often viewed as 'evidence' or 'proof' of the risks associated with smoking in the home (Fig. 3, quote e). Seven participants stated that they found the texts and emails received easy to understand, and they often compared the $PM_{2.5}$ levels received in texts from one day to the next (Fig. 3, quote f). One participant needed help from their partner to understand the graphs. Three participants could not easily access the weekly emails using their mobile phones (Fig. 3, quote g).

Table 1
Median of mean $PM_{2.5}$ concentrations at baseline and follow-up, and median change in time spent over the WHO 24-hour guideline limit for $PM_{2.5}$ (25 μg/m^3), by centre and overall.

Centre	N	Median of baseline mean $PM_{2.5}$ concentration (μg/m^3)	Median of follow-up mean $PM_{2.5}$ concentration (μg/m^3)	Median $PM_{2.5}$ change for paired samples (interquartile range) (μg/m^3)	Median $PM_{2.5}$ change as a % of baseline (interquartile range) %	Median change in % time over WHO guideline limit %
Athens	20	20.0	14.0	−3.2 (−7.6 – 0.9)	−24.0 (−35.6 – 9.8)	−8.6
Barcelona	18	102.7	67.3	− 11.2 (−44.3 – 1.3)	−18.3 (−3.5 – 6.1)	−0.5
Florence	3	32.0	19.0	−4.8 (−11.8 – 1.8)	−12.0 (−35.7 – 3.5)	−0.1
Milan	18	17.0	14.0	−2.1 (−11.2 – 0.6)	−18.0 (−53.6 – 1.4)	−1.6
Stirling	27	64.0	59.0	−8.3 (−30.3 – 22.8)	−12.0 (−37.1 – 19.8)	−5.5
Overall	86	33.0	33.0	−4.1 (−18.5 – 3.8)	−19.0 (−39.9 – 9.2)	**−3.3**

A Wilcoxon signed rank test was conducted on the paired baseline and follow-up mean concentrations of all centres over the course of the intervention, showing that this change was statistically significant ($p = 0.008$). Due to the small sample sizes available, significance testing was not conducted on samples by centre.
Mean $PM_{2.5}$ declined in most homes between baseline and follow-up at each centre. Fig. 2 plots mean $PM_{2.5}$ at baseline (X axis) and follow-up (Y axis) for each participant across all centres. The dots on the lower right of the diagonal line (lower concentration at follow-up) graphically show the level of decline.

Table 2
Themes interpreted from the follow-up telephone interview data.

Core theme	Sub-themes
Acceptability of air quality monitoring	- Personalised feedback - User experience - Interpretation and impact of results
Acceptability of mobile health techniques	- Daily (text) vs. weekly (email) feedback - User experience - Interpretation and impact of information received
Raising the issue of smoking in the home with other household members	- SHS as a collective responsibility - Household-level communications - Ability to influence household-level change
Changes made as a result of the intervention	- Reduced cigarette consumption - Changing where/when smoking takes places indoors - Taking smoking right outside the home - Switching to an e-cigarette
Barriers to smoking behaviour change in the home	- Other adult smokers in the household - Changing existing routines - Health-related barriers (mental health, physical illness, addiction) - Practical barriers (weather, dark nights, comfort) - Psychological factors (motivation, stigma, guilt)
Perceived benefits of taking part	- Changes in smoking behaviour in the home - Acquiring new knowledge - Increased awareness of the risks of smoking in the home

4. Discussion

Based on the results of this study, the Measuring for Change intervention can reduce SHS exposure in homes over the course of a month-long intervention. However, this reduction does not typically lead to participants having fully smoke-free homes, instead leading to significant but small reductions of about 19% in mean $PM_{2.5}$ concentrations and 3.3% in percentage time spent over the WHO guideline limit

