

Manuscript Details

Manuscript number	ENVINT_2018_1248_R1
Title	Using air-quality feedback to encourage disadvantaged parents to create a smoke-free home: results from a randomised controlled trial
Article type	Research Paper

Abstract

Objective: To determine if low-cost air-quality monitors providing personalised feedback of household second-hand smoke (SHS) concentrations plus standard health service advice on SHS were more effective than standard advice in helping parents protect their child from SHS. **Design:** A randomised controlled trial of a personalised intervention delivered to disadvantaged mothers who were exposed to SHS at home. Changes in household concentrations of fine Particulate Matter (PM2.5) were the primary outcome. **Methods:** Air-quality monitors measured household PM2.5 concentrations over approximately 6 days at baseline and at one-month and six-months post-intervention. Data on smoking and smoking-rules were gathered. Participants were randomised to either Group A (standard health service advice on SHS) or Group B (standard advice plus personalised air-quality feedback). Group B participants received personalised air-quality feedback after the baseline measurement and at 1-month. Both groups received air-quality feedback at 6-months. **Results:** 120 mothers were recruited of whom 117 were randomised. Follow up was completed after 1-month in 102 and at 6-months in 78 participants. There was no statistically significant reduction in PM2.5 concentrations by either intervention type at 1-month or 6-months, nor significant differences between the two groups at 1-month ($p=0.76$) and 6-month follow-up ($p=0.16$). **Conclusions:** Neither standard advice nor standard advice plus personalised air-quality feedback were effective in reducing PM2.5 concentrations in deprived households where smoking occurred. Finding ways of identifying homes where air-quality feedback can be a useful tool to change household smoking behaviour is important to ensure resources are targeted successfully.

Keywords	Indoor air quality; Environmental Tobacco Smoke; Second-hand Smoke; Children; PM2.5; Education
Taxonomy	Exposure by Inhalation, Indoor Exposure Monitoring, Environmental Health Exposure
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Suggested reviewers	Emilia Zainal Abidin, Kamran Siddiqi, Esteve Fernandez

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Response to reviewers 250718.docx [Response to Reviewers]

FS2SF Quantitative Paper 180618_tracked changes.doc [Revised Manuscript with Changes Marked]

Highlights_FIRSTSTEPS.docx [Highlights]

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Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
Data will be made available on request

Dear Editor

We have pleasure in re-submitting our manuscript 'Using air-quality feedback to encourage disadvantaged parents to create a smoke-free home: results from a randomised controlled trial' for consideration by Environmental International. We are delighted that the three reviewers provided such positive comments on our previous manuscript and have given us the opportunity to further strengthen our work. We include a word file explaining in detail the changes we have made in response to the reviewers' comments, together with a tracked changes version of the new manuscript and a clean (changes accepted) version.

We have carried out these changes as quickly as possible as we note that our funder (the Chief Scientist Office in Scotland) has a process of providing open access funding fees provided the paper is accepted within 18 months from the end of the project <http://www.cso.scot.nhs.uk/outputs/cso-open-access-policy/> . As the project ended on 31/01/17 this date is, for us, 31st July 2018. We fully understand that it may not be possible to reach a decision on our changes in this tight timescale but if there was any way of doing so then we would be very grateful.

We can again confirm that the work has not been previously published and is not under consideration by any other journal.

Best wishes

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Title: Using air-quality feedback to encourage disadvantaged parents to create a smoke-free home: results from a randomised controlled trial

Journal: Environment International

Response to reviewers' comments

We are extremely grateful to the reviewers for their time and effort in reviewing this manuscript and for recognising the novelty and importance of the work. The comments have been helpful in our revision of this work. We provide detailed responses to each point in the document below and have used tracked changes to the initial manuscript to assist with the re-review.

Reviewer #1

This manuscript presents the results of a RCT of a novel intervention to reduce SHS exposure in homes using air-quality monitors. The RCT shows an excellent design and execution. The authors show the results that indicate a lack of positive effect of the intervention, and discuss the reasons for such a lack of effect. In my opinion the clarity and transparency how the authors report the results is very important and hence I want to congratulate the authors. Moreover, they discuss in-depth the potential explanations for these results.

Response

Thank you for these positive comments which we really appreciate. We are delighted that you found the paper provides a clear and transparent write-up of this important study.

1.1 Introduction. The introduction is too long and in my view some paragraphs could be omitted or moved to the Discussion: 3rd paragraph, and first half of the 5th paragraph.

Response

We have shortened the length of the introduction as the reviewer advised. We have moved most of the 3rd paragraph to the section of the discussion comparing our results to previous studies and also moved the first sentence of paragraph 5 to the beginning of the discussion.

1.2. Methods: It is not clear in which exactly consist the intervention, since part of it is explained under the heading 1.1 and part of it under the heading 1.5. In my opinion, the clarity of the Methods section would be improved by assigning a new heading "1.2" labelled "Intervention" in which the intervention is explained (with part of the material currently in 1.1 and the former 1.5 heading).

Response

We have re-written the methods sections as advised. There is now a clear section describing the intervention using some of the material from sections 1.1 and 1.5. We hope this brings greater clarity and also addresses reviewer point 1.3 below.

1.3. Moreover, please indicate in the text the moments when the feedback is provided, since it only appears in the figure. It has to be clearly stated that the intervention is the use of the air-quality monitors AND the feed-back provided, and in this sense, the frequency and timing of the feed-back is essential.

Response

We have now added this information to the new intervention section of the methods and further emphasised the timing of feedback in the 'PM2.5 measurement' section.

1.4. In fact, I believe that the lack of effect of the intervention could be attributed to the "low" intensity of intervention, this is, in the frequency of the feed-back. Discussion: As previously

mentioned, the authors should elaborate about the regime of the feed-back provided as the potential reason for the lack of effect (part of this idea is currently almost at the end of the Discussion).

Response

This is an excellent point and we have now added some text to our discussion to highlight the fact that air quality feedback was provided on just a single occasion prior to the follow-up measurement. This is now combined with the discussion about Klepeis' study using immediate alarms when PM_{2.5} concentrations increase and our own study (TACKSHS) that will provide daily feedback to smokers about their household air quality.

Reviewer #2

Smoke-free homes is a matter of public concern and health and therefore, both researchers and health stakeholders would be interested in the current study. In the manuscript by Semple et al., the authors describe an intervention study on changes in tobacco smoke pollution in the home, as measured by air particulate matter (PM_{2.5}) concentration. Overall this is a very interesting study, thoroughly conducted, executed and presented.

Response

We thank the reviewer for their encouraging words about the study and our presentation of the findings.

2.1 In the limitations section of the manuscript, the authors do state that PM_{2.5} is produced by various sources and therefore its application as surrogate marker for SHS, should be implemented with caution. However, there is also a large seasonal variation of outdoors/indoors PM_{2.5} concentration due to other than SHS sources, which should also be taken into consideration, particularly in a study like the one by Semple et al. which was conducted almost throughout one whole year. Information on the time (e.g. month) each step of the study was conducted as well as on the means of indoor heating of the two groups should be given.

Response

This is an interesting point and highlights one of the advantages of carrying out work in Scotland on measuring SHS. As we note, and as the reviewer recognises, PM_{2.5} is produced by other sources not least ambient air pollution. However, air quality even in urban areas of Scotland tends to be very good with low levels of ambient PM_{2.5} and there is very little seasonal variation. We have checked the government air quality data for the whole of 2015 (the year most of the fieldwork was carried out) at the urban outdoor monitoring site in Lanarkshire. The monthly daily averages of PM₁₀ (typically PM_{2.5} is about two-thirds of PM₁₀ values) range from 14 to 21 ug/m³ with no discernible seasonal pattern (see figure below). This, together with the fact that heating in Scottish households is almost universally by electric and closed system gas central heating systems with no PM emissions, suggest that most PM measured in these home settings comes from smoking activity. We have added some additional text to the discussion to reflect these points.

Statistics for South Lanarkshire Hamilton

Year:

2015 ▼

Parameter:

PM10 particulate matter (Hourly measured) ▼

Update Statistics

Monthly Statistics (monthly averages) for 2015

The monthly data below are average concentration data, followed by data capture rates (shown as a percentage of each month).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16	19	21	19	15	16	14	16	17	21	16	17
98%	99%	99%	100%	68%	100%	97%	98%	98%	80%	100%	86%

Annual Statistics for 2015

Annual Hourly Mean	17	µg/m ³ (TEOM FDMS)	Ratified	93% DC
Max Daily Mean	69	µg/m ³ (TEOM FDMS)	Ratified	93% DC
Max Hourly Mean	210	µg/m ³ (TEOM FDMS)	Ratified	93% DC

Data taken from http://www.scottishairquality.co.uk/latest/site-info?site_id=SL05&view=statistics

2.2. There is a confusion regarding the periods between baseline and follow up periods: are they 1 and six months or 3 and 15 weeks (fig 1)?

Response

The baseline measurement takes place between visit 1 and 2 with feedback provided usually about 1 week later. The follow-up periods were targeted at 1 month and 6 months later but the exact dates varied depending on availability of the participant. We have added some text to the methods ('intervention' section) to clarify this for the reader.

2.3. Table 2 shows medians and confidence intervals while the relevant text (lines 738-744) shows medians and IQR. This is also confusing, should be the same.

Response

We have made this change to the results section and now present just the medians and 95% confidence interval.

2.4. Figure 2 line 794:" Then" instead of "the"

Response

We have made this change.

2.5. Throughout the text: punctuation marks should follow the bracketed references (e.g. line 183 ...with a smoker[6-7]. instead ofwith a smoker.[6-7])

Response

We have made this change throughout the manuscript.

Reviewer #3

The article is highly novel, attempting to find ways to help population who are still being continually exposed to SHS despite the many advancement achieved in this field, especially in Scotland. The article combines behavioural-based science and hygiene methods and is highly relevant to public

health professionals, not to mention countries itself, as many countries within the UN group is attempting to achieve the end game of tobacco by 2025 in some countries and 2045 in other parts of the world. Although this manuscript does not really represent example of what is working, identifying the barriers to a successful intervention is also a gap in itself, which will help other researchers in the future. As the manuscript is already well-written, minimal comments are given.

Response

We thank the reviewer for their encouraging comments and recognition of the fact that it is equally important to publish the studies of negative findings.

3.1. Introduction, page 7 - The meta-analysis indicated that these approaches generally had an impact on reducing household PM2.5 or air nicotine levels; though all studies reported evidence of continuing SHS 'contamination' post-intervention. – explanation on PM2.5 within this paragraph will help readers improve understanding.

Response

We have now defined PM2.5 within the paragraph as suggested to make this sentence easier for the reader to understand.

3.2 Methodology - NHS SHS advice information. Suggest adding some detail and maybe any report of the effectiveness (or non-effectiveness) of the information in helping parents. What are the advice specifically asked? This info may be relevant in encouraging NHS to improve information or tailor-made info based on the types of population being focused on.

Response

See response to point 1.2 where we now provide a clearer description of the intervention. The standard advice was 'Very Brief Advice' on second-hand smoke and children that was based around the UK National Centre for Smoking Cessation and Training and a local National Health Service Lanarkshire leaflet highlighting the health harms of SHS. We are not aware of any studies that have evaluated the effectiveness of this standard advice. The reviewer's point is therefore now incorporated in the final discussion where we note that those receiving the standard advice did not achieve any statistically significant improvement at follow-up suggesting that improvements and targeting of this advice may be required.

3.3 Suggest to add information with regards to the location of measurement and why living room was specifically chosen. How does the measurement represents the exposure to the children? What are the evidence?

Response

This is a great point and to address this we've now added text explaining that the living room was selected as (a) the room in the home where people spend most waking time in the home and (b) there is evidence from Spain showing a high correlation between nicotine concentrations measured in the living room and child's bedroom. We have also previously reported a small study showing associations between bedroom and living room PM levels in smoking homes <http://journals.sagepub.com/doi/full/10.1177/1420326X14527301>

3.4. SHS feedback, suggest some info on the WHO 25 µg/m³ threshold in text to explain about its significance, in terms of health etc.

