Health Technology Assessment

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Synopsis

Technology-enabled CONTACT tracing in care homes in the COVID-19 pandemic: the CONTACT non-randomised mixed-methods feasibility study

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Abstract

Background: Coronavirus disease 2019 devastated lives in care homes for older people, where residents faced higher mortality risks than the general population. Infection prevention and control decisions were critical to protect these vulnerable residents. Infection prevention and control measures like 'lockdowns' had their own risks, such as social isolation, alongside assumed benefits. A key non-pharmaceutical intervention for managing infections is contact tracing. Traditional contact tracing, which relies on recalling contacts, is not feasible in care homes where approximately 70% of residents have cognitive impairments. The CONtact TrAcing in Care homes using digital Technology intervention introduces Bluetooth-enabled wearable devices for automated contact tracing. We provided structured reports (scheduled regularly and in reaction to positive COVID-19 cases) on contact patterns to homes to support better-informed infection prevention and control decisions and potentially reduce blanket restrictive measures. We also partnered with the PROTECT COVID-19 research team to examine air quality in two of our homes.

Methods: CONTACT was a non-randomised mixed-method feasibility study in four English care homes. Recruitment was via care home research networks, with individual consent. Data collection included routine device data, case report forms, qualitative interviews, field observations of care home activity and an adapted Normalisation Measure Development questionnaire survey to explore implementation using normalisation process theory. Quantitative data were analysed using descriptive statistical methods, and qualitative data were thematically analysed using normalisation process theory. Intervention and study delivery were evaluated against predefined progression criteria.

Results: Of 156 eligible residents, 105 agreed to wear a device, with 102 (97%) starting the intervention. Of 225 eligible staff, 82.4% (*n* = 178) participated. Over 2 months, device loss and battery failure were significant: residents lost 11% of devices, with half replaced. Staff lost fewer devices, just 6.5%, but < 10% were replaced. Fob wearables needed more battery changes than card-type devices (15% vs. 0%). Homes variably understood structured and reactive feedback but were unlikely to act on it. Researcher support for interpreting reports was valued. Homes found information useful when it confirmed rather than challenged preconceived contact patterns. Staff privacy concerns were a barrier to adoption. Study procedures added to existing work, making participation burdensome.

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The perceived burden of participation, amplified by the pandemic context, outweighed the benefits. CONTACT did not meet its quantitative or qualitative progression criteria.
Limitations: Researchers had to pragmatically adapt procedures, resulting in suboptimal implementation choices from an implementation science perspective. Future research should co-design interventions with homes, focusing on implementation and wearability as much as technical effectiveness.
Conclusion: A definitive trial of CONTACT was not feasible or acceptable to care homes, partly due to the shifting pandemic context and demands on homes. With more effective implementation, Bluetooth-enabled wearable systems as part of 'Internet of Things' in homes could be used to: (1) better understand airborne transmission risks, ventilation and air quality and (2) make important relational aspects of care quality and residents' quality of life more transparent.
Future work: We will continue to explore the possibilities of Bluetooth-enabled wearables for modelling social networks, movement, infection risks and quality in care homes with academic and care partners.
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Synopsis

This report outlines research examining the feasibility and acceptability of a Bluetooth-enabled (BLE) digital wearable contact-tracing system in UK care homes during the COVID-19 pandemic – the CONtact TrAcing in Care homes using digital Technology (CONTACT) study. This work was commissioned by the National Institute for Health and Care Research (NIHR's) COVID-19 Recovery and Learning program as part of the Health Technology Assessment (HTA) programme. The study had three main components: (1) an evaluation of the technical performance of the CONTACT intervention system hardware (BLE wearables and Internet of Everything infrastructure), (2) an evaluation of the feasibility and acceptability of the CONTACT intervention in care homes and the study procedures needed for a future planned definitive cluster randomised controlled trial (RCT) and (3) a process evaluation to explore the generative mechanisms behind the feasibility and acceptability results.

Research rationale

Context: care homes and their population

Approximately 490,000 people live, and ~700,000 work, in the UK's 17,598 care homes.[1] COVID-19 reduced the sector by ~37,500 beds, but a growing number of older adults will require more care home provision.[2] Care home residents have complex care needs. Approximately 70% of residents (approximately 300,000) have some form of dementia or severe memory problems,[3] and frailty is common. Frailty increases susceptibility and leads to an inadequate response to infection. In the first wave of the COVID-19 pandemic in the UK, 80.2% of care home residents were older than 65 years, many had cognitive impairment, and lived with chronic conditions that increase respiratory virus infection risk: diabetes (13–17%) and chronic obstructive pulmonary disease (13–15%).[4]

Effects of the pandemic on residents and the care home workforce

Of the 66,112 care home resident deaths between March and June 2020 in England and Wales, 19,394 (29%) were attributed to COVID-19.[3] Infection rates were as high as 80%, and mortality rates of 30–50% were seen in some homes.[5,6] Care home residents accounted for between 30% and 40% of all UK COVID-19-related deaths.[3] The VIVALDI study team reported at least one confirmed case of coronavirus among staff or residents in 56% of their 9081 care homes.[7] In homes with one positive case, ~20% of residents and 7% of staff tested positive for COVID-19.[7]

Care home staff are a key route of COVID-19 transmission into and out of homes[5,8] and endured mortality rates in excess of the wider, non-caring workforce. Direct care workers were at the highest risk, with 76% of social care workforce deaths in care staff (204 of 268 deaths).[4]

For most residents, a care home is their final home until they die. Quality of life is as important as quality of care, and interaction and contact with friends and relatives are important. This is an important contextual backdrop for infection prevention and control (IPC) efforts of care homes during the pandemic. IPC *may* reduce transmission risk, but strategies focusing on increased physical isolation of residents through 'locking down' homes, zoning, isolation and quarantining[9] risk increasing residents' social isolation. *Pre-pandemic*, social isolation in care homes was common, with 96% of residents experiencing loneliness (35%) or severe loneliness (61%).[10]

Estimates of the psychosocial effects of the pandemic and the associated IPC on residents, families and staff are uncertain. Most studies have examined the *perceived* impact on *residents* of staff, visitors and families. In Ireland, O'Caoimh *et al.*[11] found that of 202 residents' families, almost half (49%) reported their resident family member as 'not coping well' with restrictions. Half of the participants reported reduced mood, ability to undertake activities of daily living, and further cognitive decline. Paananen *et al.*,[12] using qualitative interviews, reported that perceived social isolation leads to sudden progression in memory disorders and deterioration in physical abilities. Residents and family members experienced anxiety, grief and severe stress, to the extent that families were concerned that missing social contact and activity would lead to death.[12] In a Dutch context, Wammes *et al.*[13] surveyed 1997 relatives of nursing home residents who reported increased loneliness (76%), sadness (66%) and diminished quality of life (62%) in their care home-dwelling family member. Among English care home providers, one study found that 80% of homes reported lower mood and oral intake and more isolation in residents, all attributed to policies of isolation from visitors and families or infection control efforts.[14]