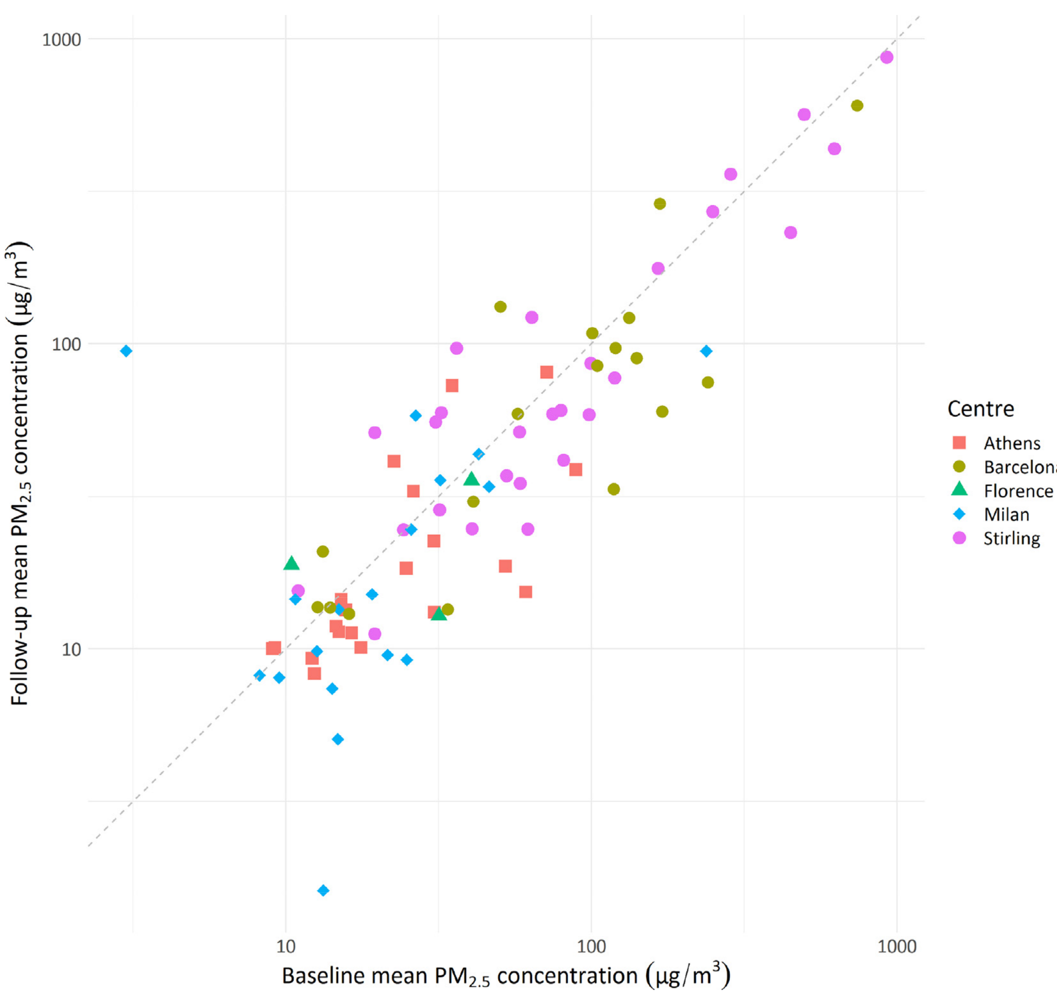

Fig. 2. $PM_{2.5}$ concentrations at baseline and follow-up in each participating home. Results to the lower right of the identity line represent declines in $PM_{2.5}$ concentration over the intervention period.

Participant outcomes and experiences of taking part in the intervention

a. "I probably smoke less because I'm going all the way out to the garden now [to smoke]…I think I can keep these changes up. It's been 5-6 weeks now and it's more of a habit now." (P22)

b. "He [partner] has really cut down… I would like to see no smoking in the house at all. I'm not going back to smoking in here now, no way." (P31)

c. "I wasn't fully aware of the risks of smoking in the home, but I'm more aware now… that's the good thing about the study…it's raised my awareness and knowledge." (P01)

d. "Taking smoking outside completely is a difficult thing to achieve. With depression and anxiety it can be hard to go outside anyway." (P35)

Acceptability of air quality monitoring and mobile health techniques

e. "When I changed my smoking behaviour and took my smoking out in the garden, I could see a difference in the [$PM_{2.5}$] levels. It's very easy for people to say to you that that's what you need to do - take your smoking outside – but without evidence, for me, it just goes in one ear and out the other." (P04)

f. "I really enjoyed seeing the texts. I found them interesting, just to see if the changes I did make made any differences to the levels you got in the texts. When the numbers were lower, it became a competition with myself to do even better the next day." (P35)

g. "The emails were fine. I can only get them on my phone though, as I don't have a

Fig. 3. Participant experiences of taking part in the intervention.

for $PM_{2.5}$ over 24 h in the home. This, alongside the telephone interview findings, suggests that the intervention leads to participants giving greater consideration to the impact of smoking on household air quality and/or the harms of SHS, but being unable to take all the necessary steps to make the home entirely smoke-free all of the time.

This study represents a new approach to air quality feedback for smoke-free homes, incorporating novel techniques such as SMS messaging and internet-based feedback. Other studies of air quality feedback interventions have used either immediate (Hughes et al., 2018; Harutyunyan et al., 2013) or significantly delayed (Ratschen et al., 2017; Semple et al., 2018) feedback. This study is the first to use a hybrid approach, combining near-immediate feedback through SMS messages with delayed, in-depth researcher-supported feedback through emails and phone calls.