Response

We have added information in the methods section regarding feedback of information on household PM2.5 concentrations in relation to the WHO guidance value.

3.5. Minor comments, table 1, p=XXX, p can be deleted?

Response

We have made this change to table 1.

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4 **Using air-quality feedback to encourage disadvantaged parents to create a smoke-**
5 **free home: results from a randomised controlled trial**

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36 | Word count: ~~4497~~441; figures: 2; tables 2. References: ~~4239~~

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38 Abstract word count: 243
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59 **Abstract**
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62 **Objective:** To determine if low-cost air-quality monitors providing personalised
63 feedback of household second-hand smoke (SHS) concentrations plus standard health
64 service advice on SHS were more effective than standard advice in helping parents
65 protect their child from SHS.
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73 **Design:** A randomised controlled trial of a personalised intervention delivered to
74 disadvantaged mothers who were exposed to SHS at home. Changes in household
75 concentrations of fine Particulate Matter (PM_{2.5}) were the primary outcome.
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81 **Methods:** Air-quality monitors measured household PM_{2.5} concentrations over
82 approximately 6 days at baseline and at one-month and six-months post-intervention.
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84 Data on smoking and smoking-rules were gathered. Participants were randomised to
85 either Group A (standard health service advice on SHS) or Group B (standard advice plus
86 personalised air-quality feedback). Group B participants received personalised air-quality
87 feedback after the baseline measurement and at 1-month. Both groups received air-
88 quality feedback at 6-months.
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98 **Results:** 120 mothers were recruited of whom 117 were randomised. Follow up was
99 completed after 1-month in 102 and at 6-months in 78 participants. There was no
100 statistically significant reduction in PM_{2.5} concentrations by either intervention type at 1-
101 month or 6-months, nor significant differences between the two groups at 1-month
102 (p=0.76) and 6-month follow-up (p=0.16).
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117 **Conclusions:** Neither standard advice nor standard advice plus personalised air-quality
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119 feedback were effective in reducing PM_{2.5} concentrations in deprived households where
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121 smoking occurred. Finding ways of identifying homes where air-quality feedback can be
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123 a useful tool to change household smoking behaviour is important to ensure resources are
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125 targeted successfully.
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131 **Keywords:** Environmental Tobacco Smoke, Second-hand Smoke, Children, PM_{2.5},
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133 Education, Intervention
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171 **1. Introduction**
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174 Second-hand tobacco smoke (SHS) is a common indoor air pollutant linked to a wide
175 range of respiratory;^[1-2] cardiovascular [3] and early life ill-health effects;^[4] -with
176 exposure more common in disadvantaged households;^[5] Non-smokers who live with
177 smokers can have high SHS exposures, particularly young children who spend much of
178 their day at home with a smoker;^[6-7] Globally it is estimated that 40% of children
183 experience regular exposure to SHS with much of this exposure occurring in their own
184 home;^[8] The global burden of this exposure is estimated to be over 600,000 deaths and
185 almost 11 million disability-adjusted life-years per year. Children are particularly
186 vulnerable to the effects of SHS exposure and suffer 28% of these deaths and 61% of this
187 morbidity;^[9]

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197 Enabling parents to create a smoke-free home is challenging but it is one of the key ways
198 that children's exposure to SHS can be reduced globally. Scotland is at the forefront of
199 protecting children from exposure to SHS with the Scottish Government's 'Take it Right
200 Outside' campaign including a world first: a governmental target to reduce the proportion
201 of children exposed to SHS at home by 50% (from 12% to 6%) by 2020;^[10] Increased
202 adoption of smoke-free homes in low income populations has also been shown to
203 increase cessation rates and prevent relapse;^[11] There is a need for good quality
204 evidence on ways to increase the proportion of smoke-free homes in different settings.
205 The most recent Cochrane review [12] of programmes to reduce children's exposure to
206 SHS screened 57 relevant studies but identified that only 6 used objective measures of
207 children's SHS exposure to evaluate intervention effectiveness. None of the included
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227 studies used air-quality feedback. A recent systematic review and meta-analysis [13]
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229 identified seven interventions designed to encourage smoke-free homes that had used
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231 objective measures of household air quality as an outcome measure. The meta-analysis
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233 indicated that these approaches generally had an impact on reducing household air
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235 concentrations of fine particulate matter (PM_{2.5}) or air-nicotine levels within the
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237 household; though all studies reported evidence of continuing SHS ‘contamination’ post-
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239 intervention.
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244 Methods to measure SHS in indoor settings using airborne fine particulate matter (PM_{2.5})
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246 as a marker of SHS concentrations have been used in tobacco control science over the
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248 past decade [14-16]. Several studies have explored the concept of air-quality feedback to
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250 modify smoking behaviour in the home [17-19]. The REFRESH study recruited 59
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252 smoking mothers in Scotland and provided PM_{2.5} measurement data over a 24-hour
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254 period as the primary tool in a motivational interview aimed at empowering parents to
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256 make their home smoke-free. [17] That study found that mothers who received air-quality
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258 feedback reduced PM_{2.5} concentrations by approximately one-third although the study
259
260 was too small to detect a difference with the control group. More recent work by
261
262 Ratschen and colleagues [18] studied a similar approach with disadvantaged smoking
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264 parents in Nottingham. That study compared a complex intervention combining
265
266 personalised air quality feedback, behavioural support and nicotine replacement therapy
267
268 for temporary abstinence with usual care involving standard advice. The 24h PM_{2.5}
269
270 concentration in intervention homes reduced exposure about one-third at the 12-week
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272 follow-up. Hughes et al [19] have reported an intervention involving an air-quality
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283 ~~instrument with warning lights and alarms to provide real-time feedback on particulate~~
284 ~~concentrations in smokers' home. Their work showed an average reduction of~~
285 ~~approximately 19% in households receiving this feedback compared to just 6.5%~~
286 ~~reduction in control homes.~~
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294 There are considerable challenges in rolling out this type air-quality feedback
295 intervention at scale. The REFRESH study identified low recruitment rates (when
296 potential participants were approached via GP letter); the high cost of available
297 instruments and technical complexity; and the labour costs of delivering, setting up and
298 collecting instruments from participants' homes [20]. Recent work has identified low-
299 cost air-quality monitoring devices that have the potential to address the practical
300 problems of noise, cost and complexity of operation identified in previous studies [21].
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311 ~~This study is the first to trial the use of air-quality feedback as an intervention to~~
312 ~~encourage smoke-free homes delivered in a real-world setting as part of health~~
313 ~~professionals' routine work with smoking clients. It was nested within the First Steps~~
314 ~~Programme (FSP) in Lanarkshire in Scotland [22], providing an opportunity to overcome~~
315 ~~many of the barriers identified in the REFRESH study [23] in terms of recruiting~~
316 ~~disadvantaged parents, embedding the intervention within an existing service and use of a~~
317 ~~simpler, low-cost device to deliver air-quality feedback.~~ The aim of the study was to
318 determine if delivery of personalised air-quality feedback plus standard advice on the
319 health effects of SHS was more effective than standard advice on its own in encouraging
320 changes to household smoking as measured by objective assessment of PM_{2.5}
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339 concentrations one-month later. The study was nested within the First Steps Programme
340 (FSP) in Lanarkshire in Scotland [22], providing an opportunity to overcome many of the
341 barriers identified in the REFRESH study [23] in terms of recruiting disadvantaged
342 parents, embedding the intervention within an existing service and use of a simpler, low-
343 cost device to deliver air quality feedback.
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395 **Methods**
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397 *1.1. Study design*
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399 This was a randomised controlled trial which compared standard advice to achieve a
400 smoke-free home against standard advice plus personalised air-quality feedback.
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403 Vulnerable mothers who smoked or lived with smokers and were engaged with the
404 Lanarkshire FSP were eligible. FSP is an early intervention programme provided by the
405 National Health Service in Lanarkshire, Scotland, providing vulnerable first-time mums
406 with intensive, free, one-to-one support during and after pregnancy to give their babies
407 the best possible start in life. Support includes considering the child's exposure to SHS
408 and where appropriate exploring options to reduce this. Over 30% of mothers involved in
409 the programme are smokers with 48% of homes having one or more smoking adult
410 resident.
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422 First Steps (FS) workers identified clients who were thought likely to have SHS exposure
423 in the home either from self-report of household smoking or observations of the presence
424 of SHS within the home. Participants were excluded from the study if they were: under
425 16; they were unable to give informed consent due to physical or mental incapacity; or
426 there was no smoker resident within the household. FS workers identified clients who
427 were thought likely to have SHS exposure in the home either from self-report of
428 household smoking or observations of the presence of SHS within the home. These
429 clients were invited to take part in the study; information sheets were provided and
430 written informed consent gained. PM_{2.5} measurements were made after randomisation,
431 and one and six months afterwards. Participants were randomised to group A or B by a
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451 member of the research team blind to the participants' details, using the ID number and
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453 randomisation function in Microsoft Excel. A short baseline questionnaire was completed
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455 to determine self-reported current smoking, household smoking rules and attitudes
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457 towards smoking. ~~Group A participants received only standard NHS advice on the~~
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459 ~~harmful effects of SHS after the baseline visit. Air quality feedback was provided to this~~
460
461 ~~group only after the 6-month follow-up. Group B participants received standard NHS~~
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463 ~~SHS advice plus personalised air quality feedback at the baseline measurement. Project~~
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465 ~~home visits were built into the existing FSP programme of weekly contacts with clients.~~
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467 ~~Figure 1 shows the overall research design. Full engagement over the 6-month period~~
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469 ~~involved nine visits where study materials were used.~~
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475 Questionnaires assessed changes in smoking, household rules and quit attempts at the 1-
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477 and 6-month follow-ups. All study participants received a £10 shopping voucher on
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479 completing the baseline and a further £20 on completion of the 6-month follow-up visit.
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481 The primary outcome was change in the household PM_{2.5} measurements concentration
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483 after one month. Ethical approval for the study was obtained from the NHS North of
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485 Scotland Research Ethics Committee (REC reference: 14/NS/0030; Protocol number:
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487 2/012/14; IRAS project ID: 150095).
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491 1.2. *Lanarkshire FSP Intervention*

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493 Project home visits were built into the existing FS programme of weekly contacts with
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495 clients. Full engagement over the 6-month period involved nine visits where study
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497 materials were used. Figure 1 shows the overall research design. In summary, both
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505 groups had PM_{2.5} measurements made in their homes at three time points: baseline, one-
506 month after they received the intervention and then at approximately six months post
507 intervention. Group A participants received standard UK National Health Service (NHS)
508 advice on the harmful effects of SHS delivered as ‘very brief advice’ similar to that
509 recommended by the UK National Centre for Smoking Cessation and Training, after the
510 baseline measurement (visit 3 – week 3) and again at follow-up (visit 6 – approximately
511 week 9). Group B participants received this same standard NHS SHS advice but
512 additionally received personalised air-quality feedback at the baseline measurement and
513 follow-up visits. FSP

