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ARTICLE

A qualitative process evaluation using the behaviour change wheel approach: Did a whole genome sequence report form (SRF) used to reduce nosocomial SARS-CoV-2 within UK hospitals operate as anticipated?

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Abstract

Purpose: The aim of this study was to conduct a process evaluation of a whole-genome sequence report form (SRF) used to reduce nosocomial SARS-CoV-2 through changing infection prevention and control (IPC) behaviours within the COVID-19 pandemic.

Methods: We used a three-staged design. Firstly, we described and theorized the purported content of the SRF using the behaviour change wheel (BCW). Secondly, we used inductive thematic analysis of one-to-one interviews ($n = 39$) to explore contextual accounts of using the SRF. Thirdly, further deductive analysis gauged support for the intervention working as earlier anticipated.

Results: It was possible to theorize the SRF using the BCW approach and visualize it within a simple logic model. Inductive thematic analyses identified the SRF's acceptability, ease of use and perceived effectiveness. However, major challenges to embedding it in routine practice during the unfolding COVID-19 crisis were reported. Notwithstanding this insight, deductive analysis showed support for the putative intervention functions '*Education*', '*Persuasion*' and '*Enablement*'; behaviour change techniques '1.2 *Problem*

solving', '2.6 *Biofeedback*', '2.7 *Feedback on outcomes of behaviour*' and '7.1 *Prompts and cues*'; and theoretical domains framework domains '*Knowledge*' and '*Behavioural regulation*'.

Conclusions: Our process evaluation of the SRF, using the BCW approach to describe and theorize its content, provided granular support for the SRF working to change IPC behaviours as anticipated. However, our complementary inductive thematic analysis highlighted the importance of the local context in constraining its routine use. For SRFs to reach their full potential in reducing nosocomial infections, further implementation research is needed.

KEYWORDS

behaviour change, behaviour change wheel, COVID-19, hospital, infection prevention and control, sequence report form

Statement of Contribution

What is already known on this subject?

- Health psychology remains under-used within infection prevention and control (IPC) interventions.
- For genomic insights to be understood by a range of health care professionals and elicit changes in IPC behaviour, ways of translating complex genomic insights into a simple format are needed. These simple translation tools can be described as whole genome sequence report forms (SRFs).
- Nothing is currently known about the use of SRFs, for SARS-CoV-2 or other infections, to change hospital-based IPC behaviour.
- Health psychological tools such as the behaviour change wheel (BCW), the behaviour change technique (BCT) taxonomy (BCTTv1) and the theoretical domains framework (TDF) are widely used to *develop* behaviour change interventions but are rarely used to *evaluate* them.
- Contemporary guidance on conducting process evaluations highlights the value of explicitly theorizing *how* an intervention is intended to work, before systematically examining how it actually worked in practice.

What does this study add?

- The paper presents a novel worked example of using a range of analytic techniques within a qualitative process evaluation of an SRF used during the COVID-19 pandemic in UK hospitals.
- This paper is the first to theorize the purported content of an SRF and the first to report *how* people experienced using SRFs in order to change hospital-based IPC behaviour.
- We provide qualitative evidence detailing empirical support for much of the SRF's purported content, including intervention functions such as 'Education' and 'Enablement', and for particular BCTs, '1.2 Problem solving', '2.6 Biofeedback', '2.7 Feedback on outcomes of behaviour' and '7.1 Prompts and cues', as well as causal mechanisms 'Knowledge' and 'Behavioural regulation'.

INTRODUCTION

Nosocomial infection of SARS-CoV-2, where transmission occurred within hospitals, was a major problem throughout the COVID-19 pandemic, as it presented significant health risk to both patients and health care workers (Abbas et al., 2021; Lucey et al., 2021; Oliver, 2021; Read et al., 2021), adding to the longstanding problem of health care-associated infections (HCAIs; Haque et al., 2018).

Whole-genome sequencing (WGS) can be a helpful tool used to change IPC behaviour (e.g., enhanced cleaning, patient isolation, patient movement or visitor restrictions, personal protective equipment and contract tracing). WGS typically provides retrospective insights into past infectious disease transmission routes within health care (Harris et al., 2013; Quick et al., 2016; Van El et al., 2013). Prior to COVID-19, there was growing debate about the potential of WGS for assisting with reducing HCAIs (Balloux et al., 2018; Peacock et al., 2018). However, WGS had not been used to synchronously (in real- or near real-time) to change IPC behaviour and many factors inhibited this application (Balloux et al., 2018; Parcell et al., 2021). In particular, (1) the substantial infrastructure required, (2) the political, professional and personal will to trial WGS as a tool for IPC at scale, and (3) the complexity of the insights typically delivered through WGS, which require technical and expert understanding, negatively impacting its cost-effectiveness.

The scale of the UK's response to the COVID-19 pandemic removed many of these long-standing barriers simultaneously. WGS of the SARS-CoV-2 virus became a vital global surveillance tool (e.g., identifying 'variants of concern') and introducing 'variants' into common parlance. Rapid investment across UK hospitals and laboratories also provided the necessary WGS infrastructure (Blackstone et al., 2022). Equally—unlike any other preceding time period—governments, health care professionals and researchers were all galvanized to act on WGS insights because of the gravity of the COVID pandemic and high levels of nosocomial infection, particularly early on in this pandemic. However, the necessity for expertise to interpret and understand WGS output remained problematic, and a key stumbling block for using real-time WGS to reduce nosocomial infection.

The COG-UK Hospital Onset COVID-19 Infection (HOCI) study (Blackstone et al., 2022) offered an opportunity to examine the effectiveness of rapid (<48 hr) WGS reporting to shape IPC behaviour and reduce nosocomial COVID-19 infection (Stirrup et al., 2021). For the HOCI study, a bespoke sequencing report form (SRF) was designed within a compressed time frame to translate WGS insights into actionable direction for IPC teams and assist with the UK's emergency COVID-19 response. Thus, the SRF was a WGS translation tool that indicated the likely time and location of nosocomial transmission events in order to elicit targeted changes in IPC behaviour. The SRF removed the need for experts to interpret and understand WGS outputs.

Given the SRF's rapid development in an emerging crisis of nosocomial infection, and the context of the first UK COVID-19 lockdown, there was no opportunity for early input into its development from those with training in health psychology and expertise in behaviour change theory. Nor was there a chance to engage in a process of systematic intervention development as recommended (see O'Cathain et al., 2019). For the current study, with its aim of conducting a process evaluation of the SRF as part of a larger non-randomized trial concerned with its effectiveness, this particular situation necessitated both an initial analysis of the SRF to detail its purported content (to detail how the SRF was thought to work before it was rolled out within the trial), as well as a subsequent analysis of how it had actually been used in practice during the Alpha variant wave of COVID-19 as reported by health care professionals.