The pandemic harmed the psychosocial health of residents' families and care home staff, with lonely relatives, diminished well-being and lower quality of life.[11] In Scotland, 76% of 444 family carers surveyed had a General Health Questionnaire (GHQ, scale from 0 to 16) score of 12 points or more – indicating 'clinical mental distress'. Family caregivers had an average GHQ score of 18.16 (in contrast to GHQ scores of 12.7 for the general public during the pandemic).[15] In England, qualitative researchers found the staff to be emotionally exhausted, guilty and frustrated as a result of the pandemic's effects on work and care home life,[16] and experiencing guilt and burnout.[17,18]

Many managers described staff shortages, and 30% of the care homes reported continuing to use staff who worked across sites and agency-employed staff. Cross-site work is a known risk factor for COVID-19 care home outbreaks.[3,4] Policies related to care homes in areas such as IPC, personal protective equipment, visiting, testing and reporting are rapidly changing. Eighteen significant policies were introduced between March and June in 2020 alone.[14] IPC itself was a source of uncertainty for many managers; in the COVID-SEARCH study, conducted after the first wave of the pandemic, 49 of the 188 uncertainties expressed by 250 managers and staff in a closed WhatsApp™ group related to IPC.[19]

The need for contact tracing in homes

The UK's vaccination programme using the Oxford-AstraZeneca non-replicating viral-vectored vaccine (ChAdOx1 nCoV-19; AZD1222) and Pfizer-BioNTech mRNA-based vaccine (BNT162b2; rINN tozinameran) for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was rolled out in UK care homes during winter 2021, at the start of the CONTACT study. A single dose of either vaccine reduced the risk of infection by 56% after 4 weeks and 62% after 5 weeks in residents and reduced SARS-CoV-2 transmission. However, the risk of infection was not entirely eliminated, as evidenced by the continued outbreaks in care homes post vaccination. The need for non-pharmaceutical IPC interventions – including contact tracing – to prevent transmission in care homes remains.[20] Testing of staff and residents *without* contact tracing means that 'smarter' (i.e. targeted) IPC is impossible, and greater restrictions become more likely, negatively impacting the quality of life and relationships between residents and families. Ignoring the contacts of visitors from outside the home may also mean less effective public health interventions and increased community transmission risk.[21] Contact tracing could also help homes manage other contact-related diseases such as influenza, respiratory syncytial virus (RSV) and norovirus.[22]

Knowing more about contact networks in care environments is a promising but often-absent aspect of IPC. Myall *et al.*[23] used routine documentary data from a UK and Swiss hospital to construct the networks of contacts at each site and examined how well a model with only three variables [network closeness, direct contacts with infectious patients (network derived) and local COVID-19 prevalence] predicted COVID-19 infection while hospitalised. The model performed well without the network data: area under the curve in a receiver operating curve (AUC-ROC) 0.85 (95% CI 0.82 to 0.88). But knowledge of the networks of contacts improved performance: AUC-ROC in the Swiss hospital increased from 0.84 (95% CI 0.82 to 0.86) to 0.88 (0.86 to 0.90); AUC-ROC in the UK hospital increased from 0.49 (0.46 to 0.52) to 0.68 (0.64 to 0.70).[23] These findings were not generated from BLE wearables or in care homes, but they illustrate how knowledge of dynamic networks of contacts in institutions generate information that could inform IPC.

Martignoni *et al.*[25] found that efficient contact tracing can offer effective control, even in communities with reduced immunity. Efficient tracing was defined as an adequate proportion of symptomatic individuals whose contacts will be traced, multiplied by the proportion of contacts that will be quarantined. For example, as long as more than 50% of the contacts of symptomatic individuals are identified and quarantined quickly – within 2 days of symptom onset – outbreaks can be controlled.[24] Higher infection incidence in a population, or less efficient tracing methods, can overwhelm manual tracing methods.[24]

Digital methods *may* improve efficiency by tracing more people faster but will only lead to greater effectiveness if accompanied by appropriate quarantining and other non-pharmaceutical interventions.

Conventional structured interviews and documentary contact tracing were ineffective in the care homes. Many homes have 70–80% of residents living with dementia, and staff often have more than 50 contacts per day. Recalling historic contacts using interviews is unfeasible and makes achieving trace 50–70% of contacts that must be traced to control an outbreak in a population.[24,26]

Technology for more efficient contact tracing?

While the NHS test and trace-style semi-automated contact tracing using BLE smartphones and apps may reduce the burden on contact-tracing teams and can help reduce cases,[27] smartphone-based solutions to support contact tracing have limited utility in care homes, as few residents use such technology, and staff are often discouraged from using them in the workplace.

Wearable digital devices have the potential to overcome the limitations of contact tracing in care homes by using human recall and smartphones. Small, discrete, wearable technology (in fob, tag or wristwatch forms), with long battery life, can capture interactions between individuals, in their environments, and generate and store contact tracing information.

Evidence on the efficacy and effectiveness of digital wearables for contact tracing in the context of pandemics is mixed. In a rapid (systematic) review of the Cochrane Collaboration of digital devices for contact tracing in epidemics,[18] only 5 of the 13 included studies featured wearable devices or radio frequency identification (RFID) sensors (akin to Apple AirTag®, One Apple Park Way, Cupertino, CA). Simulation-based models are more commonly used than empirical/epidemiological evaluation methods. The assumptions made in these models are variable and questionable. For example, some models assume 0% effectiveness of contact quarantine and others 100%; similarly, the effectiveness of isolating positive cases ranged from 0% to 90%.[18] Anglemyer *et al.* found low certainty evidence (from cohort studies) that digital approaches to contact tracing can identify more close contacts than manual/traditional approaches.[18] Not all studies involved wearables/RFID sensors, however, and none were in long-term care or care home settings. RFID sensors, which are ostensibly similar to the BLE-based wearables in our study, are location based. Specifically, the location markers in an environment pick up, store and transmit when the RFID tags are near them. They did not consider interactions between the tags themselves. All that can be deduced from the data generated is that tags X, Y and Z were in locations A, B or C; not that Tag X was closer to Tag Y than Tag Z.

Other reviews of technology-enhanced, automated and semi-automated contact tracing call for the need for future research into, ‘the empirical effects on disease transmission’ and impact on those aspects of contact-tracing systems that drive the required population coverage for effective tracing: uptake, ethical and equity considerations.[28]

Primary studies of digital contact-tracing approaches based on models of spread, mortality and identification are more sanguine. Wilmink *et al.*[29] suggested that a wearable-based system, similar to CONTACT: with feedback to long-term care facilities and based on social networks and knowledge of human traffic and movement in the homes, could reduce infections by ~52%. However, the uptake needs to be sufficient, contacts need to be identified quickly, and appropriate action should be taken. Wilmink’s positive findings are tempered by the model’s unvalidated assumptions, the unknown ‘real-world’ performance of the model itself, and – with the benefit of post-CONTACT study hindsight – optimistic adoption and attrition rates in (simulated) homes.