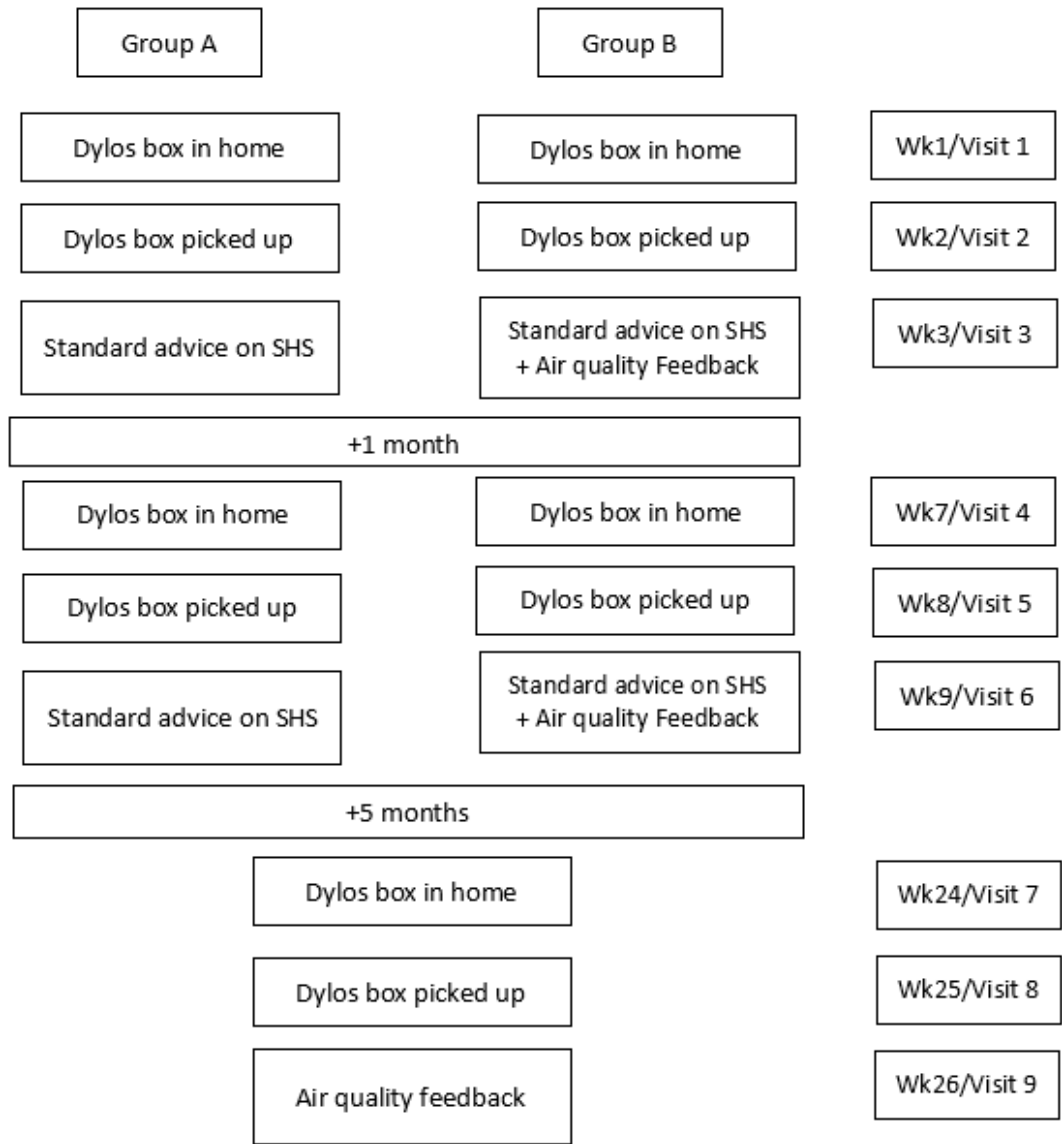
514 Feedback of personalised air-quality measurements involved 1-to-1 discussion between
515 the FSP worker and mother using a simple 4-page pamphlet which included: their air-
516 quality feedback graph showing temporal changes in PM_{2.5} concentrations over the
517 measurement period; summary quantitative information on the air-quality measurements
518 in their home; information on the effects of SHS; and practical advice on how to reduce
519 SHS. The feedback included information on the proportion of time when household
520 PM_{2.5} concentrations exceeded the World Health Organisation (WHO) guidance value of
521 25µg/m³ as a health-based air quality benchmark [24]. The air quality feedback pamphlet
522 was produced by the FSP administrator and provided to the participant usually within one
523 week of the measurements having taken place. Feedback was provided to Group B at
524 visit 3 (week 3 after recruitment), again at visit 6 (approximately week 9), and finally at
525 visit 9 (approximately week 26). Group A received all their air quality feedback only on
526 conclusion of their involvement, at visit 9 (week 26).

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563 is an early intervention programme provided by the National Health Service in
564 Lanarkshire, Scotland. FSP provides vulnerable first-time mums with intensive, free,
565 one-to-one support during and after pregnancy to give their babies the best possible start
566 in life. Support includes considering the child's exposure to SHS and where appropriate
567 exploring options to reduce this. Over 30% of mothers involved in the programme are
568 smokers with 48% of homes having one or more smoking adult resident.
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578 1.3. Training

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580 Seventeen FSP workers who delivered the intervention received a half-day training
581 course which included: Good Clinical Practice; the health effects of SHS; the recruitment
582 process; using the Air Quality Monitor; and how to discuss the measurements with
583 mothers to encourage them to make their homes smoke-free. The FSP administrator (TH)
584 was trained in downloading data from air-quality instruments and preparing personalised
585 feedback graphs using Microsoft Excel.
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Figure 1: Overall research design. Each participant received nine visits over a 26-week period. [Group A = standard care; Group B = standard care plus air quality feedback]



1.4. *PM_{2.5} measurements*

A Dylos DC1700 Air Quality Monitor (Dylos Inc, CA, USA) was installed in the main living-room of participants' homes to measure PM_{2.5} in the home for 3-7 days on three occasions (baseline, +1 month post-intervention, +6 months post-intervention). The living-room was selected as the area of the home where the family will spend most of their waking hours within the home setting. There is also recent evidence that living-room and child's bedroom concentrations of air nicotine are well correlated [25]. The Dylos is a low-cost instrument that has been utilised by several research groups to provide real-time data on PM_{2.5} as a proxy for SHS concentrations-[19,264]. It is a simple laser-based particle counter that has been shown to provide data on SHS aerosol that is broadly comparable with data provided by 'gold-standard' optical particle counting instruments-[275]. It costs approximately £300 (US \$400); has near-silent operation and is simple to install and activate to logging mode with a single press of one button.

1.5. ~~SHS feedback~~

~~Feedback of personalised air-quality measurements involved 1-to-1 discussion between the FSP worker and mother using a simple 4-page pamphlet which included: their air-quality feedback graph showing temporal changes in PM_{2.5} concentrations over the measurement period; summary quantitative information on the air-quality measurements in their home; information on the effects of SHS; and practical advice on how to reduce SHS. This pamphlet was produced by the FSP administrator and provided to the participant usually within one week of the measurements having taken place.~~

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733 *4.6.1.5. Power calculation and sample size*
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735 Using air-quality at 1-month as our primary outcome measure the study was powered
736 (>80% power with alpha level of 0.05) to detect a difference of at least 30% between
737 groups. To achieve this power we sought to recruit 120 participants to have
740 approximately 50 participants in each arm at the 1-month follow-up stage.
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746 *4.7.1.6. Analysis*
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748 The data from each instrument was downloaded using proprietary software (Dylos
749 Logger (v1.6) and exported to Microsoft Excel to allow temporal analysis and production
750 of graphical feedback. Particle number concentrations were converted to mass
751 concentrations using a previously validated method-[275]. For each sampling period in
752 each household a customized Excel spreadsheet was used to produce summary statistics
753 of PM_{2.5} concentrations including the mean, the peak value, and the percentage of
754 measurement time the instrument recorded values above thresholds. Differences in
755 characteristics between groups and between baseline and follow-up PM_{2.5} mean
756 concentrations were analysed using IBM SPSS (v23) using Student's t-tests for
757 continuous variables and Pearson's Chi Square for categorial variables. Statistical
758 significance was set at p<0.05.
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787 **2. Results**
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789 *2.1. Recruitment*
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791 Recruitment took place between June 2014 and February 2016. 171 mothers enrolled in
792 the FSP were invited to take part, of which 120 agreed (response rate 70.2%). Of these,
793 117 completed baseline measurements, 59 in Group A and 58 in Group B. 102 completed
794 the 1-month follow-up with 78 completing the 6-month stage. Characteristics of the
795 participants are provided in Table 1. Reflecting the population of young, vulnerable
796 mothers that this cohort was drawn from, participants' median and Inter-Quartile Range
797 (IQR) age was 21 (19-23) with 54% of participants living in areas in the bottom 20% in
798 the Scottish Index of Multiple Deprivation (SIMD). Approximately two-thirds (69%)
799 were smokers and three-quarters lived in a flat or tenement (72%), with 1 in 3 reporting
800 no access to private or shared garden space (33%). The only statistical difference between
801 the two groups was that participants in the standard care group (A) were more likely to be
802 pregnant at the time of recruitment.
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Table 1: Characteristics of study participants [Group A = standard care; Group B = standard care plus air quality feedback]

	Overall	Group A	Group B	p value
Number of participants	117	59	58	
Age: mean (range) in years	21.6 (17-43)	21.4 (17-38)	21.7 (17-43)	p=0.666
SIMD#: mean (range)	2.8 (1-10)	2.7 (1-7)	3.0 (1-10)	p=0.449
Smokers	81 (69%)	36 (61%)	45 (76%)	p=0.071
Pregnant	29%	37%	21%	p=0.048
Garden space available	67%	75%	64%	p=0.106
Self-report smoke-free home at baseline	27%	23%	32%	p=0.270
Baseline measurement duration: mean (range) in minutes	7890 (2213-9056)	7956 (2213-9056)	7824 (2237-9056)	p=0.709
Baseline PM _{2.5} average: mean (range) in µg/m ³	67.5 (4.5-424)	73.4 (4.5-424)	61.4 (5.1-295)	p=0.418
Baseline PM _{2.5} peak [^] : mean (range) in µg/m ³	547 (48.3-1126)	558 (48.3-1105)	537 (63-1126)	p=0.678
Baseline PM _{2.5} % time >25 µg/m ³ : mean (range)*	40.0 (1-100)	39.0 (1-100)	38.9 (1-100)	p=0.984

The Scottish Index for Multiple Deprivation decile (A score of 1 is the 10% most deprived; 10 is the 10% most affluent)

[^] The peak exposure refers to the highest 1-minute concentration recorded in the home.

* The 25 µg/m³ threshold is used as a marker of the proportion of time where the household PM_{2.5} concentration exceeded the World Health Organisation 24h guidance value [246] for fine particulate pollution.

2.2. Air quality results

A total of 2,278,614 minutes of valid air-quality data was obtained from 297 visits to participants' homes. Table 1 provides a breakdown of household PM_{2.5} measurements made at baseline including the household average, peak and percentage of time measurements were above the WHO 24-hour guidance value (25 µg/m³)[246].