Process evaluations are broadly intended to help with identifying what has worked and what has not within interventions. Various guidance exists for conducting process evaluations (Moore et al., 2015), typically stressing the centrality of *theorizing* intervention content, preferably prior to intervention rollout, then describing how interventions actually worked in practice, in addition to exploring the relevance of the intervention's context (Craig et al., 2018). However, process evaluations are more common within implementation science (Curran et al., 2013; Kislov et al., 2019; May et al., 2018) than health psychology, particularly with use of tools such as the behaviour change wheel (BCW), the behaviour change technique (BCT) taxonomy (BCTTv1) and the theoretical domains framework (TDF; Michie

et al., 2013, 2014), although there is increasing recognition of the advantages of deeper knowledge transfer between these sister disciplines (Presseau et al., 2022) and a range of designs are emerging (AUTHORS et al., 2022, 2023; Chiang et al., 2018; Moran & Gutman, 2021; Musgrave et al., 2021; Steinmo, Fuller, et al., 2015).

Our aim was to detail the content of the SRF using the BCW approach and then assess whether and how participants thought it had worked in practice. Therefore, we implemented a novel three-staged process evaluation design using the BCW and making the most of both inductive (bottom-up) and deductive (top-down) thematic analysis. Our goal was not to optimize the SRF through understanding lessons learned from its implementation (e.g., Steinmo, Michie, et al., 2015) but to assess whether and how it had worked as anticipated at a granular level. This kind of focus may be particularly useful for process evaluations of novel, or previously untheorized interventions. Although mixed methods can be used across the range of process evaluation designs, here—given our particular focus—we use qualitative data alone.

Research questions

1. Using the BCW approach to analyse the content of the SRF, what were its putative active ingredients in terms of intervention functions, BCTs and TDF domains?
2. Using inductive thematic analysis, how did participants perceive the SRF working in practice?
3. Using the BCW approach to analyse interview data of the SRF working in practice, was there evidence via deductive thematic analysis, to support the SRF working as anticipated in terms of the intervention functions, BCTs and TDF domains identified in RQ1?

METHODS

Design

A sequential three-staged qualitative process evaluation (see Figure 1 for schematic) assessing whether and how the intervention worked as anticipated: (1) Pre-trial work triangulated documentary analysis and interviews with experts to detail the purported content of the SRF using the BCW; (2) inductive thematic analysis illustrated *how* participants experienced the intervention in context; and (3) deductive analysis assessed participant accounts and qualitatively appraised if the intervention had worked as expected. Ethical approval was given by Cambridge South Research Ethics Committee (20/EE/0118).

The intervention—the sequence report form (SRF)

The SRF was designed as a pragmatic intervention to meet urgent unmet need regarding high levels of nosocomial SARS-CoV-2 infection in UK hospitals. The SRF was the end product of considerable scientific innovation and multi-staged hospital processes that included taking samples from patients, sequencing SARS-CoV-2, comparing the sequence to banks of other samples and using complex statistical analyses to generate the SRF itself (see Colton et al, 2023 and Stirrup et al., 2021 for more detail). It was only after the SRF had already been developed that the process evaluation team became involved in the project.

Figure 2 shows an example of the SRF. It is a single page providing a range of textual information, statements concerning the probability of nosocomial infection within the specified hospital unit (e.g., a particular ward), the probability within the particular hospital and as a graphical timeline contextualizing likely transmission within time and space. Critically, because of the rapidity and urgency of its development—and its anticipated use in uncertain, rapidly changing, emerging and heterogeneous contexts—the SRF was not accompanied by any pre-specified detail about *how*, *by whom* and *by which*

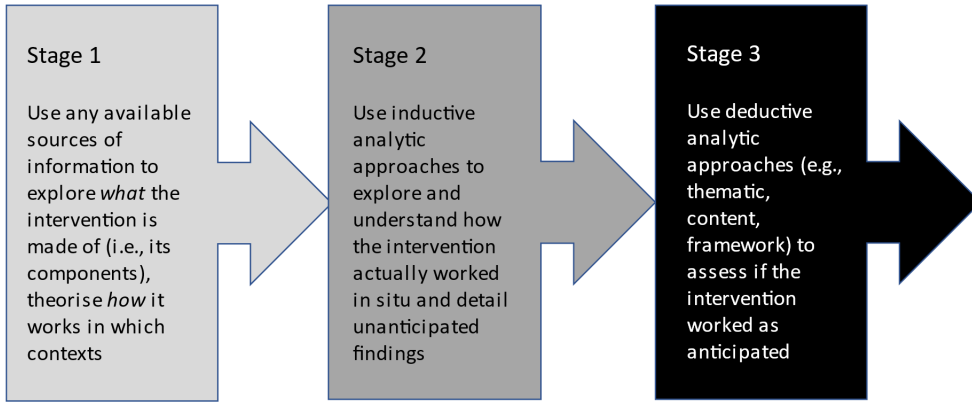

FIGURE 1 Three-staged qualitative process evaluation design.

processes, the form was intended to change IPC behaviour. In relation to the precise behaviours the SRF was intended to change, this too was unspecified during its development. However, although the trial's primary outcome was the incidence of IPC-defined SARS-CoV-2, secondary outcomes focussed on changes to IPC behaviours following receipt of the SRF. These included self-report actual changes (e.g., enhanced cleaning, visitor and staffing restrictions and provision of personal protective equipment) as well as the provision of recommendations for changes in IPC behaviour following receipt of the SRF.

Stage 1—Using the BCW approach to analyse the content of the SRF, what were its putative active ingredients in terms of intervention functions, BCTs and TDF domains?

A behavioural scientist (PF) analysed examples of SRFs (e.g., see Figure 2). This was complemented by informal interviews ($N = 9$) with a range of experts with an interest in nosocomial infections (e.g., IPC staff, virologists and microbiologists). Together, these datasets provided a rich sense of how the SRF was thought to work and which behaviours it was intended to change. To describe the intervention in highly specific ways, a series of tools associated with the behaviour change wheel (BCW) approach (Michie et al., 2011) were employed. These focussed on describing the SRF's 'intervention functions', and the specific BCTs employed using the BCTTv1 (Michie et al., 2013). Furthermore, the SRF was also analysed using the TDF (Cane et al., 2012) to detail its putative theoretical mechanisms. This analysis of the SRF categorized its content as either having a major or minor role. Major roles were those that the team considered most explicit and clearly obvious. Minor roles were those which were more implicit, less obvious and had a secondary aspect. PFs initial analysis was audited by FM and discussed with the wider interdisciplinary team. This methodological approach to describing existing intervention content using the BCW is relatively commonplace (e.g., Steinmo, Fuller, et al., 2015; Younas & Gutman, 2022).

Stage 2—Using inductive thematic analysis, how did participants perceive the SRF working in practice?