Digital contact tracing using wearables is associated with known implementation and ethical challenges. Any technology must be adopted by at least 70% of the population for contact tracing.[26,30] Technology must be acceptable and not lead to unnecessary invasions of privacy or generate and/or exacerbate inequalities in benefits or potential harm.[31] But for digital contact-tracing methods to stand *any* chance of being effective, they must accurately and reliably capture contacts. To the best of our knowledge, no studies evaluating the real-world (as opposed to simulated) accuracy of BLE wearable devices in a care home/long-term care context exist. Some studies have compared device-generated contacts with manually recalled contacts or other digital methods in hospital contexts. Ho *et al.*[32] identified 796 self-reported staff–patient contacts (between 17 patients and 162 staff members). Of these, 68% (n = 539) were not captured either by a wearable device or by scrutiny of electronic medical records. The wearables in their study had a sensitivity of 72.2% and specificity of 87.7%, suggesting some utility in identifying contacts of positive cases.[32]

Protocol

The protocol plan (v4.0) for conducting and analysing the feasibility study and process evaluation is available at https://njl-admin.nihr.ac.uk/document/download/2035361. We originally planned a web-based 'dashboard' for homes to be able to access real time, continuously updated reports of infection trends and patterns in their homes. Home managers told us in the recruitment period that they were unlikely to access this dashboard, so this was dropped from the intervention.

The CONTACT intervention

CONTACT is a complex intervention[33] built around BLE wearables (*Figure 1*) and an Internet of Things (IoT) system designed to monitor and analyse contact patterns within care homes to better understand infection trends, provide a basis for feeding back infection and contact patterns to homes, and plug an information deficit for managers making IPC decisions.

Key components and implementation

Device integration

Bluetooth-enabled wearables and location markers were used to detect contacts and identify their precise locations. Working with the PROTECT COVID-19[34] study team, we placed air-quality sensors in two feasibility homes (Homes 3 and 4, *Table 1*) to monitor CO_2 levels, temperature and humidity, which are key determinants of environmental quality.

Deployment

Sensor placement, derived from floor plans, concentrates on high-footfall areas such as communal spaces, bedrooms and essential service areas such as kitchens.

Installation

Each sensor and wearable device has a unique QR code identifier, enabling 'mapping' of each home's system. The average installation time per home is approximately 8 person-hours.

Participation

Consenting staff and residents were provided with wearable devices. Using unique anonymised identifiers meant that the research team did not know which staff and residents were associated with which devices. The homes were able to de-anonymise the data for contact-tracing purposes (e.g. matching device X to resident Y and staff members A and B).

Data transfer and analysis

Contact data from the devices were transmitted via a wave scanner to a Long Range Wide Area Network gateway, then to our commercial partner MicroShare's cloud servers, and the data-containing device IDs, location marker IDs and timestamps were sent to our Clinical Trials Research Unit. They were then processed to generate comprehensive summaries highlighting contact trends, patterns and potential infection risks.

Feedback mechanism

Monthly structured reports (see *Appendix 1*) were shared with care homes. We also provided ad hoc ('reactive') reports (see *Appendix 2*) to the research team when

FIGURE 1 CONTACT BLE wearables.

homes reported a positive case of COVID-19 among staff and residents. Reports detailed contact between infected and non-infected individuals and provided insights on contact durations, frequencies and high-risk (high-contact areas) zones within the homes. Our feedback and support approach was built around known characteristics of effective feedback mechanisms[36] and was co-designed with in-house 'study champions' and periodically refined based on staff feedback, for example, simplifying infection trends and individual risk visualisation.

Follow-up and support: After delivering each report, a researcher engaged with the home after 3 days to clarify uncertainty, answer questions, and promote understanding and potential action. The meetings and calls were documented for process evaluation.

Principal findings and analysis

The technical performance of the CONTACT intervention

Regardless of how well-implemented, BLE wearables for contact tracing will be ineffective if they cannot accurately and reliably capture the contacts between two or more people/devices within 2 m of each other. Accordingly, we carried out 200 simulation-based experiments in which the actual device distances were controlled and compared them to the computed distances from BLE devices. We evaluated the performance of the wearable system in 13 different scenarios designed to mirror the challenges encountered in care homes, namely suboptimal device placement, different building materials and obstructions between devices. The results were published in the *Journal of Occupational and Environmental Hygiene*.[25] We computed contact-detection success rates and the impact of following the manufacturer's guidelines on increasing the success rate (fidelity with recommendations); being indoors or outdoors; the effects of common signal obstructions such as clothing or bags; and the impact of device type (i.e. fob vs. card) on detection accuracy.

The performance of the CONTACT system was heavily influenced by the environment in which the devices were used and the ways in which they were used (i.e. implementation). Both fob and card forms of BLE wearable, when used as intended and without obstacles in place, generated an accuracy of 84.7% of the true contacts correctly recorded. However, when using more closely mirrored *actual* implementation in care homes (i.e. BLE wearables placed in pockets or handbags, attached to wheelchairs or with a partial wall obstructing the signal), accuracy was only *64.2%*.

Thus, the form of the BLE wearables was not important in terms of technical performance but did matter in terms of feasibility and acceptability. Each BLE device, whether a fob, worn watch or brooch-style, or card differed by only small amounts: mean difference over five distances from 0.5 to 2.5 m and standard deviation (SD) for each BLE wearable form was fob watch, 0.21 m, 0.25; fob brooch, 0.5 m, 0.42; and card 0.19 m, 0.17. All devices were susceptible to reductions in accuracy by being placed in a bag or under a scarf; calculated distances were greater than (actual) physical distances, which is likely to lead to false negatives when used with a particular time–distance contact threshold. Outdoors, the device results varied more, with a lower contact-detection success rate than for experiments conducted indoors. The effects of walls and doors meant that false-positive contacts could be generated, even when people or devices were in different rooms. We concluded that BLE devices could provide effective proximity detection in care homes in which residents' mobility is limited and BLE wearables are worn correctly without obstruction. However, in many homes, residents are mobile, have dementia or other cognitive impairments, and have limited control over where devices are placed and controlling for obstacles. Careful implementation of systems such as CONTACT is crucial for obtaining accurate and reliable information. The data for our simulations are available at https://github.com/kishibutt/contact-experiments-data.

TABLE 1 The four care homes in which feasibility and acceptability were evaluated

Home	Type	Ownership[35]	Maximum capacity	Number of staff	Number of residents	Number of residents with dementia	Device type issued
Home 1	Residential care	For-profit independent	30	25	26	6	Card
Home 2	Residential care	For-profit independent	15	21	15	2	Card
Home 3	Nursing care	For-profit independent	28	37	23	5	Fob
Home 4	Dual registered for residential and nursing care	For-profit non- private Equity chain	102	120	87	25	Fob

TABLE 2 CONTACT progression criteria

Criterion	Objective	Green	Amber	Red
Acceptability of the intervention	Proportion of participants wearing the device	71%+	51–70%	< 50%
Provision of the intervention	Proportion of active CONTACT devices not recording data for > 1 week	20%	21–30%	> 31%
Acceptability of CONTACT feedback report	Demonstrated acceptability of outputs ascertained through home manager interviews	Judged qualitatively with Study Steering Committee		

The feasibility and acceptability of the CONTACT intervention

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We examined the feasibility and acceptability of the CONTACT intervention and planned study procedures in four care homes in North and West Yorkshire, UK (see *Table 1*) using a non-randomised mixed-methods design.[37] The need for effective non-pharmaceutical infection prevention measures such as contact tracing in pandemics remains in care homes, but traditional approaches to contact tracing are not feasible in care homes. The CONTACT intervention introduced BLE wearable devices (BLE wearables) as a potential solution for automated contact tracing. Using structured reports and reports triggered by positive COVID-19 cases in homes, we fed contact patterns and trends back to homes to support better-informed infection prevention decisions and to reduce the blanket application of restrictive measures. The intervention was applied to the entire home, and the staff and residents provided written consent to participate in the study. We wanted to include visitors to the homes in the study, but the homes told us (during recruitment or early in the intervention period) that the lack of reception staff (in two homes) or additional burden associated with study procedures for collecting visitor data and device use (all four homes) was too great, and that this part of the planned study was unacceptable.