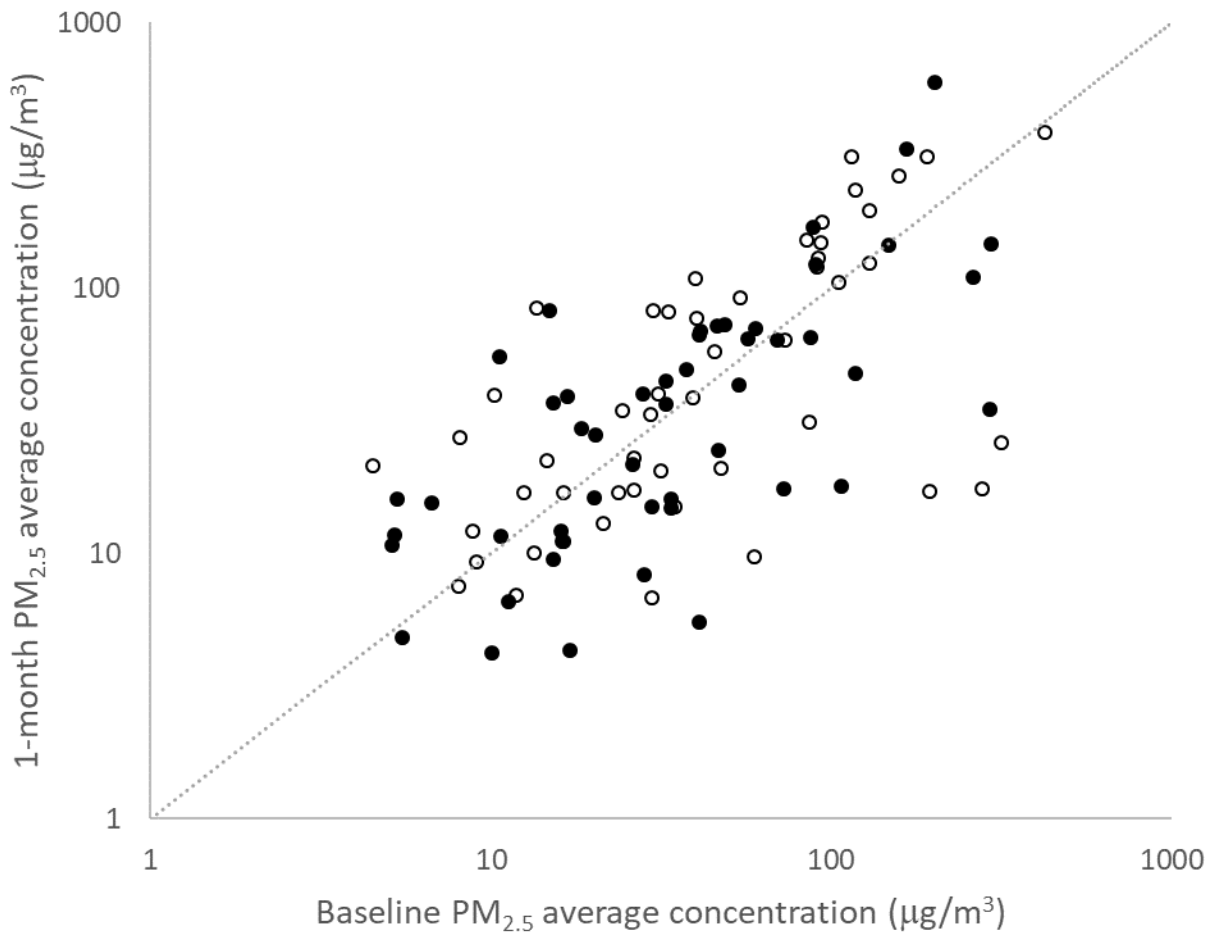
After excluding participants who did not complete the 1-month follow up or for whom the measurement duration at the follow-up visit was <24 hours (n=2 at 1-month; n=1 at 6-months) the median (95% Confidence Interval)IQR difference between 1-month and baseline PM_{2.5} measurements for Group A (n=50) was +3.8 (-16.439 to 28.8-8.4); Group B (n=50) was 10.1 (-22.3 to 11.8 24.5, -14.7) µg/m³ (p=0.76 for comparison). Similar results were found for comparison between the 6-month and baseline PM_{2.5} measurements, with Group A (n=40) -1.7 (-18.3 to 4.5 26.5, 8.8); Group B (n=37) -1.0 (-8.1 to 21.2 11.4, -16.2) µg/m³ (p=0.16). A similar pattern was found when the change was expressed as a percentage change relative to the baseline measurement to account for the variation in measured concentrations at baseline. Table 2 provides these data in summary form. Figure 2 illustrates this change by paired measurements for each home with each data point providing the baseline and 1-month follow-up average PM_{2.5} concentrations measured.

Table 2: Change in PM_{2.5} between baseline and +1 and +6 month follow-up. Expressed as an absolute change and as a percentage of the baseline measurement. [Group A = standard care; Group B = standard care plus air quality feedback]

Allocation group	Baseline to +1 month change		Baseline to +6 months change	
	A	B	A	B
Number of participants	50	50	40	37
Change in average PM _{2.5} µg/m ³ : median and 95% Confidence Interval	+3.8 (-16.4 to 28.8)	+1.1 (-22.3 to 24.5)	-1.7 (-18.3 to 4.5)	-1.0 (-8.1 to 11.4)
Change in average PM _{2.5} as a percentage of baseline measurement: median and 95%	+20% (-6 to 43)	+3% (-24 to 36)	-8% (-34 to 13)	-6% (-27 to 40)

Confidence Interval				
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Figure 2: Scatterplot illustrating the paired PM_{2.5} average values from each home measured at baseline and then again at +1 month, divided by allocation group (A group = clear circles; B group = black circles). The black 1:1 line represents zero change; points to the left of the line indicate an increase in SHS levels after 1 month and points to the right of the line indicate homes that had reduced SHS levels after 1 month.



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1011 The baseline PM_{2.5} concentrations from homes where the participants self-reported
1012 having a smoke-free home at baseline (i.e. responded positively to the statement that
1013 ‘Smoking is not allowed inside your home’) (n=31) was found to be significantly lower
1014 than those who confirmed smoking (n=82) was allowed in the home. The median and
1015 (95% CI) value was 14.9 (10.7-20.8) compared to 48.2 (39.3-75.3) µg/m³. Analysis was
1016 also carried out after excluding these 31 self-reported smoke-free homes (at baseline) but
1017 the lack of significant change and similarity in response between the intervention groups
1018 was maintained.
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1031 2.3. *Self-reported changes in household smoking*

1032 Questionnaires were completed by 114 participants at baseline; 95 at 1-month and 72 at
1033 6-month stages. Not all participants provided a response to all questions. At 1-month
1034 10/47 Group A participants reported becoming a ‘smoke-free’ home compared to 12/45
1035 in Group B (Pearson’s Chi-square = 0.205). Similar changes were noted at 1-month in
1036 self-reported quitting (4 from Group A and 2 from Group B) or self-reported reduction in
1037 smoking (6 from Group A and 10 from Group B). At 1-month, reported smoking by the
1038 participant ‘in the presence of children inside the home’ was reduced for 5/46 participants
1039 in Group A and 5/47 in Group B (none reported smoking ‘more than before’) (p=0.284).
1040 Similarly, 8/44 (Group A) and 7/48 (Group B) participants reported other smoking adults
1041 in the home ‘smoking less than before’ in the presence of children at 1-month follow-up
1042 (p=0.307).
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1067 **3. Discussion**
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1069 This study is the first to trial the use of air-quality feedback as an intervention to
1070 encourage smoke-free homes delivered in a real-world setting as part of health
1071 professionals' routine work with smoking clients. The study demonstrated that
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1073 measurement of household air quality and personalised feedback of results to a group of
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1075 disadvantaged mothers of young children was achievable at scale and could be
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1077 incorporated by health professionals within existing health care services provided to
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1079 parents. Recruitment was high with over 70% of eligible mothers agreeing to participate
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1081 in the study, indicating a high level of interest in receiving this type of individual data
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1083 about SHS concentrations in the home. Follow-up participation was also good with over
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1085 87% of those who completed the baseline measurements taking part at 1-month, and 67%
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1087 at 6-month follow-up. However, this adequately powered RCT using an objective
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1089 measurement of smoke-free status (PM_{2.5}) found that home SHS levels did not change in
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1091 either arm of the trial. Whilst PM_{2.5} feedback has proven effective in reducing household
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1093 SHS concentrations after selection from the general population, this study indicates that
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1095 different strategies may be required for vulnerable families such as those included in this
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1097 trial.
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1105 The practicalities of delivering the intervention generally worked well despite the
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1107 complexities of: installing the device three times per household; collecting one-week
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1109 later; having the data downloaded and the feedback pamphlet generated centrally by one
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1111 FSP administrator; and meeting with the participant as soon as possible thereafter.
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1114 Logistical difficulties highlighted by the FSP workers and administrator included: the
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length of time it took to download the data; the need to prepare hard-copies of feedback reports in colour (FSP workers did not have local printing facilities); liaison with FSP workers who had substantial caseloads and covered large geographical areas.

The pre-intervention baseline household PM_{2.5} concentrations showed broadly similar median (34 µg/m³) and IQR (16-88 µg/m³) values to those previously reported in other Scottish homes where smoking is permitted (median 31 µg/m³; IQR (10-111 µg/m³))[7]. At baseline nearly two-thirds of homes (64.1%) had average PM_{2.5} concentrations greater than the WHO guidance value for 24-hour average exposure (25 µg/m³) with 1 in 5 (20.5%) showing average values greater than 100 µg/m³. It is worth considering that these 24-hour PM_{2.5} levels would generate considerable media attention if they were present in outdoor air in urban environments. Indeed, these data suggest that fine particulate air pollution is greater than the annual average PM_{2.5} concentration in Beijing (51 µg/m³)[287] one of the most polluted cities in the world, in about one-third of the homes that took part in this study.

These results can be compared to other studies that have used personalised air quality feedback, albeit from different populations. The REFRESH study recruited 59 smoking mothers in Scotland and provided PM_{2.5} measurement data over a 24-hour period as the primary tool in a motivational interview aimed at empowering parents to make their home smoke-free [17]. That study found that mothers who received air-quality feedback reduced PM_{2.5} concentrations by approximately one-third although the study was too small to detect a difference with the control group. More recent work by Ratschen and

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1179 colleagues [18] studied a similar approach with disadvantaged smoking parents in
1180 Nottingham. That study compared a complex intervention combining personalised air
1181 quality feedback, behavioural support and nicotine replacement therapy for temporary
1182 abstinence with usual care involving standard advice. The 24h PM_{2.5} concentration in
1183 intervention homes reduced exposure about one-third at the 12-week follow-up. Hughes
1184 et al [19] have reported an intervention involving an air-quality instrument with warning
1185 lights and alarms to provide real-time feedback on particle concentrations in smokers'
1186 home. Their work showed an average reduction of approximately 19% in households
1187 receiving this feedback compared to just 6.5% reduction in control homes.
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1189 ~~From the REFRESH study [17] and more recent work in Nottingham [18] those mothers~~
1190 ~~who received personalised air-quality feedback had average reductions in household~~
1191 ~~PM_{2.5} concentrations of about 30%. The change was not statistically significant in the~~
1192 ~~REFRESH study given the small sample size and, in this respect, the present findings are~~
1193 ~~similar.~~

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1209 The reasons for the lack of change in PM_{2.5} concentrations in the current study are unclear
1210 but may involve the disadvantages experienced by this group and include the dual
1211 barriers of a lack of opportunity to make changes and lack of support from other smoking
1212 adults. Qualitative interviews carried out with a selection of study participants [298]
1213 demonstrated that the intervention increased mothers' capability to change smoking
1214 behavior in the home, through better awareness of the risks to their children from SHS
1215 exposure. However, taking significant action was often constrained by their limited, and
1216 often changing, social and environmental opportunities, including smoking of other
1217 adults in the home setting. Recent work on the barriers, motivators and enablers to
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1235 creating a smoke-free home have shown the complex interplay that exists in many homes
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1237 can make the process difficult [\[3029-310\]](#).
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1242 The intervention was based on review of behavioural interventions to reduce indoor
1243 smoking by parents which led to the development of the AFRESH behavior theory
1244 programme described in detail elsewhere [\[321\]](#). Review of the literature indicated that
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1246 incorporating objectively assessed feedback data and motivational interviewing appear to
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1248 be the most popular adopted intervention methods and the most effective for SHS
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1250 reduction with parents and caregivers of young children. Simply providing written
1251 information about the risks of SHS is not an effective strategy for this specific behaviour
1252 change type and instead ongoing support and interaction may play a vital role in the
1253 success of such SHS reduction interventions. The review also identified that it is
1254 necessary to strike a balance between making the intervention intensive enough to be
1255 effective but also ensuring too many sessions are not required, as the target population
1256 (often socioeconomically disadvantaged people) may find multiple session attendance
1257 problematic.
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1269 1270 1271 1272 1273 1274 1275 *3.1. Strengths and limitations*

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1278 In addition to the objective assessment of air-quality in each home, a particular strength
1279 of the study over other previous work was the duration of measurements. Air-quality data
1280 were collected for an average of 127 hours (5.3 days) during each stage in each home. In
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1291 addition to the potential bias from the Hawthorne effect during short measurement
1292 periods, [332], FSP workers reported that household activity (number of adults, number
1293 of cigarettes smoked, hours spent indoors etc.) was often highly variable due to complex
1294 issues around substance misuse, unemployment and changing relationships. There is
1295 significant potential to misclassify household concentrations of SHS through the use of
1296 snapshot or even 24h measurement of PM_{2.5} and longer duration measurement reduces
1297 the chance of people changing their behaviour whilst measurements are being made.

1300 Gathering data over 3-7 days is likely to have reduced these potential biases and provided
1301 a more accurate picture of SHS concentrations within each home at baseline and follow-
1302 up.
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1314 There were several limitations mostly due to the delivery challenges of real-world
1315 settings, structures and events. For example, a small number of participants moved home
1316 during the 6-months and so measurements were not always taken in the same setting.