Participants

From 14 total study sites, a purposive sample of five focal sites was selected for in-depth data collection. To show heterogeneity of experience with the SRF, sites were selected to be varied in relation

COG-UK HOCI Summary Report

Focus sample — UID0009

Report date	29-Oct-2020	Unit	Unit_93
Sample ID	-	Previous unit(s)	
Sample date	12-May-2020	Hospital	Hospital_5
COG-UK HOCI ID	-	Reporting hub	-
COG-UK ID	UID0009	Reported by	-
Admission date	21-Apr-2020	Symptomatic	Yes; onset date unknown

Report

Lineage: B.1.p73

Focus patient's sample sequence is closely matched to samples below, possibly linked by transmission.

⚠️ Infection within unit is very highly probable* ⚠️

Number	Sample ID	COG-UK ID	Other unit(s)	Sample date	Admission date	Type
1	-	UID0006	-	09-May-2020	30-Apr-2020	Patient
2	-	UID0018	-	09-May-2020	28-Apr-2020	Patient
3	-	UID0017	-	08-May-2020	01-May-2020	Patient
4	-	UID0022	-	12-May-2020	11-Apr-2020	Patient
5	-	UID0021	-	09-May-2020	01-May-2020	Patient
6	-	UID0032	-	05-May-2020	27-Apr-2020	Patient

Infection within hospital has low probability

Number	Sample ID	COG-UK ID	Unit	Other unit(s)	Sample date	Admission date	Type
7	-	UID0025	Unit_92	-	08-May-2020	04-May-2020	Patient
8	-	UID0193	-	-	24-Apr-2020	-	Patient
9	-	UID0194	-	-	26-Apr-2020	-	Patient

Please check IPC data, and PATIENT and HCW movement, particularly for the 10-14 days preceding the date of the focus patient's sample.

- Infection from a visitor has low probability* (visitors not allowed on unit)
- Community-acquired infection has low probability*

** likelihood of transmission risk: 0-30% low ; 30-50% moderately low; 50-70% probable; 70-85% high; 85-100% very high*

Timeline

Generated on: 29-Oct-2020
GLUE version: 1.1.103
CoV-GLUE version: 0.1.13
COG-UK version: 0.1.6
HOCI version: 0.1.10
Author: Josh Singer <josh.singer@glasgow.ac.uk>

FIGURE 2 Example of the SRF.

to prior case rates, hospital size, familiarity with sequencing and geography. Data collection started after the SRF had been used for at least 14 days within the rapid phase of WGS—where the target turnaround time for output was within 48 hr. Within each site, a senior member of staff involved in

the study approached a broad range of professionals engaged in the use and implementation of WGS. Those interested in participating were sent participant information sheets. A mutually convenient time was arranged, and interviews were conducted using online meeting platforms. One researcher (FM) conducted all interviews.

Within each of the selected sites, a sample of between six and nine participants took part. The final sample comprised 39 participants, 27 identified as female (69%) and 12 as male (31%), with an age range of 20–70. Participants' roles within the study varied and were not limited to those who directly used the SRF to change IPC behaviour (e.g., clinical fellow, sequencing laboratory manager, bioinformatician and research nurse). This was important, as implementing the SRF could involve a complex chain of professionals; the details of *how*, *by whom* and *by which processes* the SRF was intended to change IPC behaviour were not pre-specified because the intervention needed to work within the labile pandemic context, as well as in inherently heterogeneous hospital systems.

Procedure

Data collection occurred across the peak and decline of the Alpha variant (23.12.2020–02.06.2021). One-to-one, semi-structured interviews (30–90 min) followed a topic guide exploring participants' thoughts and experiences of the SRF. The topic guide was not focussed directly on discussing the results of the analysis in Stage 1 (RQ1) but instead wholistically explored participants' context-bound experiences of the SRF within their hospital, and their perspectives of the teams and various individuals involved—in addition to the wider context of COVID-19 and the demands of the trial itself. Interviews were audio-recorded, transcribed by a professional transcribing company and anonymized.

Analysis

PF and FM engaged in multiple data readings and discussions and then developed an initial coding frame containing broad categories of data, some of which were pre-specified (i.e., 'participant perspectives on the SRF'). Transcripts were then chunked using this broad coding frame by a wider team of five researchers including PF, JM and FM—responsible for one site each. Combined data from each site were then collated, and inductive analyses were conducted (led by PF) of the 'participants' perspectives on the SRF' (RQ2). This simple atheoretical approach to process evaluation remains relatively commonplace (e.g., Jakubowski et al., 2022; Pichon et al., 2022).

Stage 3—Using the BCW approach, was there evidence via deductive thematic analysis, to support the SRF working as anticipated in terms of the intervention functions, BCTs and TDF domains identified in RQ1?

We conducted a further BCW analysis, systematically mapping interview data to the putative intervention function, BCT and TDF content of the SRF identified in Stage 1. This analysis was independent of Stage 2. This deductive analysis categorized the relative level of support for the putative behaviour change content of the SRF within the qualitative data as either 'strong', 'weak', 'nuanced' or 'no support'. Relative support was gauged primarily by frequency of data occurrence, both across the interviews as a whole, and within each participant's account. Beyond frequency, relative support was assessed by the pragmatic importance of the finding, and the temporal and historical context of the data (e.g., in relation to the peak of the Alpha variant). Iterative discussion within the research team finalized the agreed level of support. This analysis was led by RL. This approach to process evaluation, assessing relative support for purported intervention content at a granular level, is uncommon.

RESULTS

RQ1—Using the BCW approach to analyse the content of the SRF, what were its putative active ingredients in terms of intervention functions, BCTs and TDF domains?

We described the purported content of the SRF using tools from the BCW approach. Figure 3 provides a logic model incorporating the BCW elements we identified. On the left, we show key elements of the context that were important. On the right, we show the intervention outcomes. Further narrative detail of this analysis is provided in the tables addressing RQ3 below.

RQ2—Using inductive thematic analysis, how did participants perceive the SRF working in practice?

Here, we present a narrative account reflecting our inductive thematic analysis. This provides a contextualized account within which to consider the subsequent RQ3 analyses. Despite the challenging backdrop of the COVID-19 pandemic, most participants shared the view that the SRF was acceptable, beneficial and useful. Largely positive accounts of the SRF spanned three themes: its ease of understanding; its perceived efficacy and perceived impact on IPC behaviours; and issues of assimilation into existing work.