The purpose of this feasibility study was to inform our decision to progress (or not) to a cluster randomised definitive trial that would require more (public) funding. The criteria for disease progression are given in *Table 2*.

Wearable acceptability and provision criteria are based on accepted levels of required uptake for effective contact tracing.[30] The acceptability of feedback is a pragmatic criterion derived from studies of information use in healthcare performance.[39]

The homes implemented the CONTACT intervention for 2 months between 1 November 2021 and 31 March 2022. Of the eligible and consenting residents, 102 (97%) started the intervention and wore BLE devices. Of the 225 eligible staff, 82.4% participated. Residents and staff members were overwhelmingly female (73% and 86.7%, respectively). Almost 40% of the residents (37.6%) had a dementia diagnosis, and most of the staff participants were involved in frontline care (64%) and had a permanent role (90%). Less than one per cent of the staff worked more than at home.

Some aspects of the implementation were successful. For example, 70% of the residents and 87% of the staff received BLE wearables before the feasibility start date in their homes. However, the process of issuing and logging resident devices from participant consent was inefficient, with a mean of 41 days (SD = 23.87) in homes. These delays have contributed to resident withdrawals. Staff devices were issued only slightly more efficiently (mean, 36 days; SD, 15.31). The devices themselves produced implementation challenges: 11% of residents and 6.5% of staff devices were lost or damaged, while half of the resident devices were replaced, < 10% of staff devices were. The BLE wearable form impacted the battery life. Fobs required battery changes, but card-type devices did not (15% vs. 0%). Waves and gateways (the technology that enabled data capture and transmission) were sometimes unplugged, for example, by cleaning staff to use equipment, but our safety systems quickly enabled remedial action and kept the system online. The technical infrastructure performed well, with no substantive issues transferring captured data from the homes to our commercial partner's servers and then to university secure data systems. We compared the expected and observed data to identify the reliability of the data capture in situ and evaluate whether BLE wearables were functioning as expected: only around a third of the staff and resident devices were consistently reliable. Reasons included battery failure, inappropriate device placement (e.g. in handbags), or homes not keeping accurate records of device changes.

Home managers are not always fully engaged in the project. Implementing the technology and delivering the study procedures require (virtual) training. Of the 34 key staff invited to the training sessions, only 22 (65%) attended. Our structured and reactive feedback was variably understood by homes, but managers were clear that the CONTACT analyses were unlikely to be acted upon. Reasons why included 'not trusting' device-generated contact patterns, lack of faith in the quality of the data, and the trade-offs involved in action, such as risking compromising staff trust in management if harmful behaviours were tackled based on CONTACT's analyses. CONTACT's information was often viewed more positively when it confirmed preconceived beliefs (that IPC behaviours were adequate) or patterns of contact (that a resident was unlikely to have had contact with a specific resident):

> *The scheduled reports seem to replicate what was happening, it made sense as it showed staff were supposed to be where they should be. That give me the confidence it was picking up the people it should. It then translated into confidence that it would be a useful tool to monitor where the infections were and how they would be transferred.*
>
> *Home 1, Manager*

> *The triggered report was helpful as it confirmed what we suspected. One resident was positive, her neighbour goes into her room a lot and we see this in the report and a staff member that seen her on the day. We tested both individuals, and both were (COVID-19) positive.*
>
> *Home 4, Manager*

Staff privacy was a major barrier to adoption; staff feared being 'tracked' and this eroded trust in the technology. Study procedures (in particular, screening and consent) were added to the existing work, making participation burdensome. Participation in CONTACT did not outweigh the perceived study burden. Perception amplified by the pandemic context. Some managers saw some utility for CONTACT-style technology, but *outside* the rigorous and clinical trial/research context.

> *If this wasn't a trial and we had this info because this was the system we were using, I would feel comfortable saying, 'hang on a minute, this is showing, this is showing and this is what we can do about it' as an assessment to present to anybody…outside of a trial. It would have given me the confidence to say this is what the infection is doing, and we can safely isolate that and carry on doing what we are doing with the other residents, so the residents don't suffer from lack of visitors.*
>
> *Home 3, Manager*

Our projected compliance and participation rates are too low to justify a definitive trial. Two of our progression criteria were rated 'amber': 62.8% of the consenting residents and 67.7% of the consenting staff wore their devices for the study duration. Only 29.2% of the resident devices recorded data 'correctly' during the 2 months, constituting a 'red' criterion rating. Our qualitative findings also suggested that issues of 'wearability', given the characteristics of the wearers, and the burden of implementation and study procedures outweighed the perceived value of the information generated. A large-scale definitive trial of BLE wearables for contact tracing and feedback-informed IPC in care homes was unfeasible and unacceptable, at least in the context of the shifting COVID-19 pandemic demands. Our overall recommendation is that future research involving BLE wearable technology for tracing applications should co-design interventions (including enhanced wearability) and studies with care homes, focusing more on successful intervention implementation than just evaluating technical effectiveness.

The generative mechanisms behind CONTACT's lack of feasibility and acceptability

To be feasible, homes had to learn new ways of working to accommodate CONTACT's technology and feedback in their everyday work. We undertook a process evaluation alongside our feasibility and acceptability study to help understand the results and optimise future work,[37] because it explains and predicts innovation-related work in social contexts such as care homes. We used the normalisation process theory (NPT)[40,41] to frame our data collection, organisation and analysis. We adopted a mixed-methods approach using qualitative interviews, field notes and observations, study case report forms (CRFs) and documents, quantitative survey instruments and counts of activity.

Thirteen themes related to the four core NPT constructs were developed (*Table 3*).