1317 Similarly, partners or other adults living in the home sometimes changed between
1318 baseline and follow-up and so conditions were not always directly comparable. The
1319 intervention was delivered by 17 FSP workers and while all received identical training,
1320 the type of feedback and advice received by participants may have differed. The
1321 intervention was intentionally delivered as part of an existing relationship between the
1322 participant and their FSP worker, and possibly pre-existing differences in those
1323 relationships may have influenced the way the information was received and acted on.
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1347 In a few cases devices were switched off for periods of time during measurements. This
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1349 was sometimes due to interruptions in electricity supply or may have been due to
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1351 participants/others in the home deciding to switch the device off because of the desire to
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1353 prevent the device measuring high levels of SHS during smoking. However, compliance
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1355 was high with the number and duration of periods of lost data small in comparison to the
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1357 time instruments were in homes. There was no evidence that data loss was more frequent
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1359 at follow-up than baseline and so we do not think this had a significant impact on our
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1361 results.
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1367 A further limitation of the study is the use of PM_{2.5} as a marker for SHS. While this
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1369 method has been used extensively in tobacco control research as a means of quantifying
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1371 SHS concentrations,^[14-16] PM_{2.5} is not specific to tobacco smoke and can arise from
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1373 non-smoking sources such as ambient air pollution, cooking and use of solid fuels. While
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1375 it is possible that some increases of PM_{2.5} may have been due to non-smoking activity
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1377 (particularly frying of food), it is also possible that smoking may have continued in these
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1379 homes during periods when the participant was unaware of the behaviour of (other)
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1381 smoking adults. We believe that our PM_{2.5} measurements are likely to provide robust
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1383 information on household SHS data and e note data from the Scottish Government
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1385 ambient air quality monitor located in Hamilton, the administrative centre of the
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1387 Lanarkshire area, that shows low PM concentrations and no discernible seasonal variation
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1389 with monthly average PM₁₀ concentrations across 2015 ranging from 14 to 21 µg/m³
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1391 (PM_{2.5} is typically about 60% the value of PM₁₀) [34-35] and d-draw on PM_{2.5}
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1394 concentration data gathered from previous studies in Scotland that showed average
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1401 concentrations in typical smoke-free homes were 3 $\mu\text{g}/\text{m}^3$ [7] and 8-16 $\mu\text{g}/\text{m}^3$ even when
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1403 combustion sources such as coal, wood and gas were used for heating or cooking
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1406 purposes. [363]. While measurement of air nicotine would provide a tobacco-specific
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1408 method of quantifying SHS concentrations, this approach would currently not provide
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1410 time-resolved information and would require expensive (and slow) chemical laboratory
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1412 analysis: something that is likely to be a barrier to any future use of this intervention
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1414 approach. New technologies under development may provide real-time nicotine
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1416 concentrations using low-cost methods [347] or utilise data on particle size distributions
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1418 from different emission sources to differentiate SHS from other household aerosols
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concentrations in typical smoke-free homes were 3 $\mu\text{g}/\text{m}^3$ [7] and 8-16 $\mu\text{g}/\text{m}^3$ even when combustion sources such as coal, wood and gas were used for heating or cooking purposes. [363]. While measurement of air nicotine would provide a tobacco-specific method of quantifying SHS concentrations, this approach would currently not provide time-resolved information and would require expensive (and slow) chemical laboratory analysis: something that is likely to be a barrier to any future use of this intervention approach. New technologies under development may provide real-time nicotine concentrations using low-cost methods [347] or utilise data on particle size distributions from different emission sources to differentiate SHS from other household aerosols [385]. Work on using the differential response of the Dylos to fine and coarse PM to identify SHS from other aerosols may also provide a way forward in quantifying the contribution of smoking to indoor air pollution. [396].

The intervention method used delayed feedback of air quality data and provided this feedback only once at baseline and again at the one-month follow-up. It was necessary to take the device back to the office to perform the download and generation of the graphical and numerical feedback. This meant that feedback was typically provided one week after completion of the measurement period. There is evidence that rapid feedback is more effective in eliciting change in health and safety behaviors [4037] and future work should examine methods to provide more immediate feedback to those engaging in smoke-free home interventions. Providing air quality feedback on just a single occasion (prior to the follow-up assessment) may be another reason that the study showed no effect on those receiving the intervention. Work by Klepeis and colleagues has begun to explore

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1459 the use of warning lights and alarms on air quality monitors used to measure SHS [\[264\]](#).
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1462 Our group has also recently initiated a study to examine SHS concentration feedback
1463 using a Dylos connected to the internet to upload data in real-time to then provide
1464 participants with mobile phone SMS, email and telephone feedback and guidance
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1466 [ClinicalTrials.gov Identifier: NCT03151421].
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1472 It is also possible that the intervention was not sufficiently strong to change behavior in a
1473 sustained manner. There is evidence from the literature on health warnings that ‘shock’ is
1474 often short-lived and does not produce long-term changes in smoking behavior [\[4138\]](#).
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1478 This may be particularly true if there are significant barriers to enacting change and the
1479 subject has limited capacity to change: the single parent caring for a young child in a
1480 high-rise flat has fewer options in terms of modifying their smoking behavior compared
1481 to someone living with a partner in a ground floor home with access to garden space.
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1489 We also note that the current best practice of offering standard NHS advice on the health
1490 harms of SHS produced reductions in PM_{2.5} concentration in the control arm of the study.
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1493 We are not aware of any studies that have evaluated the effectiveness of ‘standard’ or
1494 ‘very brief advice’ on SHS from Health Professionals to smoking parents and recommend
1495 that future work looks at how this can be improved and better targeted to help protect
1496 children from SHS at home.
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1504 The FSP provides support to young mothers and the intervention was therefore targeted at
1505 this group despite the fact that other adults (partners, parents, visitors) may be smokers in
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1515 the home. While the intervention hoped to provide mothers with the motivation and tools
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1517 to engage with other adult smokers this is very likely to be subject to differences in
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1519 family dynamics and social circumstances. Future work should consider an ‘all
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1521 household’ approach where the intervention is delivered to all those who smoke in the
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1523 home and have an interest in the child’s health [\[4239\]](#).
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1530 3.2. Conclusions

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1532 Personalised feedback of air-quality information using low-cost devices can be
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1534 successfully integrated into routine services provided by health care providers. The
1535
1536 overall results show that, in this group of disadvantaged mothers, there was no change in
1537
1538 household SHS concentrations after delivery of the intervention. On this basis it seems
1539
1540 unlikely that personalised air-quality feedback is sufficient, in itself, to change smoking
1541
1542 behaviour in disadvantaged households in Scotland and similar countries where there is
1543
1544 already a high awareness of the risks of SHS. Providing personalised air-quality feedback
1545
1546 may not be suitable for all groups of smoking parents and may instead need to be tailored
1547
1548 to those at a more advanced stage of change in terms of household smoking rules and,
1549
1550 importantly, with the physical and social opportunities to change. Further work is
1551
1552 required to identify the types of smoking households where air-quality feedback can play
1553
1554 a role in supporting parents to protect their children from SHS. More immediate feedback
1555
1556 methods delivered to all adults in the home may be key to achieving sustained household
1557
1558 behavior change in relation to smoking.
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1571 **Competing interests**
1572

1573 None of the authors have any competing interests.
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1578

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1580
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1586 **Contribution statement**
1587

1588 SS, ST, AA, SM, SL and ROD conceived, designed the study and obtained funding. TH,
1589
1590 SM and LA managed the FSP workers and the collection of the data; TH carried out the
1591
1592 production of the air-quality feedback for each participant. SS analysed the data, wrote
1593
1594 the first draft of the manuscript and is the guarantor for this study. All authors made
1595
1596 contributions to and approved the final manuscript.
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1600

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Highlights

- Health professionals can successfully deliver personalized air quality information in home settings
- We found no evidence that air-quality feedback helps create a smoke-free home
- Finding parents for whom this intervention may work requires a targeted approach

Abstract

Objective: To determine if low-cost air-quality monitors providing personalised feedback of household second-hand smoke (SHS) concentrations plus standard health service advice on SHS were more effective than standard advice in helping parents protect their child from SHS.

Design: A randomised controlled trial of a personalised intervention delivered to disadvantaged mothers who were exposed to SHS at home. Changes in household concentrations of fine Particulate Matter (PM_{2.5}) were the primary outcome.

Methods: Air-quality monitors measured household PM_{2.5} concentrations over approximately 6 days at baseline and at one-month and six-months post-intervention. Data on smoking and smoking-rules were gathered. Participants were randomised to either Group A (standard health service advice on SHS) or Group B (standard advice plus personalised air-quality feedback). Group B participants received personalised air-quality feedback after the baseline measurement and at 1-month. Both groups received air-quality feedback at 6-months.

Results: 120 mothers were recruited of whom 117 were randomised. Follow up was completed after 1-month in 102 and at 6-months in 78 participants. There was no statistically significant reduction in PM_{2.5} concentrations by either intervention type at 1-month or 6-months, nor significant differences between the two groups at 1-month ($p=0.76$) and 6-month follow-up ($p=0.16$).

Conclusions: Neither standard advice nor standard advice plus personalised air-quality feedback were effective in reducing PM_{2.5} concentrations in deprived households where

smoking occurred. Finding ways of identifying homes where air-quality feedback can be a useful tool to change household smoking behaviour is important to ensure resources are targeted successfully.

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4 **Using air-quality feedback to encourage disadvantaged parents to create a smoke-**
5 **free home: results from a randomised controlled trial**