Ease of understanding

Participants mostly supported the SRF enabling the easy understanding of insights from WGS. Participants described the SRF's succinct and straightforward content as facilitating rapid action 'at a glance' (*Site 2*). This sense of simplicity was often framed by implicit comparisons with other ways of communicating genetic information 'it's way more useful having a report like this than providing the phylogeny' (Site 1). Participants frequently cited the novel visualization of transmission, along with the simple narrative conclusion, as the form's greatest strengths. Participants strongly supported the idea that a key—and novel—component of the SRF was its use of visuals and plain English to communicate WGS insights:

> The visual timeline at the bottom of the report I think's been particularly useful, especially useful when communicating the results to other staff members who are not, you know, so involved with the sequencing side of it … it's really helpful to be able to show, you know, ward nurses: 'look you've had this case, now it looks closely matched to this case, that was there five days ago, a week ago' or whatever, and so yeah, I think that's, that's been really good.
>
> (Site 2)

In contrast, a very small minority of participants reported the SRF was difficult to use and interpret. Despite repeated assertions across the data from a variety of staff that the form's simplicity rendered specialist training in interpreting its content unnecessary, a few staff did report residual confusion:

> I could not interpret [the SRF] at all. I purely looked for names and hospital numbers, but the actual information on it, and again that brings me back to having a little bit of background knowledge in relation to typing [i.e., g*enome sequencing*] and how it works. I very much had to lean on my virology colleagues and micro [*microbiology*] colleagues

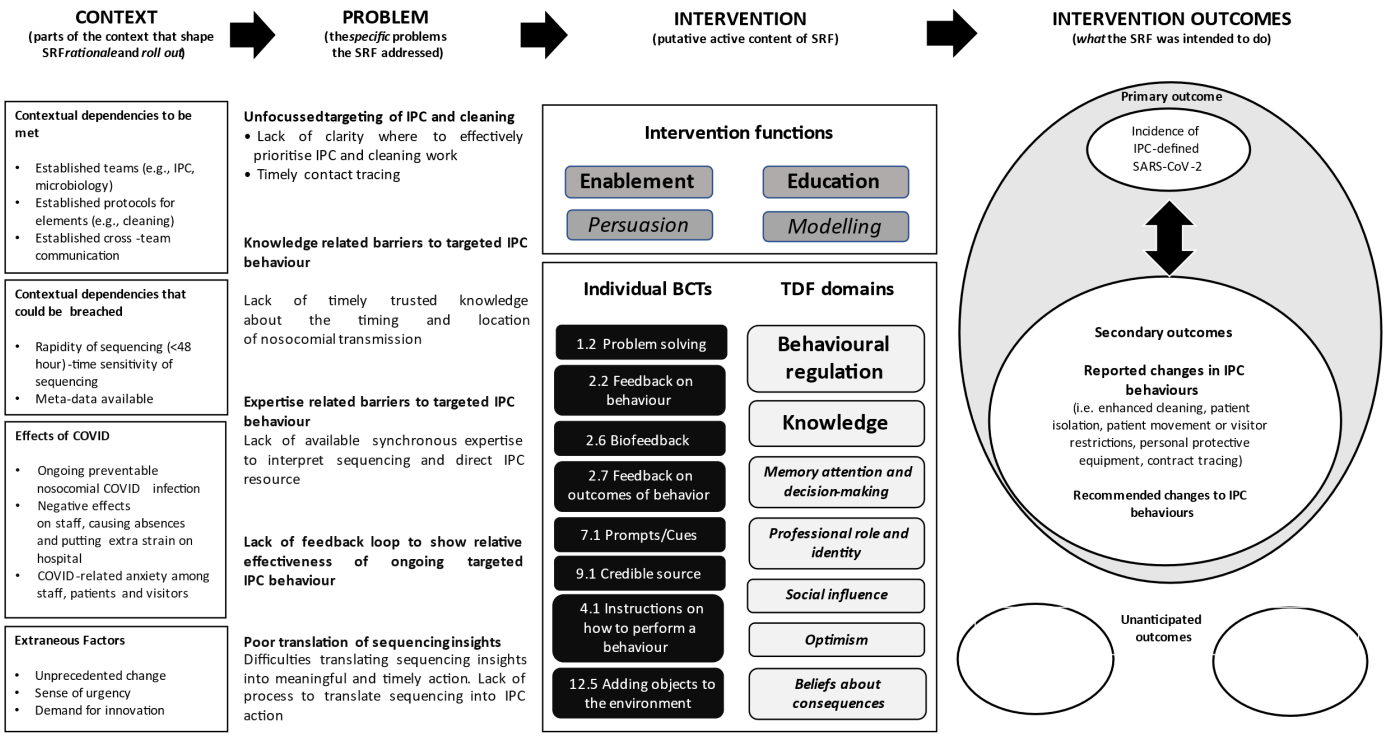

FIGURE 3 Logic model depicting the purported content of the SRF using the BCW approach. *Note*: In relation to intervention content, bold relates to major content and italics relates to minor content.

> who have more of a knowledge of typing. […] I definitely looked at it and went "I have no idea what that means, can somebody interpret that for me?", which is a shame because I feel like it, I would love to look at it and "go, ah, that means that." […] But the actual physical form that came through to tell us, yeah I wouldn't say I had a Scooby Doo [i.e., *a clue*], I'm afraid. […] We'd like more knowledge on that though. I felt a bit stupid I have to say.
>
> (Site 3)

Perceived efficacy and perceived impact on IPC behaviours

In relation to perceived efficacy and perceived impact, most participants shared the sense of the SRF's particular value in objectively and rapidly tracking transmission pathways, and subsequently prompting IPC action:

> That was probably the most interesting part [looking at SRFs] because … you could actually see it working… so … when we were in a flow of "okay we've got this patient come through – this is the report," and speaking to [HOCI PI], and then the nurses reacting to that, and making decisions based off of what we found in the reports, it was really interesting just to see the link between all of it, and just how it can help and it could help in the future.
>
> (Site 5)

The benefit of being presented with objective and actionable information was echoed by the majority of participants. The SRF's provision of both timing and location of nosocomial cases was reported as crucial to staff's capacity to 'very quickly get a grip on what's going on with this patient' (Site 3). This notion of the value of objective information—in the context of ongoing uncertainty—was echoed by many, evoking a sense of relief in knowing that 'the sequence doesn't lie' (Site 3). Gratitude for impartial clarity was oft repeated—participants almost unanimously agreed on the SRF providing 'clear' and actionable information.

Issues of assimilation into existing work

In relation to assimilation into existing work, our analysis speaks to the complex context in which the SRF was used (i.e., the peak of the Alpha variant in Spring 2021). The SRF was assimilated in some sites and by some participants, but this was far from universal. On the one hand, where the SRF was seen to work in practice, it was able to be assimilated over time 'there was a bit of a shift in the mindset of some of our infection control staff around "actually this could be very beneficial for us"' (Site 1). However, in other places and times, other factors constrained its assimilation. These related to the 'flood' of patients with COVID and the volume of patients with nosocomial infection, 'it was simply too busy to do it, it would have been nice to have done it' (*Site 5*). There was a sense that there was a 'goldilocks zone' in which the SRF could work but that if there was too little or too much infection its ability to change IPC was limited:

> Although in the thick of it, I think we're all thinking, actually, what, how realistic is it? I think, if you have one or two cases it's more realistic. When you're actually doing only what's possible as opposed to what's desirable, it maybe isn't going to make a big difference.
>
> (Site 1)