Coherence: The sense-making of staff and residents undertook CONTACT's purpose and value. Homes varied

TABLE 3 Generative mechanism themes and NPT constructs

NPT construct	Theme	Illustrative data
Coherence | sense-making	Variable buy-in	*'Staff and residents had a lack of understanding. My understanding wasn't there, and I can't expect someone to understand something that I don't understand myself'* (Home 1, Study champion)
	Legitimacy and credibility	*'No investment from staff, it was not engrained within in the care home enough. As much as we could tell them to wear them, there are more than 100 people. I think it was up to the leads to encourage staff to wear the device, and that approach wasn't there. The staff didn't really remember or care to do it'* (Home 4, Study champion)
	Across-role engagement	Managers and senior staff demonstrated understanding and engagement, others had minimal understanding and engagement
	Carer engagement	*'I wear my device at all times, but I know others take theirs off'* (Home 2, Care assistant)
Cognitive participation | work to promote CONTACT engagement	Identifying and appointing the *right* key staff	In three smaller homes, managers took on champion roles as there were no staff judged to have the requisite skills
	Finding and engaging gatekeepers for whole home engagement	Against advice, one home appointed multiple study champions. In three smaller homes, managers assumed study champion roles and struggled to enact work required. Staff were gatekeepers (of variable quality) for recruiting and retaining resident participation
	Enacting study tasks	Variable staff commitment meant key study tasks (CRFs, device logs, battery records) were variably completed
	Diverse motivations	Motives for participation were not always COVID-19 related
	Acceptability and wearability	Some staff removed devices when undertaking key personal care (assisting with feeding or personal hygiene). Some resident devices were in suboptimal locations masking contacts (handbags, cupboards and drawers). Managerial estimates of compliance (~80% wear) did not match observed reality (7% in one 15-minute observation period of 41 people in a communal area)
Collective action | individual's CONTACT enactment work	Balancing workload against available resources	*'...difficult to prepare for such a big workload when one doesn't know what's coming. Don't know until you do it. Wouldn't have put us off, but we would have been better prepared'* (Home 4, Manager)
	Training and support from a distance	Remote and virtual training led to attendance of between 33% and 100% (mean 65%)
	Credibility of CONTACT data	*'I wasn't confident with some of the data on the scheduled report because the locations were showing people were having contacts and congregating in the corridors, and I know for sure that they don't meet there. So that was lacking in the accuracy, a lot of the contacts in my home happen in rooms, like day rooms and dining rooms'* (Home 3, Manager) *'The scheduled reports seem to replicate what was happening, it made sense as it showed staff were supposed to be where they should be. That give me the confidence it was picking up the people it should. It then translated into confidence that it would be a useful tool to monitor where the infections were and how they would be transferred'* (Home 1, Manager)
Reflexive monitoring | appraising CONTACT	Negative feedback learning loops and balance	*'The triggered report covered mostly what we knew already. I did analyse the scheduled report which identified which residents are most at risk. But if you find out which individuals are most at risk, what can you really do with that information? We can make people isolate but then you lose staff. The staff do a lateral flow test before work every morning, that's the protection we already have, without losing too many staff'* (Home 4, Study champion)

in the scale and extent of their commitment to and understanding of technology and study procedures. Leadership credibility was important but not sufficient to outweigh competing priorities among other staff; management and direct care staff saw CONTACT differently. Interviews revealed that few residents had a detailed recollection of why they were wearing the fobs or cards; ironically, memory-related limitations were part of the rationale for CONTACT's automated contact tracing.

Cognitive participation: The ways staff and residents engaged with CONTACT and their roles. Work to promote (cognitive participation) and enact (collective action) CONTACT was burdensome and failed to be prioritised over competing COVID-19-related demands on time and scarce human and cognitive resources. The timeliness of key study tasks such as CRF completion and notifications of battery changes and damage to wearables tailed off over time. Adaptation was common, largely because staff felt some devices 'got in the way' of care delivery. However, adaptations such as putting devices in handbags or on walking frames and wheelchairs potentially compromise BLE signals, performance and reliability.

Collective action: How CONTACT was implemented and the interactions involved in enacting it. The individual burden for study champions was significant and meant that if the staff were to enact study procedures and promote effective adoption, they had to reduce the time spent on other – everyday – work. The (perceived) opportunity costs of CONTACT are significant. Training required to carry out study procedures was delivered online, but attendance was variable, and competing priorities were evident. Thus, homes were not fully engaged in the task. The CONTACT data presented in the feedback reports led to some cognitive dissonance with the staff members' everyday experiences. Patterns and trends that challenged perceived contact patterns were often rejected, often on the grounds of the credibility, trustworthiness and face validity of the CONTACT data and analysis. Conversely, the patterns that supported the perceptions were welcomed and acceptable. Brown *et al.*'s meta synthesis[39] as part of feedback theory development highlights the importance of credibility and its key role in workers' intentions and actions:

> *Credibility was how health professionals perceived the trustworthiness and reliability of the feedback. Recipients were more likely to believe and engage with credible feedback, which facilitated Interaction, Verification, Acceptance, Intention, and Behaviour.*[39]

Reflexive monitoring: Work done by homes to appraise the effects of CONTACT. Overall, the experience of adopting CONTACT and interaction with the feedback led to a negative feedback cycle of learning for managers and champions, which could challenge valued staff relationships and trust, even when a challenge was warranted because of infection risk-promoting behaviours; enacting study procedures well meant 'underperforming' in everyday work and the risk of censure from colleagues. CONTACT's passive components (location makers, wave scanners and gateways) became accepted over time, but the active components (BLE wearables) failed to be viewed more positively over time. CONTACT had to fit the context and existing work to be successfully implemented and stand a chance of improving IPC behaviours.[36,39] It did not fit. Homes had to rapidly adapt and change their work repeatedly during the 2 years of the pandemic.[42] CONTACT was trying to adapt to work that itself was adapting.

CONTACT costs

The ways in which planned users of a technology perceive its costs and values are an important determinant of adoption.[43] There were no direct financial costs to the care homes for taking part in CONTACT, but it was clear that technology adoption, and to a greater extent, study procedures, came at too high a cost in terms of time, opportunity costs, and effort in understanding the value of the information generated for managerial IPC decision-making.

We wanted to have some idea of the potential costs to the NHS and Social Care system of CONTACT if its adoption was wider than our initial feasibility study. Using the micro-costing approach of Xu *et al.*,[44] we examined the costs to our four homes if they had paid for the technology (see *Appendix 3*, costs). Resources associated with CONTACT were captured using invoices (i.e. CONTACT equipment costs), research team activity logs, care home staff time surveys documenting study activities, and time spent on the activity. The costs were from December 2021 in the Great British pounds (£). The mean annual cost per participant was £176.53 including equipment, installation, training, CONTACT and delivery costs. After a year (with equipment, training and set-up costs no longer present), the total cost per participant would be reduced to £164.39.

Ultimately, and in part due to its research study context, CONTACT's utility for IPC was insufficient, given the perceived burden and complexity involved.

Bluetooth-enabled wearables' potential in care homes

It would be tempting to conclude that BLE wearables for contact tracing have little promise or cannot become a part of normal work in care homes. We believe that this is premature. Ultimately, CONTACT's technology, if adequately implemented, generates social network data that hitherto have not existed: who has contact with whom, when, where and for how long. CONTACT's focus was on IPC and COVID-19 contact tracing; however, there are two examples of wider potential applications worthy of highlighting.