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59 **Abstract**
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62 **Objective:** To determine if low-cost air-quality monitors providing personalised
63 feedback of household second-hand smoke (SHS) concentrations plus standard health
64 service advice on SHS were more effective than standard advice in helping parents
65 protect their child from SHS.
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73 **Design:** A randomised controlled trial of a personalised intervention delivered to
74 disadvantaged mothers who were exposed to SHS at home. Changes in household
75 concentrations of fine Particulate Matter (PM_{2.5}) were the primary outcome.
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82 approximately 6 days at baseline and at one-month and six-months post-intervention.
83 Data on smoking and smoking-rules were gathered. Participants were randomised to
84 either Group A (standard health service advice on SHS) or Group B (standard advice plus
85 personalised air-quality feedback). Group B participants received personalised air-quality
86 feedback after the baseline measurement and at 1-month. Both groups received air-
87 quality feedback at 6-months.
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98 **Results:** 120 mothers were recruited of whom 117 were randomised. Follow up was
99 completed after 1-month in 102 and at 6-months in 78 participants. There was no
100 statistically significant reduction in PM_{2.5} concentrations by either intervention type at 1-
101 month or 6-months, nor significant differences between the two groups at 1-month
102 (p=0.76) and 6-month follow-up (p=0.16).
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117 **Conclusions:** Neither standard advice nor standard advice plus personalised air-quality
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119 feedback were effective in reducing PM_{2.5} concentrations in deprived households where
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121 smoking occurred. Finding ways of identifying homes where air-quality feedback can be
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123 a useful tool to change household smoking behaviour is important to ensure resources are
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125 targeted successfully.
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130 Keywords: Environmental Tobacco Smoke, Second-hand Smoke, Children, PM_{2.5},
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171 **1. Introduction**
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174 Second-hand tobacco smoke (SHS) is a common indoor air pollutant linked to a wide
175 range of respiratory[1-2], cardiovascular [3] and early life ill-health effects[4], with
176 exposure more common in disadvantaged households[5]. Non-smokers who live with
177 smokers can have high SHS exposures, particularly young children who spend much of
178 their day at home with a smoker[6-7]. Globally it is estimated that 40% of children
179 experience regular exposure to SHS with much of this exposure occurring in their own
180 home[8]. The global burden of this exposure is estimated to be over 600,000 deaths and
181 almost 11 million disability-adjusted life-years per year. Children are particularly
182 vulnerable to the effects of SHS exposure and suffer 28% of these deaths and 61% of this
183 morbidity[9].
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198 Enabling parents to create a smoke-free home is challenging but it is one of the key ways
199 that children's exposure to SHS can be reduced globally. Scotland is at the forefront of
200 protecting children from exposure to SHS with the Scottish Government's 'Take it Right
201 Outside' campaign including a world first: a governmental target to reduce the proportion
202 of children exposed to SHS at home by 50% (from 12% to 6%) by 2020[10]. Increased
203 adoption of smoke-free homes in low income populations has also been shown to
204 increase cessation rates and prevent relapse[11]. There is a need for good quality
205 evidence on ways to increase the proportion of smoke-free homes in different settings.
206 The most recent Cochrane review [12] of programmes to reduce children's exposure to
207 SHS screened 57 relevant studies but identified that only 6 used objective measures of
208 children's SHS exposure to evaluate intervention effectiveness. None of the included
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227 studies used air-quality feedback. A recent systematic review and meta-analysis [13]
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229 identified seven interventions designed to encourage smoke-free homes that had used
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231 objective measures of household air quality as an outcome measure. The meta-analysis
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233 indicated that these approaches generally had an impact on reducing air concentrations of
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235 fine particulate matter (PM_{2.5}) or nicotine within the household; though all studies
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237 reported evidence of continuing SHS ‘contamination’ post-intervention.
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242 Methods to measure SHS in indoor settings using airborne PM_{2.5} as a marker of SHS
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244 concentrations have been used in tobacco control science over the past decade[14-16].
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246 Several studies have explored the concept of air-quality feedback to modify smoking
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248 behaviour in the home[17-19].
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250 There are considerable challenges in rolling out this type air-quality feedback
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252 intervention at scale. The REFRESH study identified low recruitment rates (when
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254 potential participants were approached via GP letter); the high cost of available
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256 instruments and technical complexity; and the labour costs of delivering, setting up and
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258 collecting instruments from participants’ homes[20]. Recent work has identified low-cost
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260 air-quality monitoring devices that have the potential to address the practical problems of
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262 noise, cost and complexity of operation identified in previous studies[21].
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268 The aim of the study was to determine if delivery of personalised air-quality feedback
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270 plus standard advice on the health effects of SHS was more effective than standard advice
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272 on its own in encouraging changes to household smoking as measured by objective
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274 assessment of PM_{2.5} concentrations one-month later. The study was nested within the
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283 First Steps Programme (FSP) in Lanarkshire in Scotland [22], providing an opportunity
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285 to overcome many of the barriers identified in the REFRESH study [23] in terms of
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287 recruiting disadvantaged parents, embedding the intervention within an existing service
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289 and use of a simpler, low-cost device to deliver air quality feedback.
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339 **Methods**
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341 *1.1. Study design*
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343 This was a randomised controlled trial which compared standard advice to achieve a
344 smoke-free home against standard advice plus personalised air-quality feedback.
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347 Vulnerable mothers who smoked or lived with smokers and were engaged with the
348 Lanarkshire FSP were eligible. FSP is an early intervention programme provided by the
349 National Health Service in Lanarkshire, Scotland, providing vulnerable first-time mums
350 with intensive, free, one-to-one support during and after pregnancy to give their babies
351 the best possible start in life. Support includes considering the child's exposure to SHS
352 and where appropriate exploring options to reduce this. Over 30% of mothers involved in
353 the programme are smokers with 48% of homes having one or more smoking adult
354 resident.
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367 First Steps (FS) workers identified clients who were thought likely to have SHS exposure
368 in the home either from self-report of household smoking or observations of the presence
369 of SHS within the home. Participants were excluded from the study if they were: under
370 16; they were unable to give informed consent due to physical or mental incapacity; or
371 there was no smoker resident within the household. Information sheets were provided
372 and written informed consent gained. Participants were randomised to group A or B by a
373 member of the research team blind to the participants' details, using the ID number and
374 randomisation function in Microsoft Excel. A short baseline questionnaire was completed
375 to determine self-reported current smoking, household smoking rules and attitudes
376 towards smoking.
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397 Questionnaires assessed changes in smoking, household rules and quit attempts at the 1-
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399 and 6-month follow-ups. All study participants received a £10 shopping voucher on
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401 completing the baseline and a further £20 on completion of the 6-month follow-up visit.
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403 The primary outcome was change in the household PM_{2.5} concentration after one month.
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405 Ethical approval for the study was obtained from the NHS North of Scotland Research
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407 Ethics Committee (REC reference: 14/NS/0030; Protocol number: 2/012/14; IRAS
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409 project ID: 150095).
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414 1.2. *Intervention*

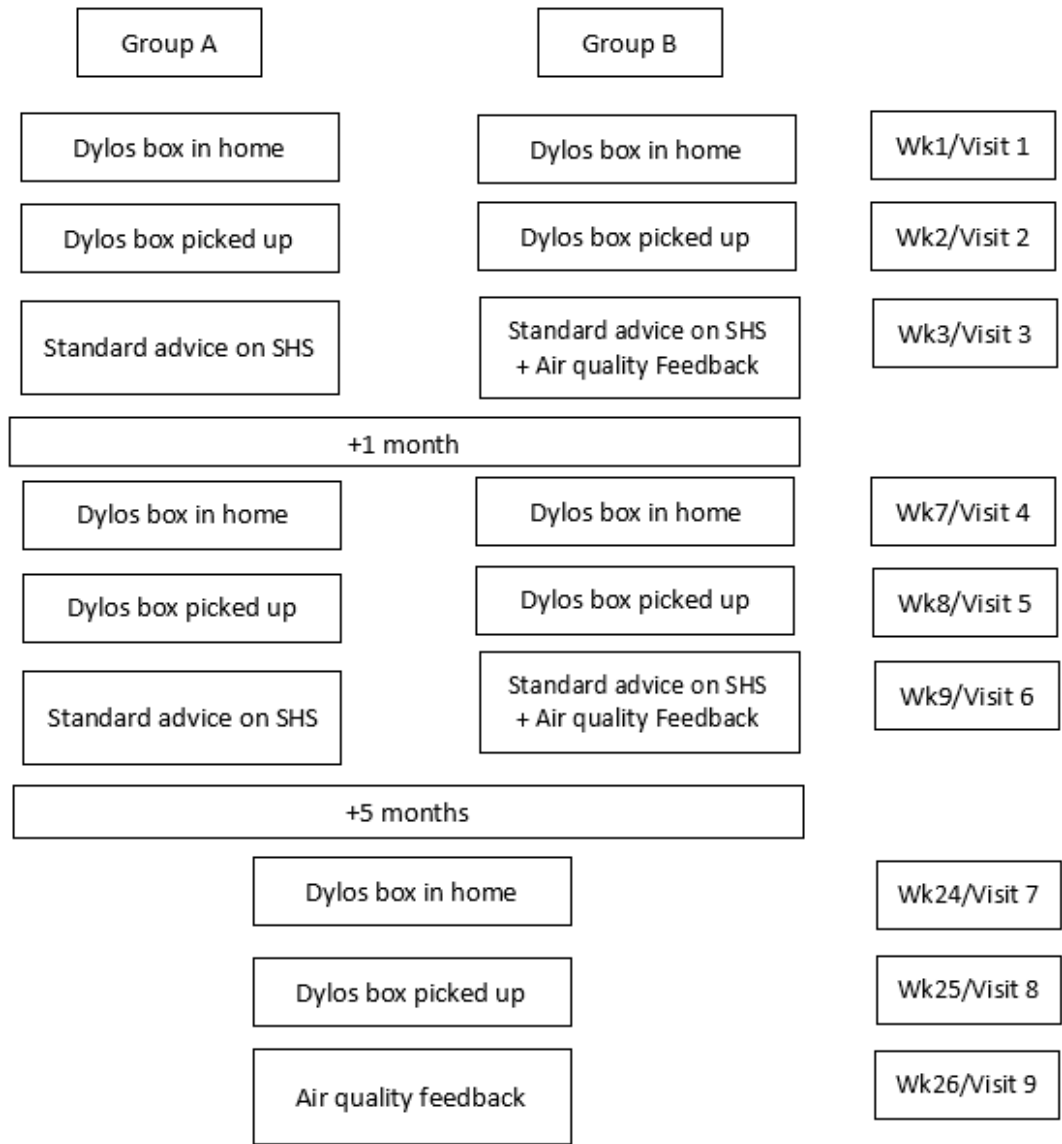
416 Project home visits were built into the existing FS programme of weekly contacts with
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418 clients. Full engagement over the 6-month period involved nine visits where study
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420 materials were used. Figure 1 shows the overall research design. In summary, both
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422 groups had PM_{2.5} measurements made in their homes at three time points: baseline, one-
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424 month after they received the intervention and then at approximately six months post
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426 intervention. Group A participants received standard UK National Health Service (NHS)
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428 advice on the harmful effects of SHS delivered as ‘very brief advice’ similar to that
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430 recommended by the UK National Centre for Smoking Cessation and Training, after the
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432 baseline measurement (visit 3 – week 3) and again at follow-up (visit 6 – approximately
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434 week 9). Group B participants received this same standard NHS SHS advice but
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436 additionally received personalised air-quality feedback at the baseline measurement and
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438 follow-up visits.
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451 Feedback of personalised air-quality measurements involved 1-to-1 discussion between
452 the FSP worker and mother using a simple 4-page pamphlet which included: their air-
453 quality feedback graph showing temporal changes in PM_{2.5} concentrations over the
454 measurement period; summary quantitative information on the air-quality measurements
455 in their home; information on the effects of SHS; and practical advice on how to reduce
456 SHS. The feedback included information on the proportion of time when household
457 PM_{2.5} concentrations exceeded the World Health Organisation (WHO) guidance value of
458 25µg/m³ as a health-based air quality benchmark [24]. The air quality feedback pamphlet
459 was produced by the FSP administrator and provided to the participant usually within one
460 week of the measurements having taken place. Feedback was provided to Group B at
461 visit 3 (week 3 after recruitment), again at visit 6 (approximately week 9), and finally at
462 visit 9 (approximately week 26). Group A received all their air quality feedback only on
463 conclusion of their involvement, at visit 9 (week 26).
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481 *1.3. Training*

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483 Seventeen FSP workers who delivered the intervention received a half-day training
484 course which included: Good Clinical Practice; the health effects of SHS; the recruitment
485 process; using the Air Quality Monitor; and how to discuss the measurements with
486 mothers to encourage them to make their homes smoke-free. The FSP administrator (TH)
487 was trained in downloading data from air-quality instruments and preparing personalised
488 feedback graphs using Microsoft Excel.
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Figure 1: Overall research design. Each participant received nine visits over a 26-week period. [Group A = standard care; Group B = standard care plus air quality feedback]