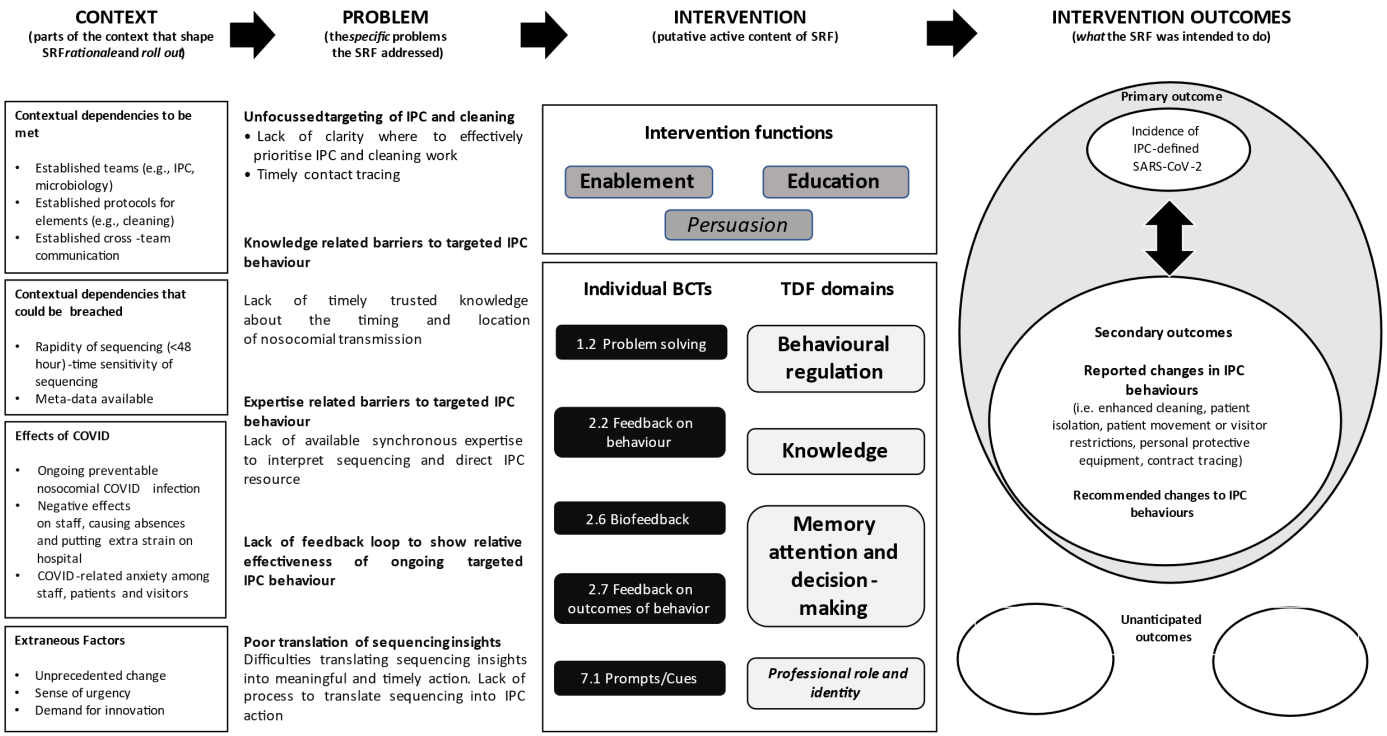

FIGURE 4 Revised logic model depicting insights into the actual working of the SRF using the BCW approach. *Note*: In relation to intervention content, bold relates to major content and italics relates to minor content.

The final issue that affected the assimilation of the SRF into existing work and practice related to a series of factors that extended beyond the SRF and related to what people did with the SRF and its results. These factors related to the dynamic organizational environments in which the SRF was introduced. Issues that affected the effective dissemination of the SRF's insights included the ability to prioritize the SRF within the context of an unfolding hospital crisis, interpersonal processes such as inter- and intra-team dynamics, meetings and staff availability, software and innovation to enable team working on the SRFs within the COVID crisis. Elsewhere, we focus exclusively on these implementation issues in more detail (R. Lesier, J. MLeod, F. Mapp, O. Stirrup, J. Blackstone, C. J. R. Illingworth, G. Nebbia, J. Price, L. B. Snell, T. Saluja, & J. Breuer, unpublished data).

RQ3—Using the BCW approach to analyse interview data of the SRF working in practice, was there evidence via deductive thematic analysis, to support the SRF working as anticipated in terms of the intervention functions, BCTs and TDF domains identified in RQ1?

In this section, we assess relative support for the intervention working as we had anticipated. Figure 4 provides a high-level overview of this work. The third column in Tables 1–3 all summarize this deductive analysis of the SRF content.

How the SRF worked through considering its broad intervention functions

In relation to analysis supporting the SRF's use of the BCW's putative intervention functions, Table 1 describes how we found strong support for both 'Education' and 'Enablement'. We also found some nuanced support for '*Persuasion*', yet no support for '*Modelling*'.

How the SRF worked through considering its behaviour change techniques

In relation to the SRF working as anticipated at the level of its BCTs (Table 2), we found broad support for many but not all the BCTs we had identified within the SRF.

How the SRF worked through considering its theoretical mechanisms

Table 3 shows that, in relation to theoretical mechanisms, our analysis of participant data provided broad support for the SRF working as anticipated. With regard to the two main mechanisms that we had previously identified as particularly important within the SRF, 'Knowledge' and 'Behavioural regulation', we found strong support.

DISCUSSION

This paper presents a novel example of a behaviourally focused qualitative process evaluation. Using a three-staged design employing diverse qualitative and behavioural analyses, we evaluated an intervention (i.e., the SRF) created to elicit changes in the intensity and location of infection prevention and control behaviours to reduce nosocomial COVID infection in UK hospitals. Through using the BCW approach and inductive thematic analysis, we provided a detailed sense of how the SRF worked in the context of the second wave of the UK COVID-19 pandemic and in relation to the purported content we had earlier identified. Our empirical findings enable us to consider what can be usefully learned about the SRF to help shape the future use of SRFs for other nosocomial infections. To our knowledge, this paper is the first in the world to provide a focussed evaluation of SRFs within infectious disease. While the HOCI study was not unique in examining the real-time use of sequence data to address nosocomial transmission (Illingworth, 2021), parallel studies have not been accompanied by comprehensive process evaluation.

TABLE 1 Putative intervention functions and their empirical support.