First, in conjunction with the PROTECT COVID-19[34] study team, we used the CONTACT IoT infrastructure in two homes to 'bolt on' remote sensors to capture data on important determinants of environmental quality [air quality (CO_2 levels), temperature and humidity]. Homes averaged CO_2 levels of ~800 ppm or lower in most spaces, indicating reasonable air quality. However, spikes in peak values indicated suboptimal air quality. This likely reflects increased occupancy at certain times of the day (e.g. staff rooms at shift handovers or breaks). Using specialist software and algorithms (CONTAM[45] modelling), we occasionally observed high levels of CO_2 and infection risk, and natural ventilation rates rarely exceeded three ACH (air changes per hour), with some bedrooms and corridors considerably lower. The low CO_2 values were likely a result of low occupancy, rather than a good ventilation. Given the role of ventilation in reducing infection risk from airborne viruses, there is considerable potential for future research to evaluate efforts to increase natural ventilation in care homes (and ventilation-related behaviours by staff). CONTACT's IoT infrastructure and ability to produce detailed and dynamic data on social networks and traffic in environments could improve information in infection models.[29]

In the second area, social network data generated from CONTACT-like systems may help improve home quality. Our study's primary focus was IPC, but we have previously written about the determinants of quality in care homes.[46] Quality in homes is 'relational': it is driven by the quality and quantity of contacts and networks that residents and staff develop and sustain. CONTACT's BLE wearables and analysis surfaced these networks often with unexpected and uncomfortable results.[47] CONTACT revealed elements of relational ties in homes that (1) have the potential to influence quality and (2) may have otherwise been tacit or hidden. Examples include:

- Despite the scale of contacts in the four homes (n = 204,087), only 2% of interactions were over 2 minutes. Of these, the staff had double the proportion of interactions among residents (67.4%, n = 3296 vs. 32%, n = 1568).
- Only one home had equivalent interactions between staff and residents, and three had far more contact between staff than between staff and residents.
- Being able to identify the most and least connected community residents and staff, providing valuable clues to unequal workloads and missed social isolation, differences that are reflected in each home's 'weight' (tie strength), and median duration of interactions. Homes' median weights varied from 5 (few connections) to 79 (many connections), with median durations between just 8 and 13 minutes (interquartile ranges of 4 and 18 minutes).
- Being able to identify subcommunities within a home and patterns of interaction strength and quantity in the daily routine. For example, social network analysis (SNA) revealed that the largest home had fewer and less cohesive subcommunities than the others. Smaller homes had more subcommunities but were more cohesive. We have previously shown how important concepts such as 'reciprocity'[46] in relational networks can be measured – albeit with some additional data collection – in care homes.[48] Auto generated network data from BLE wearable systems could make this new information visible and amenable to quality improvement – for example, examining reciprocity over time as a proxy for valuing residents.[46,48]

BLE wearable-generated data within IoT systems could facilitate a more nuanced approach to targeted quality-improvement interventions, including network interventions to increase size and quality of social net works in homes.[49] Genuinely reflecting the relational nature of the concept, network data could enable better planning, implementation and evaluation of quality improvement, in ways that reflect actual social ties, work and interactions that happen in homes, rather than work and relations 'as imagined'.[50]

Strengths and weakness, and what could have been done differently

CONTACT was the first study to evaluate BLE wearables in a care home and contact-tracing context. This showed that some essential research procedures (screening and deploying key intervention components) could be undertaken relatively quickly and effectively, others, such as consenting residents without capacity, visitor registration, data completion and essential maintenance of intervention equipment.

The IoT infrastructure was easily and cheaply installed and enabled us to see the possibilities of CONTACT-type technology in areas such as environmental quality, targeted quality and network interventions. Again, these are novel uses and, especially in the case of targeted quality improvement, offer the possibility of a stepwise advance in the state of art.[48,51]

Data from interviews, observations and automated sources helped check our assumptions and combat the limitations of biases from self-reported methods. For example, the observed number of devices worn contradicted self-reported behaviours. Conversely, staff interviews revealed that observed adherence to recorded study procedure compliance masked a sense of burden and resentment towards study tasks, creating negative learning and feedback loops and negative reflexive monitoring. For example, changing device batteries increased study reporting requirements for staff and disincentivised essential battery changes.

CONTACT was devised, developed and commissioned rapidly from inception to commencement in 4 months. This demonstrated that partnerships between academia, technology, and care industries and useful data can be developed quickly. We provided social network data to the UK SAGE – Scientific Advisory Group for Emergencies – Social Care subgroup and facilitated engagement with the UK PROTECT National Core Study on COVID-19 air-quality and ventilation studies. The process evaluation highlights our data limitations and helps calibrate uncertainty estimates.

CONTACT has several limitations. First, not all participants using technology participated in the feasibility assessment. Key staff left during the study, such as the manager in Home 1, severely affecting the implementation of the technology and study procedures.

Coronavirus disease pandemic restrictions have hampered research teams' in-person presence in care homes. This means that the vast majority of implementation and support activities were undertaken remotely. This impeded the development, implementation and evaluation of the study. At the time of hugely competing demands on time and attention for managers, remote methods designed to help staff acquire new skills and knowledge, and use new information were suboptimal. A CONTACT-style intervention may be more feasible post restriction.

The pandemic context and rapid study commissioning led us to compromise and deploy pragmatic approaches to the (limited) co-creation of technology and implementation. Co-creation post deployment focused too heavily on workarounds for the existing issues. This study highlights the importance of thorough co-development to prevent compromising interventions.[52]

Our formal 2-month feasibility evaluation period was insufficient for technology to become an integrated part of care homes' daily work. It was clear that the CONTACT intervention was not embedded into homes, but we cannot rule out the possibility that a longer period in the homes may have helped establish and sustain greater levels of trust between homes and research teams, and between homes and technology and data.

The SNA metrics generated (as a secondary focus of the study) from BLE wearables provided only partial insights into quality in care homes. Metrics must be interpreted in this context. Interestingly, when staff offered contextualised explanations for some findings – for example, the far greater number of staff than staff–resident interactions – these did not explain the SNA results. As with all wearable-generated SNA, CONTACT generated undirected home network data. This meant that understanding some key concepts such as 'reciprocity' was impossible without more (qualitative) data collection. The absence of a key measure of quality[46,48] was a missed opportunity but would also impose additional costs and burdens.

Our recruitment and pre-feasibility study workup occurred prior to the UK's COVID-19-vaccination programme. Implementation and feasibility assessment were performed after vaccination. The pandemic context changed, as did the perceived relative advantage of CONTACT's information and technology. This is likely to have reduced the chances of adoption.[53,54]

Lessons learnt for future research/limitations

Effective implementation is as important as the technical efficacy of the technologies used.[48] Future research involving BLE wearable systems should concentrate on applying known strategies for successful research with care homes[55] – co-producing BLE wearable systems that minimise the burden on homes. Facilitators, such as privacy, trust and the utilisation of valuable data from such systems, should be the focus of the planning and implementation phases. Some barriers were so significant – for example, the privacy concerns of staff and the interplay of these concerns with infection risk-increasing behaviours (such as congregating in smoking shelters) – that a sustained period of relationship-building and the co-production of implementation approaches seems almost unavoidable for sustainable adoption.