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563 *1.4. PM_{2.5} measurements*
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565 A Dylos DC1700 Air Quality Monitor (Dylos Inc, CA, USA) was installed in the main
566 living-room of participants' homes to measure PM_{2.5} in the home for 3-7 days on three
567 occasions (baseline, +1 month post-intervention, +6 months post-intervention). The
568 living-room was selected as the area of the home where the family will spend most of
569 their waking hours within the home setting. There is also recent evidence that living-
570 room and child's bedroom concentrations of air nicotine are well correlated [25]. The
571 Dylos is a low-cost instrument that has been utilised by several research groups to
572 provide real-time data on PM_{2.5} as a proxy for SHS concentrations[19,26]. It is a simple
573 laser-based particle counter that has been shown to provide data on SHS aerosol that is
574 broadly comparable with data provided by 'gold-standard' optical particle counting
575 instruments[27]. It costs approximately £300 (US \$400); has near-silent operation and is
576 simple to install and activate to logging mode with a single press of one button.
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593 *1.5. Power calculation and sample size*
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595 Using air-quality at 1-month as our primary outcome measure the study was powered
596 (>80% power with alpha level of 0.05) to detect a difference of at least 30% between
597 groups. To achieve this power we sought to recruit 120 participants to have
598 approximately 50 participants in each arm at the 1-month follow-up stage.
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606 *1.6. Analysis*
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608 The data from each instrument was downloaded using proprietary software (Dylos
609 Logger (v1.6) and exported to Microsoft Excel to allow temporal analysis and production
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619 of graphical feedback. Particle number concentrations were converted to mass
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621 concentrations using a previously validated method[27]. For each sampling period in
622
623 each household a customized Excel spreadsheet was used to produce summary statistics
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625 of PM_{2.5} concentrations including the mean, the peak value, and the percentage of
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627 measurement time the instrument recorded values above thresholds. Differences in
628
629 characteristics between groups and between baseline and follow-up PM_{2.5} mean
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631 concentrations were analysed using IBM SPSS (v23) using Student's t-tests for
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633 continuous variables and Pearson's Chi Square for categorial variables. Statistical
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635 significance was set at p<0.05.
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675 **2. Results**
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677 *2.1. Recruitment*
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679 Recruitment took place between June 2014 and February 2016. 171 mothers enrolled in
680 the FSP were invited to take part, of which 120 agreed (response rate 70.2%). Of these,
681 117 completed baseline measurements, 59 in Group A and 58 in Group B. 102 completed
682 the 1-month follow-up with 78 completing the 6-month stage. Characteristics of the
683 participants are provided in Table 1. Reflecting the population of young, vulnerable
684 mothers that this cohort was drawn from, participants' median and Inter-Quartile Range
685 (IQR) age was 21 (19-23) with 54% of participants living in areas in the bottom 20% in
686 the Scottish Index of Multiple Deprivation (SIMD). Approximately two-thirds (69%)
687 were smokers and three-quarters lived in a flat or tenement (72%), with 1 in 3 reporting
688 no access to private or shared garden space (33%). The only statistical difference between
689 the two groups was that participants in the standard care group (A) were more likely to be
690 pregnant at the time of recruitment.
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Table 1: Characteristics of study participants [Group A = standard care; Group B = standard care plus air quality feedback]

	Overall	Group A	Group B	p value
Number of participants	117	59	58	
Age: mean (range) in years	21.6 (17-43)	21.4 (17-38)	21.7 (17-43)	0.666
SIMD#: mean (range)	2.8 (1-10)	2.7 (1-7)	3.0 (1-10)	0.449
Smokers	81 (69%)	36 (61%)	45 (76%)	0.071
Pregnant	29%	37%	21%	0.048
Garden space available	67%	75%	64%	0.106
Self-report smoke-free home at baseline	27%	23%	32%	0.270
Baseline measurement duration: mean (range) in minutes	7890 (2213-9056)	7956 (2213-9056)	7824 (2237-9056)	0.709
Baseline PM _{2.5} average: mean (range) in µg/m ³	67.5 (4.5-424)	73.4 (4.5-424)	61.4 (5.1-295)	0.418
Baseline PM _{2.5} peak [^] : mean (range) in µg/m ³	547 (48.3-1126)	558 (48.3-1105)	537 (63-1126)	0.678
Baseline PM _{2.5} % time >25 µg/m ³ : mean (range)*	40.0 (1-100)	39.0 (1-100)	38.9 (1-100)	0.984

[#] The Scottish Index for Multiple Deprivation decile (A score of 1 is the 10% most deprived; 10 is the 10% most affluent)

[^] The peak exposure refers to the highest 1-minute concentration recorded in the home.

* The 25 µg/m³ threshold is used as a marker of the proportion of time where the household PM_{2.5} concentration exceeded the World Health Organisation 24h guidance value [24] for fine particulate pollution.

2.2. Air quality results

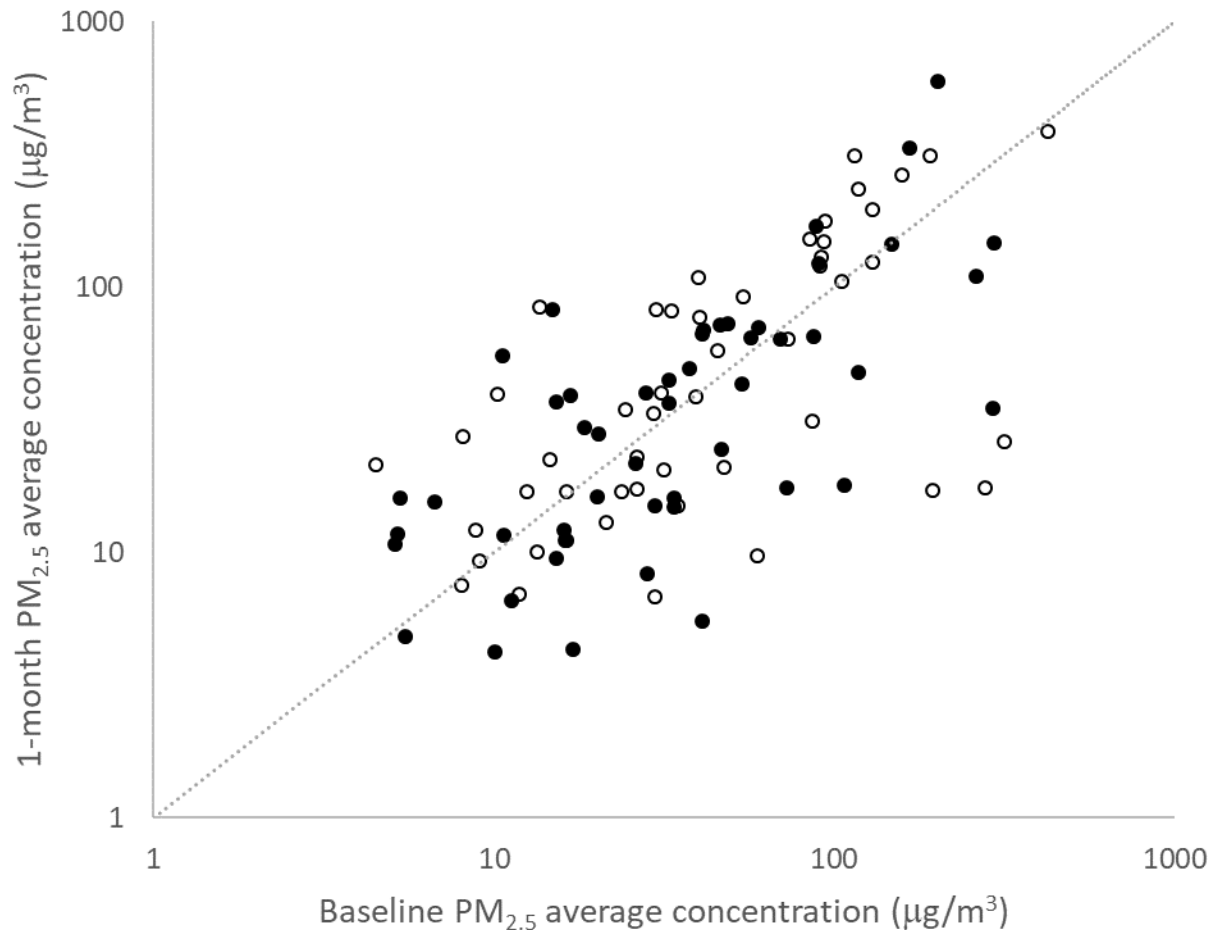
A total of 2,278,614 minutes of valid air-quality data was obtained from 297 visits to participants' homes. Table 1 provides a breakdown of household PM_{2.5} measurements made at baseline including the household average, peak and percentage of time measurements were above the WHO 24-hour guidance value (25 µg/m³)[24].

After excluding participants who did not complete the 1-month follow up or for whom the measurement duration at the follow-up visit was <24 hours (n=2 at 1-month; n=1 at 6-months) the median (95% Confidence Interval) difference between 1-month and baseline PM_{2.5} measurements for Group A (n=50) was +3.8 (-16.4 to 28.8); Group B (n=50) was 1.1 (-22.3 to 24.5) µg/m³ (p=0.76 for comparison). Similar results were found for comparison between the 6-month and baseline PM_{2.5} measurements, with Group A (n=40) -1.7 (-18.3 to 4.5); Group B (n=37) -1.0 (-8.1 to 11.4) µg/m³ (p=0.16). A similar pattern was found when the change was expressed as a percentage change relative to the baseline measurement to account for the variation in measured concentrations at baseline. Table 2 provides these data in summary form. Figure 2 illustrates this change by paired measurements for each home with each data point providing the baseline and 1-month follow-up average PM_{2.5} concentrations measured.

Table 2: Change in PM_{2.5} between baseline and +1 and +6 month follow-up. Expressed as an absolute change and as a percentage of the baseline measurement. [Group A = standard care; Group B = standard care plus air quality feedback]

Allocation group	Baseline to +1 month change		Baseline to +6 months change	
	A	B	A	B
Number of participants	50	50	40	37
Change in average PM _{2.5} µg/m ³ : median and 95% Confidence Interval	+3.8 (-16.4 to 28.8)	+1.1 (-22.3 to 24.5)	-1.7 (-18.3 to 4.5)	-1.0 (-8.1 to 11.4)
Change in average PM _{2.5} as a percentage of baseline measurement: median and 95% Confidence Interval	+20% (-6 to 43)	+3% (-24 to 36)	-8% (-34 to 13)	-6% (-27 to 40)

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848 Figure 2: Scatterplot illustrating the paired $PM_{2.5}$ average values from each home
849 measured at baseline and then again at +1 month, divided by allocation group (A group =
850 clear circles; B group = black circles). The black 1:1 line represents zero change; points
851 to the left of the line indicate an increase in SHS levels after 1 month and points to the
852 right of the line indicate homes that had reduced SHS levels after 1 month.
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889 The baseline $PM_{2.5}$ concentrations from homes where the participants self-reported
890 having a smoke-free home at baseline (i.e. responded positively to the statement that
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899 'Smoking is not allowed inside your home' (n=31) was found to be significantly lower
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901 than those who confirmed smoking (n=82) was allowed in the home. The median and
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903 (95% CI) value was 14.9 (10.7-20.8) compared to 48.2 (39.3-75.3) $\mu\text{g}/\text{m}^3$. Analysis was
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905 also carried out after excluding these 31 self-reported smoke-free homes (at baseline) but
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907 the lack of significant change and similarity in response between the intervention groups
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909 was maintained.
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914 2.3. *Self-reported changes in household smoking*