Intervention functions and definition	Purported functions	Actual functions
Education Increasing knowledge or understanding	In order to change the IPC behaviour, the SRF explicitly provides new knowledge and understanding of HOCIs	***We found strong support for this intervention function working as anticipated*** *The SRF provides new knowledge by allowing people to understand transmission pathways better and make changes to IPC* *By providing new knowledge, the SRF sometimes confirmed what staff already knew, or simply reassured them that their efforts were worthwhile. It also led to standing down of ongoing IPC behaviours at times*
Enablement Increasing means/reducing barriers to increase capability or opportunity	In order to change IPC behaviours, the SRF clearly minimizes uncertainty to reduce barriers	***We found strong support for this intervention function as anticipated*** *The SRF provided a sense of clarity and the capacity for understanding output at a glance, allowing for changes to IPC behaviour* *The SRF allowed staff to carry out duties more efficiently and the SRF's simple, effective design facilitated its use to change IPC behaviour*
Persuasion Using communication to induce positive or negative feelings or stimulate action	In order to change IPC behaviour, the SRF clearly uses communication of expert and locally tailored knowledge to stimulate changes	***We found nuanced support for this intervention function as anticipated*** *The way by which the SRF communicated new information was well-received by some but not all; positive feeling towards the content of the SRF encouraged some staff to act*
Modelling Providing an example for people to aspire to or imitate	In order to change the intensity of IPC activities the SRF provides a specific prompt to check IPC data and patient and HCW movement	***No findings to support this intervention function working as anticipated***

Note: Major intervention functions mechanisms in bold. Minor intervention functions in italics.

TABLE 2 Relative support for the BCTS used within the SRF

BCT definition	Purported BCTs	Actual BCTs
Goals and planning		
1.2 Problem-solving Prompt the person to analyse factors influencing the behaviour and generate or select strategies that include overcoming barriers or facilitators	In order to change IPC behaviour, the SRF is asking individuals and teams to analyse the spatial (i.e., unit and ward) and temporal data (i.e., timeline) and wider information concerning the relativity of transmission risk between cases from visitors/community, and then select appropriate IPC strategies	***We found strong support for this BCT working as anticipated*** *The SRF led to increased and focussed investigation of nosocomial cases and led to changes to IPC behaviour* *The SRF prompted teams to identify specific locations/timelines of transmission and investigate and mitigate against future outbreaks through changes in IPC behaviour*
Feedback and monitoring group		
2.2 Feedback on behaviour Monitor and provide informative or evaluative feedback on performance of IPC activities	In order to change IPC behaviour, the SRF is providing feedback on recent IPC activities	***We found strong support for this BCT working as anticipated*** *The SRF demonstrated where transmission was occurring and led to changes in IPC behaviour*
2.6 Biofeedback Provide feedback using an external monitoring device as part of a behaviour change strategy	In order to change IPC behaviour, the SRF is providing external monitoring of ongoing IPC behaviour (i.e., the COVID-19 genome sequence)	***We found strong support for this BCT working as anticipated*** *The SRF objectively demonstrates where nosocomial transmission had occurred and where IPC measures have not been sufficient; this led to changes in IPC behaviour*
2.7 Feedback on outcome(s) of behaviour Monitor and provide feedback on the outcome of performance of IPC activities	In order to change IPC behaviour the SRF provides feedback on the outcomes of ongoing IPC activities (e.g., nosocomial infection)	***We found strong support for this BCT working as anticipated*** *The SRF provided clear proof of transmission pathways, enabling changes to IPC* *The SRF allowed for investigation of links that would have otherwise been missed and led to changes in IPC behaviour* *Seeing the SRF results—proof of transmission pathways—helped staff to understand its value and change IPC behaviour* *A few staff viewed the SRF as too retrospective, so although it provided feedback this was sometimes too late to provide real-time solutions*

TABLE 2 (Continued)

BCT definition	Purported BCTs	Actual BCTs
Associations group		
7.1 Prompts/Cues Introduce or define environmental or social stimulus with the purpose of promoting or cueing the behaviour. The prompt or cue would normally occur at the time or place of the performance	In order to change IPC behaviour, the SRF and its use of 'attention signs' and colour prompts change in IPC activities by providing tailored information within the organization in which HOCIs have occurred (i.e., hospital) In order to change IPC behaviour, the red colour and bolding draws the reader's attention immediately to what is important and significant within the SRF In order to IPC behaviour, the 'attention' draws the reader's attention to what is most important and significant within the SRF	***We found strong support for this BCT working as anticipated*** *The SRF's use of red typeface was effective at alerting staff's attention to the transmission pathway information and instigating changes to IPC* *The SRF's timeline was effective at communicating results to staff in a visual manner and led to changes in IPC behaviour* *The SRF's provision of clear, succinct information provided essential information on transmission pathways at a glance, leading to changes in IPC behaviour* *The SRF's elimination of the need to interpret complex data and provide clear information at a glance, made it more useful than phylogenetic trees alone at leading to changes in IPC behaviour*
Comparison of outcomes group		
9.1 Credible Source Present verbal or visible communication from a credible source in favour of or against the behaviour	In order to change the intensity of IPC activities the SRF has HOCI and COG-UK labels and branding and is clearly focused on encouraging targeted IPC activities	***We found weak support for this BCT working as anticipated***
Shaping knowledge group		
4.1 instruction on how to perform a behaviour Advise or agree on how to perform a behaviour	In order to change the intensity of IPC activities, the SRF provides explicit advice: 'please check IPC data and patient and HCW movement, particularly in the 10–14 days preceding the date of the focus patient's sample'	***We found no support this BCT working as anticipated***
Antecedents group		
12.5 Adding objects to the environment Add objects to the environment to facilitate the performance of the behaviour	The SRF is catalytic in triggering a whole cascade of IPC activities.	***We found no support for this BCT working as anticipated***

(Continues)

TABLE 2 (Continued)

BCT definition	Purported BCTs	Actual BCTs
Behaviour change elements not captured within BCT taxonomy but relating to the mode of delivery		
Simple design and lack of complexity	In order to change the intensity of IPC activities, the overall design coveys a sense of simplicity and clarity of focus. When multiple SRFs are reviewed together, other design elements draw attention to where immediate action is needed and where it is not	***We found strong support for this working as anticipated*** *The SRF's simple, effective design facilitated its use and led to changes in IPC behaviour* *The SRF provided a sense of clarity and the capacity for understanding output at a glance, allowing for changes to IPC behaviour*
Logos, local tailoring and factual elements of data and IDs etc	In order to change the intensity of IPC activities the logos, the details of dates and locations and clear connections with trusted local data systems all provide a sense of expert and trusted knowledge	***We found minimal support for this working as anticipated*** *The official nature of the SRF and its branding made the information it presented more credible and worthy of following leading to changes in IPC*

Note: Major TDF mechanisms in bold. Minor TDF mechanisms in italics.

The SRF and IPC behaviours

Our deductive BCW analysis of pre-trial data detailed a series of inter-related components and mechanisms that together provided a clear sense of the purported content of the SRF, depicted in our first logic model. Our subsequent deductive BCW analysis of post-trial interview data largely supported the pre-trial conceptualization of the SRF's content and its function, with minimal exceptions. Additionally, inductive thematic analysis of the interview data indicated that the SRF was largely seen as useful; it was easy to understand, it appeared to work and was perceived to have an impact on IPC behaviours, and in context-dependent ways, some staff found it easy to assimilate into their existing work and professional practice.