The implementation of scientific theories[41,53,56] should be used as the basis for planning, implementation and evaluation of change efforts and technology introduction. Quality-improvement interventions in care homes are common, but like other health and social care settings are prone to failure.[57] By using theory systematically and incrementally as the basis for improvement and evaluation, stepwise and compound development and learning is possible. Ivers *et al.*[58] have argued for the greater use of evidence and theory as the basis for plugging gaps in systematic improvement methods based on evidence. Similar arguments can be made for care home quality improvement using technologies to enhance the relational aspects of quality.

In addition to the use of appropriate evidence and theories of implementation, efficient research designs that enhance our knowledge of implementation and intervention effectiveness are needed. Hybrid studies that combine an implementation focus with measuring effectiveness could yield the most valuable insights for home care researchers.[59]

Trial registration details

CONTACT was prospectively registered as ISRCTN11204126, registered 17 February 2021.

Patient and public involvement

The study team included co-applicants and steering committee members with care (IS, MO), care providers, and local authority oversight experience. We also had access to existing family and carer groups associated with two of the homes in our study, which we accessed through the Nurturing Innovation in Care Home Excellence in Leeds (NICHE-Leeds) partnership (https://niche.leeds.ac.uk/). Our aim was to ensure that the voices of people who received and delivered care were represented in technical, methodological and intellectual discussions and the judgements and choices we made. We worked with our patient and public involvement (PPI) members on the study formulation and grant writing through dissemination planning. PPI input led to adjustments in consent language and procedures, home information leaflets and posters, and interpretation of results, particularly of the SNA and its significance for quality and the relational aspects of home life. PPI in care homes research is a well-established research aspiration,[60] and while it can improve the quality of research, researchers have called for more systematic approaches to establish its value and reduce uncertainties.[61] Our regular research team and Study Steering Committee meetings, alongside individual communications between researchers and PPI team members, were an effective mechanism for capturing views and allowing time for advocacy and follow-up. The pandemic context and remote working methods that impacted the delivery of the intervention also affected the aspects of effective PPI and teamwork. For example, online meetings lacked the nuance and non-verbal aspects of communication, so they were valuable for face-to-face collaboration. While we had older adults as carer representatives and research team members had parents living in care homes, we did not have any care home residents as part of the team. We indirectly accessed residents through the NICHE-Leeds family and carer group to check the planned project early in the intervention development phase of the study, just as the UK's second wave of COVID-19 infections in homes began (November 2021).

Equality, diversity and inclusion

CONTACT enrolled 202 care home residents from four care homes of a variety of for-profit providers in North England. The residents were all from white ethnic groups, and their mean age was 86.1 years (SD 8.58); most (73%) were female and had spent an average (mean) of 696 days (range 14–4130) in the home, and 37.6% had received a diagnosis of dementia. These figures mirror those of the national care home population in terms of length of stay,[62] age[63] and gender. The number of residents living with dementia was lower than the national average (www.alzheimers.org.uk/sites/default/files/migrate/downloads/dementia_uk_update.pdf) of ~80%. This is explained by our screening procedures, which require formal (medical and recorded) diagnosis in a care record. Ethnicity in care homes for the older population is not collated nationally – only 'social care' which included other types of residential and non-residential provision.[64] Accordingly, while ~25% of residents are from non-white ethnic categories, this is not directly applicable to the care home population. Our workforce was overwhelmingly female with a mean age of 42.1 years (SD 14.75), reflecting the UK population of care home staff.[1] We did not collect data on staff ethnicity, but there was diversity in ethnic categories represented.

The research team acknowledges the potential for unconscious biases rooted in personal experiences and societal norms to influence our research. To address this, we tried to be aware of and actively reflect on potential biases, seek diverse feedback through the range of viewpoints that informed our work, use established methodologies to reduce bias, and make our data collection and analysis available for scrutiny.

Implications for practice/decision-makers

The study was unable to show that CONTACT's BLE wearable and feedback-based intervention is an effective component of IPC in care homes. It is important to recognise, however, that we were evaluating not only the technology (which was by and large adequate) but also its implementation (which by and large was not) and the study procedures for a possible *future* trial (which added burden, with no immediate rewards for the time and effort invested in by homes).

Contact tracing as an intervention in a future pandemic in care homes and as part of a management strategy for other communicable and common diseases (such as norovirus or influenza) in homes remains a valuable part of pandemic and disease management,[65] but the challenge of how to enact it in care homes remains. BLE wearables may still help meet this challenge, but more research is needed to determine the most effective and acceptable way to fulfil any potential. Given the technical adequacy of CONTACT-style hardware and data quality, individual care providers may wish to use the technology as part of their own service-improvement efforts and report the results for others to learn from.

Research recommendations

More intervention development is required before BLE wearables and feedback as a basis for contact tracing and targeted and improved IPC strategies merit a definitive trial. However, the experience of evaluating the feasibility of the intervention also opens several new areas of potential for future research.

Specific research questions that arose from CONTACT included:

- Can BLE wearable-based systems and SNA be used to enhance the effectiveness and efficiency of quality improvement efforts in care homes?
- How can we effectively overcome the fears of staff associated with the introduction of new technology into home care environments?
- Do less-burdensome alternatives to RCTs (e.g. longitudinal participative observational studies) for evaluating theory and evidence-based introduction of BLE wearables into care homes result in more successful adoption?
- What interventions to increase natural ventilation in care homes are feasible and acceptable for the staff and residents?
- How can we most effectively encourage and sustain ventilation-promoting behaviours among staff and residents in care homes?
- Would an educational intervention to help care home managers understand and use infection risk and trend data result in higher-quality IPC strategies and outcomes?
- Can existing research partnerships between care homes and universities be leveraged to increase the chances of undertaking effective research on technology adoption in homes?

Conclusion

The CONTACT intervention of BLE wearables for contact tracing and feedback in a pandemic and academic study context was neither feasible nor acceptable in care homes. We planned CONTACT rapidly, implemented it using methods that were pragmatic rather than optimal and evaluated it during a shifting COVID-19 pandemic context. The existence of a successful COVID-19 vaccine and successful vaccination roll-out to care homes meant that the value of CONTACT-generated information *given* the efforts involved in generating it for homes in a research study context was simply not worth it for home managers and key staff involved in implementation. In the face of obvious challenges to feasibility, proceeding to a full-cluster randomised trial is unwarranted.

This study contributes to knowledge in a number of important ways: it was the first time that the technology had been used in this context and population; our analyses were based on actual real-world parameters rather than the assumptions and hypotheses used in most extant research; it provides an example of the costs of pragmatic adaptation to context for implementation; and how technically adequate hardware can have real-world performance compromised by psychosocial factors.

Despite the limitations of this study, the technology underpinning CONTACT is promising. Consequently, future research is recommended but with an important shift in focus: researchers should aim to co-design studies with care homes and place equal, if not greater, emphasis on the successful implementation of the intervention rather than the technical effectiveness of the wearable devices.

Additional information

CRediT contribution statement

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Data-sharing statement

The data sets generated and/or analysed during the current study are not publicly available as they contain sensitive information of residents and families of the homes, and we cannot rule out the possibility that those close to the homes may think they recognise certain aspects of context. Anonymised social network data on contact patterns for the four homes are available from the corresponding author upon reasonable request.