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916 Questionnaires were completed by 114 participants at baseline; 95 at 1-month and 72 at
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918 6-month stages. Not all participants provided a response to all questions. At 1-month
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920 10/47 Group A participants reported becoming a 'smoke-free' home compared to 12/45
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922 in Group B (Pearson's Chi-square = 0.205). Similar changes were noted at 1-month in
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924 self-reported quitting (4 from Group A and 2 from Group B) or self-reported reduction in
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926 smoking (6 from Group A and 10 from Group B). At 1-month, reported smoking by the
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928 participant 'in the presence of children inside the home' was reduced for 5/46 participants
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930 in Group A and 5/47 in Group B (none reported smoking 'more than before') (p=0.284).
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932 Similarly, 8/44 (Group A) and 7/48 (Group B) participants reported other smoking adults
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934 in the home 'smoking less than before' in the presence of children at 1-month follow-up
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936 (p=0.307).
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955 **3. Discussion**
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957 This study is the first to trial the use of air-quality feedback as an intervention to
958 encourage smoke-free homes delivered in a real-world setting as part of health
959 professionals' routine work with smoking clients. The study demonstrated that
960 measurement of household air quality and personalised feedback of results to a group of
961 disadvantaged mothers of young children was achievable at scale and could be
962 incorporated by health professionals within existing health care services provided to
963 parents. Recruitment was high with over 70% of eligible mothers agreeing to participate
964 in the study, indicating a high level of interest in receiving this type of individual data
965 about SHS concentrations in the home. Follow-up participation was also good with over
966 87% of those who completed the baseline measurements taking part at 1-month, and 67%
967 at 6-month follow-up. However, this adequately powered RCT using an objective
968 measurement of smoke-free status (PM_{2.5}) found that home SHS levels did not change in
969 either arm of the trial. Whilst PM_{2.5} feedback has proven effective in reducing household
970 SHS concentrations after selection from the general population, this study indicates that
971 different strategies may be required for vulnerable families such as those included in this
972 trial.
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993 The practicalities of delivering the intervention generally worked well despite the
994 complexities of: installing the device three times per household; collecting one-week
995 later; having the data downloaded and the feedback pamphlet generated centrally by one
996 FSP administrator; and meeting with the participant as soon as possible thereafter.
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1002 Logistical difficulties highlighted by the FSP workers and administrator included: the
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1011 length of time it took to download the data; the need to prepare hard-copies of feedback
1012 reports in colour (FSP workers did not have local printing facilities); liaison with FSP
1013 workers who had substantial caseloads and covered large geographical areas.
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1020 The pre-intervention baseline household PM_{2.5} concentrations showed broadly similar
1021 median (34 µg/m³) and IQR (16-88 µg/m³) values to those previously reported in other
1022 Scottish homes where smoking is permitted (median 31 µg/m³; IQR (10-111 µg/m³))[7].
1023
1024 At baseline nearly two-thirds of homes (64.1%) had average PM_{2.5} concentrations greater
1025 than the WHO guidance value for 24-hour average exposure (25 µg/m³) with 1 in 5
1026 (20.5%) showing average values greater than 100 µg/m³. It is worth considering that
1027 these 24-hour PM_{2.5} levels would generate considerable media attention if they were
1028 present in outdoor air in urban environments. Indeed, these data suggest that fine
1029 particulate air pollution is greater than the annual average PM_{2.5} concentration in Beijing
1030 (51 µg/m³)[28] one of the most polluted cities in the world, in about one-third of the
1031 homes that took part in this study.
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1046 These results can be compared to other studies that have used personalised air quality
1047 feedback, albeit from different populations. The REFRESH study recruited 59 smoking
1048 mothers in Scotland and provided PM_{2.5} measurement data over a 24-hour period as the
1049 primary tool in a motivational interview aimed at empowering parents to make their
1050 home smoke-free [17]. That study found that mothers who received air-quality feedback
1051 reduced PM_{2.5} concentrations by approximately one-third although the study was too
1052 small to detect a difference with the control group. More recent work by Ratschen and
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1067 colleagues [18] studied a similar approach with disadvantaged smoking parents in
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1069 Nottingham. That study compared a complex intervention combining personalised air
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1071 quality feedback, behavioural support and nicotine replacement therapy for temporary
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1073 abstinence with usual care involving standard advice. The 24h PM_{2.5} concentration in
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1075 intervention homes reduced exposure about one-third at the 12-week follow-up. Hughes
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1077 et al [19] have reported an intervention involving an air-quality instrument with warning
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1079 lights and alarms to provide real-time feedback on particle concentrations in smokers'
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1081 home. Their work showed an average reduction of approximately 19% in households
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1083 receiving this feedback compared to just 6.5% reduction in control homes.
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1089 The reasons for the lack of change in PM_{2.5} concentrations in the current study are unclear
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1091 but may involve the disadvantages experienced by this group and include the dual
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1093 barriers of a lack of opportunity to make changes and lack of support from other smoking
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1095 adults. Qualitative interviews carried out with a selection of study participants [29]
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1097 demonstrated that the intervention increased mothers' capability to change smoking
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1099 behavior in the home, through better awareness of the risks to their children from SHS
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1101 exposure. However, taking significant action was often constrained by their limited, and
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1103 often changing, social and environmental opportunities, including smoking of other
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1105 adults in the home setting. Recent work on the barriers, motivators and enablers to
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1107 creating a smoke-free home have shown the complex interplay that exists in many homes
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1109 can make the process difficult [30-31].
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1123 The intervention was based on review of behavioural interventions to reduce indoor
1124 smoking by parents which led to the development of the AFRESH behavior theory
1125 programme described in detail elsewhere [32]. Review of the literature indicated that
1126 incorporating objectively assessed feedback data and motivational interviewing appear to
1127 be the most popular adopted intervention methods and the most effective for SHS
1128 reduction with parents and caregivers of young children. Simply providing written
1129 information about the risks of SHS is not an effective strategy for this specific behaviour
1130 change type and instead ongoing support and interaction may play a vital role in the
1131 success of such SHS reduction interventions. The review also identified that it is
1132 necessary to strike a balance between making the intervention intensive enough to be
1133 effective but also ensuring too many sessions are not required, as the target population
1134 (often socioeconomically disadvantaged people) may find multiple session attendance
1135 problematic.

1152 3.1. *Strengths and limitations*

1153 In addition to the objective assessment of air-quality in each home, a particular strength
1154 of the study over other previous work was the duration of measurements. Air-quality data
1155 were collected for an average of 127 hours (5.3 days) during each stage in each home. In
1156 addition to the potential bias from the Hawthorne effect during short measurement
1157 periods [33], FSP workers reported that household activity (number of adults, number of
1158 cigarettes smoked, hours spent indoors etc.) was often highly variable due to complex
1159 issues around substance misuse, unemployment and changing relationships. There is
1160 significant potential to misclassify household concentrations of SHS through the use of
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1179 snapshot or even 24h measurement of PM_{2.5} and longer duration measurement reduces
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1181 the chance of people changing their behaviour whilst measurements are being made.
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1183 Gathering data over 3-7 days is likely to have reduced these potential biases and provided
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1185 a more accurate picture of SHS concentrations within each home at baseline and follow-
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1187 up.
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1192 There were several limitations mostly due to the delivery challenges of real-world
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1194 settings, structures and events. For example, a small number of participants moved home
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1196 during the 6-months and so measurements were not always taken in the same setting.
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1198 Similarly, partners or other adults living in the home sometimes changed between
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1200 baseline and follow-up and so conditions were not always directly comparable. The
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1202 intervention was delivered by 17 FSP workers and while all received identical training,
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1204 the type of feedback and advice received by participants may have differed. The
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1206 intervention was intentionally delivered as part of an existing relationship between the
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1208 participant and their FSP worker, and possibly pre-existing differences in those
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1210 relationships may have influenced the way the information was received and acted on.
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1215 In a few cases devices were switched off for periods of time during measurements. This
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1217 was sometimes due to interruptions in electricity supply or may have been due to
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1219 participants/others in the home deciding to switch the device off because of the desire to
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1221 prevent the device measuring high levels of SHS during smoking. However, compliance
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1223 was high with the number and duration of periods of lost data small in comparison to the
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1225 time instruments were in homes. There was no evidence that data loss was more frequent
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1235 at follow-up than baseline and so we do not think this had a significant impact on our
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1237 results.
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1241 A further limitation of the study is the use of PM_{2.5} as a marker for SHS. While this
1242 method has been used extensively in tobacco control research as a means of quantifying
1243 SHS concentrations[14-16], PM_{2.5} is not specific to tobacco smoke and can arise from
1244 non-smoking sources such as ambient air pollution, cooking and use of solid fuels. While
1245 it is possible that some increases of PM_{2.5} may have been due to non-smoking activity
1246 (particularly frying of food), it is also possible that smoking may have continued in these
1247 homes during periods when the participant was unaware of the behaviour of (other)
1248 smoking adults. We believe that our PM_{2.5} measurements are likely to provide robust
1249 information on household SHS data and note data from the Scottish Government ambient
1250 air quality monitor located in Hamilton, the administrative centre of the Lanarkshire area,
1251 that shows low PM concentrations and no discernible seasonal variation with monthly
1252 average PM₁₀ concentrations across 2015 ranging from 14 to 21 µg/m³ (PM_{2.5} is typically
1253 about 60% the value of PM₁₀) [34-35] and draw on PM_{2.5} concentration data gathered
1254 from previous studies in Scotland that showed average concentrations in typical smoke-
1255 free homes were 3 µg/m³ [7] and 8-16 µg/m³ even when combustion sources such as
1256 coal, wood and gas were used for heating or cooking purposes [36]. While measurement
1257 of air nicotine would provide a tobacco-specific method of quantifying SHS
1258 concentrations, this approach would currently not provide time-resolved information and
1259 would require expensive (and slow) chemical laboratory analysis: something that is likely
1260 to be a barrier to any future use of this intervention approach. New technologies under
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1291 development may provide real-time nicotine concentrations using low-cost methods [37]
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1293 or utilise data on particle size distributions from different emission sources to
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1295 differentiate SHS from other household aerosols [38]. Work on using the differential
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1297 response of the Dylos to fine and coarse PM to identify SHS from other aerosols may
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1299 also provide a way forward in quantifying the contribution of smoking to indoor air
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1301 pollution [39].
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1306 The intervention method used delayed feedback of air quality data and provided this
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1308 feedback only once at baseline and again at the one-month follow-up. It was necessary to
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1310 take the device back to the office to perform the download and generation of the
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1312 graphical and numerical feedback. This meant that feedback was typically provided one
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1314 week after completion of the measurement period. There is evidence that rapid feedback
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1316 is more effective in eliciting change in health and safety behaviors [40] and future work
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1318 should examine methods to provide more immediate feedback to those engaging in
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1320 smoke-free home interventions. Providing air quality feedback on just a single occasion
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1322 (prior to the follow-up assessment) may be another reason that the study showed no effect
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1324 on those receiving the intervention. Work by Klepeis and colleagues has begun to explore
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1326 the use of warning lights and alarms on air quality monitors used to measure SHS [26].
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1329 Our group has also recently initiated a study to examine SHS concentration feedback
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1331 using a Dylos connected to the internet to upload data in real-time to then provide
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1333 participants with mobile phone SMS, email and telephone feedback and guidance
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1335 [ClinicalTrials.gov Identifier: NCT03151421].
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1347 It is also possible that the intervention was not sufficiently strong to change behavior in a
1348 sustained manner. There is evidence from the literature on health warnings that ‘shock’ is
1349 often short-lived and does not produce long-term changes in smoking behavior [41]. This
1350 may be particularly true if there are significant barriers to enacting change and the subject
1351 has limited capacity to change: the single parent caring for a young child in a high-rise
1352 flat has fewer options in terms of modifying their smoking behavior compared to
1353 someone living with a partner in a ground floor home with access to garden space.
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1364 We also note that the current best practice of offering standard NHS advice on the health
1365 harms of SHS produced reductions in PM_{2.5} concentration in the control arm of the study.
1366 We are not aware of any studies that have evaluated the effectiveness of ‘standard’ or
1367 ‘very brief advice’ on SHS from Health Professionals to smoking parents and recommend
1368 that future work looks at how this can be improved and better targeted to help protect
1369 children from SHS at home.
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1379 The FSP provides support to young mothers and the intervention was therefore targeted at
1380 this group despite the fact that other adults (partners, parents, visitors) may be smokers in
1381 the home. While the intervention hoped to provide mothers with the motivation and tools
1382 to engage with other adult smokers this is very likely to be subject to differences in
1383 family dynamics and social circumstances. Future work should consider an ‘all
1384 household’ approach where the intervention is delivered to all those who smoke in the
1385 home and have an interest in the child’s health [42].
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1405 3.2. *Conclusions*
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1407 Personalised feedback of air-quality information using low-cost devices can be
1408 successfully integrated into routine services provided by health care providers. The
1409 overall results show that, in this group of disadvantaged mothers, there was no change in
1410 household SHS concentrations after delivery of the intervention. On this basis it seems
1411 unlikely that personalised air-quality feedback is sufficient, in itself, to change smoking
1412 behaviour in disadvantaged households in Scotland and similar countries where there is
1413 already a high awareness of the risks of SHS. Providing personalised air-quality feedback
1414 may not be suitable for all groups of smoking parents and may instead need to be tailored
1415 to those at a more advanced stage of change in terms of household smoking rules and,
1416 importantly, with the physical and social opportunities to change. Further work is
1417 required to identify the types of smoking households where air-quality feedback can play
1418 a role in supporting parents to protect their children from SHS. More immediate feedback
1419 methods delivered to all adults in the home may be key to achieving sustained household
1420 behavior change in relation to smoking.
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1459 **Competing interests**
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1461 None of the authors have any competing interests.
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1474 **Contribution statement**
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1476 SS, ST, AA, SM, SL and ROD conceived, designed the study and obtained funding. TH,
1477 SM and LA managed the FSP workers and the collection of the data; TH carried out the
1478 production of the air-quality feedback for each participant. SS analysed the data, wrote
1479 the first draft of the manuscript and is the guarantor for this study. All authors made
1480 contributions to and approved the final manuscript.
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