Other interventions have taken rapid feedback approaches. One trial has provided participants with real-time feedback on their air quality over a sustained period of time. This intervention, developed and tested at San Diego State University (Hughes et al., 2018; Klepeis et al., 2013; Hovell et al., 2019:) involved the use of a customised monitor with LEDs and speakers to produce specially designed auditory and visual warnings (Bellettiere, et al., 2014) when detected particle concentrations exceeded certain levels. While this provided more rapid feedback than other intervention designs, comparison of recent results to past results within the home was limited to four telephone counselling sessions over the course of three months. This may have impacted the ability of participants to set goals to reduce SHS indoors, as there was a lack of immediacy in the feedback and they may not have been able to associate particular behaviour with poor air quality results. Additionally, this intervention required the use of two air quality monitors and custom equipment to produce warnings and transmit data to researchers, increasing cost.

As a quasi-experimental study without comparison group rather than a randomised controlled trial, this study cannot definitively demonstrate causation. However, the effect size (a median decline in mean $PM_{2.5}$ concentration of 19% between baseline and follow-up periods) is similar to other published research on air quality feedback interventions (Ratschen et al., 2017; Hughes et al., 2018) which included a control group.

Unlike some other studies in this area, no non-air quality feedback elements such as nicotine replacement therapy (Ratschen et al., 2017) were included in the intervention, making this study a true test of air quality feedback as a method of promoting smoke-free homes. The value of adding a component of cessation to this smoke-free home intervention should be evaluated in further studies.

Telephone interviews were confined to a small proportion of the Scottish sub-sample of participants, and the views and experiences of those who took part are not representative of participants in the wider sample. Conducting relatively short, hand-recorded telephone interviews may have limited the detail given in participant responses to open-ended questions. However, this strategy may also have increased participation at follow-up given there was no need to schedule a home visit or take part in a longer, in-depth interview.

Intervention fidelity was heterogeneous across centres; in Milan, stage of change data were not acquired at first contact and SMS messages were sent less frequently than in other centres. The limited sample size means that this study is underpowered to detect differences between centres, but Milan had the lowest absolute median decline in $PM_{2.5}$ of any centre (-2.8 μg/m^3).

Difficulties in recruitment across all centres led to a smaller sample size than initially intended. While we observed statistically significant change in the primary outcome measure, it should be noted that this small sample size (combined with the small change in $PM_{2.5}$ observed) may increase the chance that this did not represent real change. Future studies of interventions of this type should include control elements and recruit a larger sample size to mitigate against this risk.

Recruitment strategies differed by centre which may have contributed to differences in recruitment success and participant retention (particularly in Stirling drop-out was unusually high). How to reach the target population is a matter of concern in all community-based and health promotion interventions (World Health Organisation. A guide to implementation research in the prevention and control of non-communicable diseases. Geneva:, 2016), and an important topic when implementing them.

The RAPID monitor system performed well but occasional failures in monitoring required researchers to monitor the status of each monitor on a frequent basis. Due to the nature of the system, which included several components with external wired connections, it was possible for connections to become loose if the device was accidentally knocked. Additionally, software errors occurred causing delays or failures in sending data to the server. These were partially remedied by ongoing development of the system during the course of the study, but were not completely eliminated. Using an alternative monitoring system with integrated long-term data storage and internet connection capabilities may reduce these problems further.

4.1. Alternative explanations for change

As this study did not include a control group, it is possible that $PM_{2.5}$ concentrations declined in homes for reasons not related to the intervention. The median change detected in $PM_{2.5}$ concentration between baseline and follow-up periods was statistically significant but small in absolute terms (< 5μg/m^3). Seasonal variation in ambient air pollution could have accounted for some of this change, as the month-long measurement periods used could have reflected gradual changes in $PM_{2.5}$ concentration over this time (depending on the infiltration of $PM_{2.5}$ into homes in each setting, which may relate to building design and location among other factors). Analysis of ambient $PM_{2.5}$ concentrations available from four of the five study centres using European Environment Agency (European Environment Agency. Air Quality e-Reporting (AQ e-Reporting). https://www.eea.europa.eu/data-and-maps/data/aqereporting-8 (accessed 7 Apr 2020)) monitoring station data from 2018 (not presented in this paper) indicated no correlation between change in outdoor air from baseline to follow-up periods and change in measured $PM_{2.5}$ concentrations in participating households.

5. Conclusions

An air quality feedback intervention using a hybrid of immediate and delayed feedback techniques through remote air quality monitoring is feasible and acceptable to participants, resulting in a 19% decline in $PM_{2.5}$ concentrations in homes undergoing the intervention. Participants found SMS and email messages useful in reducing SHS in their home, although some technical problems occurred viewing emails. An intervention of this kind can successfully reduce SHS exposure in the home over a short trial period, although in this group of smokers it did not lead to wholly smoke-free homes on a large scale.

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CRediT authorship contribution statement

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Declaration of Competing Interest

The authors declared that there is no conflict of interest.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2020.105738.

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