However, we now know from the wider quantitative trial results that no statistically significant changes in weekly incidence of nosocomial SARS-CoV-2 were reported across the 14 trial sites (Stirrup et al., 2022). Although, in a sensitivity analysis, in 20.7% of nosocomial cases, when the SRF was returned within 5 days, there was an impact on IPC actions. These trial findings, in combination with the positive findings reported here, beg the question of why the SRF did not work as intended at changing the primary trial outcome. In this way, beyond the form itself, pathways to the SRF's implementation were particularly important. Elsewhere, we focus on these issues in much greater detail, considering how best to support the implementation of the SRF to maximize use of its content (R. Lesier, J. MLeod, F. Mapp, O. Stirrup, J. Blackstone, C. J. R. Illingworth, G. Nebbia, J. Price, L. B. Snell, T. Saluja, & J. Breuer, unpublished data).

The SRF working as anticipated?

Analysis provided support for intervention working as anticipated pre-trial: *Education*, *Enablement*, and *Persuasion;* BCTs related 'Feedback on behaviour', 'Biofeedback', and 'Feedback on outcomes of behaviour', as well as 'Problem solving' and 'Prompts/cues'; and TDF domains 'Knowledge' and 'Behavioural regulation'. When our anticipated intervention content is compared with our actual intervention content, a few elements of the SRF appeared redundant, or in need of optimization (e.g., 'modelling' as an intervention function, BCTs '4.1 instructions on how to perform a behaviour', '12.5 Adding objects to the environment', 9.1 'Credible source' and the TDF domain 'beliefs about consequences'). Our analysis also showed that the relative importance of TDF domains 'Memory, attention, & decision-making processes' and particular visual features were more important than we had anticipated before the trial began. Crucially, one key finding related to the importance of 'Simplicity of design'—something not captured within the BCTTv1 but, nevertheless, evidently a fundamental component of the SRF. This process evaluation indicated that the SRF, even in the midst of a pandemic, worked as expected and was perceived to be useful by a range of health care professionals. SRFs may be a useful tool in the future for controlling other nosocomial infections, working to educate, enable and persuade teams to change the intensity and location of IPC behaviours. Our analysis showed the importance of simple design to features that could efficiently increase knowledge and provide feedback; it had clear instructions and used colour and bolding effectively and focussed the reader's attention efficiently. These elements should all be retained in the future and further work could be conducted to optimize them. However, our inductive analysis here (RQ2) hints at where future work around SRFs is mostly needed, relating not to the content of the SRF but to the context in which the SRF operates (see R. Lesier, J. MLeod, F. Mapp, O. Stirrup, J. Blackstone, C. J. R. Illingworth, G. Nebbia, J. Price, L. B. Snell, T. Saluja, & J. Breuer, unpublished data). Notwithstanding, we believe that further optimization work of the SRF is recommended.

Beyond the paper's findings, the study also provides a unique methodological contribution. The novel design, using three distinct stages, offers an approach for health psychologists to consider when conducting future process evaluations on interventions. The approach outlined here will not be suitable

TABLE 3 Putative theoretical domains and their empirical support

Theoretical domains framework (TDF) Domain brief explanation	Purported theoretical domains	Actual theoretical domains
Knowledge A mechanism by which change results from an awareness of the existence of something	The design of the SRF is explicitly concerned with communicating knowledge in simple ways that define the occurrence and transmission location of nosocomial infections in order to change subsequent IPC behaviour (typically, its location and intensity) The SRF delivers expert and locally tailored knowledge that is 'cutting edge' and translated to its recipients in order to change IPC behaviour. **Occurrence**: In order to change IPC behaviour, the SRF explicitly provides new knowledge—concerning probability of nosocomial infection among HOCI cases (i.e., those diagnosed post-admission). The SRF then lists other SARS-CoV-2 cases (which may or may not be HOCIs) within the hospital, which could plausibly be linked within a single transmission cluster. For example: 'Focus patient's sequence is closely matched to samples below, possibly linked by transmission' **Transmission location**: In order to change the IPC behaviour, the SRF explicitly provides new knowledge concerning locus of past COVID-19 transmission events (within unit, within hospital). For example: 'matches from same unit; risk of transmission is high' **Transmission timing**: In order to change IPC behaviour, the SRF provides explicit new knowledge concerning timing of COVID-19 transmissions. For example, details of dates are provided in addition to a visual of the 'timeline' that depicts the focus sample and close matches across dates, units and within hospitals, providing a visualization of linkage	***We found strong support for this mechanism working as we had anticipated*** *Analysis suggested that IPC behaviour was shaped by knowledge through changing awareness of:-* ***Occurrence:*** *The SRF detailed the occurrence of nosocomial transmission to change IPC behaviour* ***Transmission location:*** *The SRF provided new knowledge of the likely location of transmission to change behaviour* ***Transmission timing:*** *The SRF provided new knowledge of the likely timing of transmission events to change IPC behaviour* ***Novelty of information*** *The SRF revealed previously unknown links in transmission pathways to change IPC behaviour* ***Confirmatory knowledge*** *The SRF often confirmed staff's knowledge, rather than providing new information so sometimes did not lead to changes in behaviour but at other times led to a stand down of IPC behaviour.* ***Speed of information*** *The SRF's provision of real-time information allows for changes to IPC behaviour* ***Clarity and simplicity of knowledge*** *Succinct and clear information provision in the SRF facilitated changes to IPC behaviour*

TABLE 3 (Continued)

Theoretical domains framework (TDF) Domain brief explanation	Purported theoretical domains	Actual theoretical domains
Behavioural regulation A mechanism by which changes result from anything aimed at managing or changing objectively observed or measured actions	The SRF as a whole works to change the intensity of IPC behaviour using behavioural regulation. In order to change IPC behaviour, the SRF explicitly works to trigger a range of actions, for example 'please check IPC data, and patient and HCW movement, particularly for the 10–14 days preceding the date of the focus patient's sample'. The SRF renders the effectiveness of IPC activities visible and provides a feedback loop that illuminates effective and ineffective IPC work at a detailed level	***We found strong support for this mechanism working as anticipated*** ***Feedback on transmission****, the SRF detailed where and when transmission had occurred enabling focussed changes to IPC behaviour* ***The SRF objectively demonstrates*** *where IPC measures had not been sufficient providing a sense of behavioural surveillance and driving changes to IPC behaviour* *Seeing the SRF results provided* ***proof of transmission*** *and this helped staff to understand its value and make changes to IPC behaviour*
Memory, attention and decision processes A mechanism by which changes result from the ability to retain information, focus selectively and choose between two or more alternatives	In order to change IPC behaviours, the SRF implicitly influences choices concerning where and when to intensify or stand-down IPC activities; and the design and use of colour and graphics focuses attention where it is needed	***We found stronger support than anticipated for this mechanism working*** *Most staff provided positive feedback on physical attributes of the form and this enabled them to change their behaviour* *The SRF's use of red typeface is effective in alerting staff's attention to information on transmission pathways and should enable changes to IPC behaviour* *The SRF's use of visual timelines allows staff to focus on essential information and act immediately and change IPC behaviour* *The SRF's use of plain English to describe WGS output is more useful than relying on phylogeny alone in changing IPC behaviour*
Professional roles/Identities A mechanism by which changes result from a coherent set of behaviours and personal qualities of an individual in a work setting	*In order to change IPC behaviour the SRF implicitly evokes the professional role of its recipient(s)*	***We found nuanced support for this domain working as anticipated as the SRF used professional identity in ways that both did, and did not, contribute to changes in IPC.*** *Many staff believed the SRF made WGS knowledge accessible to all categories of staff enabling changes to IPC behaviour* *A few staff felt the SRF was only relevant to academics and those on the frontline thus this did not help to engender IPC-related behaviour change*

(Continues)

TABLE 3 (Continued)

Theoretical domains framework (TDF) Domain brief explanation	Purported theoretical domains	Actual theoretical domains
Social influences (*norms*) A mechanism by which changes result from interpersonal processes that can cause individuals to change their thoughts, feelings, or behaviours	*In order to change the intensity of IPC activities, the SRF implicitly uses social influence by publicly and expertly providing knowledge concerning granularity of risk of transmission*	***We found weak support for this domain working as anticipated*** *A couple of staff reported a sense of knowing that the SRF should be being used to change IPC behaviours*
Optimism A mechanism by which changes result from confidence that things will happen for the best or that desired goals will be obtained	*In order to change the intensity of IPC activities, the SRF implicitly creates confidence in the targeting of IPC capacity to reduce nosocomial COVID-19 transmission through its use of cutting-edge technology*	***No findings to support this theoretical domain and the hypothesized mechanism***
Beliefs about consequences A mechanism by which changes result from the acceptance of the truth or validity about outcomes of a behaviour	*In order to change the intensity of IPC activities, the SRF implicitly moderates beliefs about consequences of IPC activity in relation to beliefs about culpability/negligence for action/inaction*	***No findings to support this theoretical domain and the hypothesized mechanism***

Note: Major TDF mechanisms in bold. Minor TDF mechanisms in italics.

for all situations—for example, the three steps would not be necessary where intervention content is already well specified and understood, through the use of programme theory for example (Skivington et al., 2021). The approach here, with its unique focus on assessing granular support for the purported content of an intervention, may be particularly useful for novel interventions which are being trialled for the first time. The in-depth and systematic tracking of the interventions components echoes other perspectives that seek to illuminate context-mechanism-and outcome configurations using different analytic tools and perspectives (Pawson et al., 1997).

Strengths

Strengths include the novel process evaluation design including the use of health psychology approaches (i.e., BCW, BCTTv1 and TDF) within an IPC intervention context. The comparison of pre- and post-trial analysis of the intervention using these tools demonstrates the importance of theorizing the intervention content before trial data collection as well as after. Another strength of the study was its use of complementary deductive and inductive thematic analyses—generating an accessible narrative account of using the SRF but also to providing empirical evidence supporting the theorized content of the SRF.

Moreover, collecting qualitative data from a wide range of different health care professionals working with the SRF afforded an overall picture of experience that comprised both breadth and depth. Our analyses here, with their close focus on the SRF, provide useful knowledge for the future development of SRFs in infectious disease, alongside our analysis of challenges to its implementation and how we might overcome them (R. Lesier, J. MLeod, F. Mapp, O. Stirrup, J. Blackstone, C. J. R. Illingworth, G. Nebbia, J. Price, L. B. Snell, T. Saluja, & J. Breuer, unpublished data). Together, these findings show the importance of process evaluations to complement outcome evaluations. However, a further strength of this paper is that it outlined a design that focuses on exploring the granular content of interventions themselves. The design adds to the growing range of approaches to process evaluation (e.g., Moran & Gutman, 2021; Steinmo, Michie, et al., 2015).

Limitations

A limitation of the study relates to the span of our data collection. Interviews were carried out in only five out of 14 trial sites from the wider study, which—although offering a varied and substantial sample—this does not necessarily capture perspectives across the trial as a whole. However, these findings were shared and discussed in summer 2021 with a far broader range of staff involved in using the SRF from across all trial sites.

Another limitation was the temporal time frame of data collection, largely taking place within weeks of each site delivering SRFs rapidly and at the peak of the Alpha variant within the COVID-19 pandemic. This presented unique challenges in collecting data on the way the SRF worked when our findings themselves suggest it took time for the SRF to embed and be understood. Embedding the rapid delivery of the SRF over a longer period and exploring longer term issues of implementation may give a richer source of understanding the SRF.

If time and resource had permitted, systematic and dedicated behaviourally informed qualitative work using focus groups and interviews and the use of approaches such as the think-out-loud approach (Van Someren et al., 1994) could all have enabled an optimal SRF to have gone to trial. This process would also have generated an agreed theorized account of the SRF's putative content without the need for our post-hoc analysis of its content (Stage 1 of the design here). However, given low levels of compliance with guidance for intervention development (O'Cathain et al., 2019), many health psychologists may find themselves in this position; needing to describe and theorize interventions that are already developed or in use (Flowers et al., 2022; Moran & Gutman, 2021; Musgrave et al., 2021). For the current

study, one central challenge in addressing our first research question was the unspecified detail about exactly who needed to do what, where, when and with whom on receipt of the SRF. The HOCI study, took place in the emergency context of the COVID pandemic. In this way, given the highly labile context in which the trial took place, the precise behavioural focus of the SRF had remained unspecified. As such, this stage of the process evaluation was also important in trying to pinpoint how the SRF had been designed to change which behaviour. Finally, the tremendous burden of COVID-19 on health care professionals across the workforce cannot be overstated and may have influenced attitudes towards both the SRF itself, and participation within this study.

CONCLUSION

This paper provides empirical evidence, in the form of qualitative data, that shows support for the previously theorized content of the SRF working as an intervention to direct IPC behaviour to reduce nosocomial infection of SARS-CoV-2. The consolidation of both pre- and post-trial analysis provided an overview of how the SRF worked in practice, and also highlights its acceptability among the professionals who used it. However, to capitalize on the SRF's capacity to reduce nosocomial infection, future complementary work on embedding it into routine practice is required.

AUTHOR CONTRIBUTIONS

Acquiring funding and overall leadership (JBr); project management and running (JBl), design and theory leads (PF and FM), data collection (FM); data analysis (PF, RL, JM, FM), writing lead (PF, RL and JM), auditing and writing contributions (OS, CI, JBl, JB). All authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

Paul Flowers, Ruth Leiser, Julie McLeod, Fiona Mapp, Oliver Stirrup, Christopher JR Illingworth, James Blackstone and Judith Breuer have no competing interests to declare.

DATA AVAILABILITY STATEMENT

Given the qualitative nature of the data and the sensitive nature of some of its content in addition to participant requests – copies of the data set are not available.

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