Ethics statement

CONTACT's feasibility study and associated process evaluation of CONTACT received approval as part of the CONTACT study by the UK Health Research Authority (REC: 294390, 10/6/21).

Information governance statement

The University of Leeds is committed to handling all personal information in line with the UK Data Protection Act (2018) and the General Data Protection Regulation (EU GDPR) 2016/679. Under the Data Protection legislation, the University of Leeds is the Data Controller (registration number provided by the Information Commissioner's Office is Z553814X), and you can find out more about how we handle personal data, including how to exercise your individual rights and the contact details for our Data Protection Officer here (dpo@leeds.ac.uk).

Disclosure of interests

Full disclosure of interests: Completed ICMJE forms for all authors, including all related interests, are available in the toolkit on the NIHR Journals Library report publication page at https://doi.org/10.3310/UHDN6497.

Primary conflicts of interest: Carl A Thompson has previously provided paid scientific advice to Microshare Ltd. and has presented to the SAGE care home working group.

During the COVID-19 pandemic, Adam Gordon and Catherine Noakes participated in the UK Scientific Advisory Group for Emergencies (SAGE). Adam Gordon was a member of the SAGE care home working group, and Catherine Noakes co-chaired the SAGE Environment and Modelling Sub-Group.

Carl A Thompson: HS&DR Commissioned Panel Members, August 2015 to September 2019. HS&DR Funding Committee Members, September 2019 to September 2022. HS&DR Funding Committee (Seacole) (date unknown).

Amanda Farrin: NIHR CTU Standing Advisory Committee, May 2022 to May 2026. HTA Funding Committee Policy Group (formerly CSG), March 2014 to October 2018. HTA Clinical Evaluation and Trials Committee, November 2014 to November 2018.

Chris Bojke: HS&DR Funding Committee Members, September 2018 to September 2019. HS&DR Funding Committee (Bevan), November 2020 to September 2021. HS&DR Sub-Committee Unmet Need, November 19.

Karen Spilsbury: HS&DR Funding Committee Members, September 2013 to September 2018.

Department of Health and Social Care disclaimer

inclusive and will continually monitor best practice and guidance in relation to terminology and language to ensure that we remain relevant to our stakeholders.

Publications

Findings from CONTACT were presented at the 6th International Conference on Evidence-Based Policy in Long-Term Care, LSE, September 2022, and NICHE-Leeds 5-year celebration event, September 2023. A summary of the study was sent to each participating home manager. Five peer-reviewed articles have been published.

Thompson CA, Willis T, Farrin A, Gordon A, Dafu-O'Reilly A, Noakes C, *et al.* CONTACT: a non-randomized feasibility study of bluetooth-enabled wearables for contact tracing in UK care homes during the COVID-19 pandemic. *Pilot Feasibility Stud* 2024;**10**:125. https://doi.org/10.1186/s40814-024-01549-6

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Khaliq KA, Noakes C, Kemp AH, Thompson C; CONTACT Trial Team. Evaluating the performance of wearable devices for contact tracing in home care environments. *J Occup Environ Hyg* 2023;20:468–79. https://doi.org/10.1080/15459624.2023.2241522

Trial registration

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This synopsis provided an overview of the research award CONtact TrAcing in Care homes using digital Technology (CONTACT) - A pragmatic cluster randomised controlled trial, cost-effectiveness evaluation and theory-informed process evaluation. For other articles from this thread and for more information about this research, please view the award page (https://fundingawards.nihr.ac.uk/award/NIHR132197).

About this synopsis

The contractual start date for this research was in October 2020. This article began editorial review in January 2024 and was accepted for publication in December 2024. The authors have been wholly responsible for all data collection, analysis and interpretation, and for writing up their work. The Health Technology Assessment editors and publisher have tried to ensure the accuracy of the authors' article and would like to thank the reviewers for their constructive comments on the draft document. However, they do not accept liability for damages or losses arising from material published in this article.

List of abbreviations

AUC-ROC	area under the curve in a receiver operating curve
BLE	Bluetooth-enabled
CONTACT	CONtact TrAcing in Care homes using digital Technology
CRF	case report form(s)
IoT	Internet of Things
IPC	infection prevention and control
NICHE-Leeds	Nurturing Innovation in Care Home Excellence in Leeds
NIHR	National Institute for Health and Care Research

NPT	normalisation process theory
RCT	randomised controlled trial
RFID	radio frequency identification
SARS-CoV-2	severe acute respiratory syndrome coronavirus 2
SNA	social network analysis

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Appendix 1 CONTACT structured report to homes

CONTACT
Contact tracing in care homes using digital technology

What does your CONTACT data show?

REPORT 3 - 18/02/2022

Here are contacts* between residents, staff and visitors in your home since the previous report. This report highlights who, where and when contacts are happening and how contacts are changing over time. It also provides information on any infections occurring in your home.

CONTACT team researchers will call you in a few days to talk through the information. They can help you understand what, if any, action you might like to consider.

**CONTACT is two people within 2 metres for 15 minutes or more*

Residents with the most contacts

15 (83%) of residents had contact with another resident

17 (94%) of residents had contact with a staff member

32 (82%) of staff had a contact with a staff member

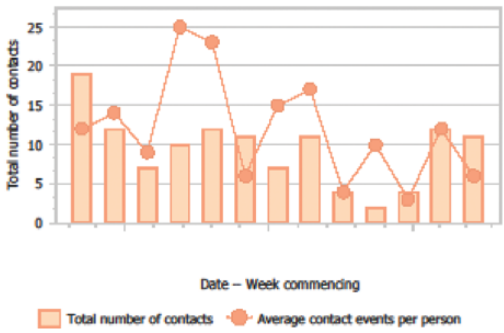
Device ID	Resident	Staff	Visitor
AC233FA8BD68	18	26	0
AC233FA8BD23	15	22	0
AC233FA8BD1A	10	26	0
AC233FA8BD2B	13	22	0
AC233FA8BD0C	12	20	0
AC233FA8BCFB	14	16	0
AC233FA8BD17	10	20	0
AC233FA8BCFA	8	18	0
AC233FA8BD1C	9	14	0
AC233FA8BD1F	12	10	0

Most contacts — Least contacts

Changes in contacts over time

The bars and lines on these graphs show different information. The bars show the total number of unique device pairings each week. Example: Device A records contact with Device B three times, Device A records contact with Device C five times, Device B records contact with Device D six times – the unique number of pairings is three.

The dots/lines in the graph show the average number of contacts that each device has had in one week. Example: like before, Device A records contact with Device B three times, Device A records contact with Device C five times, Device B records contact with Device D six times. The average is calculated by dividing the total number of contacts each device has had – 28 – by the number of devices - 4. So, the average number of contacts is 7



Resident - Resident

Key Message

Appendix 2 CONTACT 'reactive' report to homes

Cover

CONTACT
Contact tracing in care homes using digital technology

University of Leeds

Triggered Report

For the period 01/02/2022 – 03/02/2022

The CONTACT tracing technology currently in your care home transmits data relating to the number of contacts made in the home – a contact is when 2 or more devices come into contact with each other for 15 minutes or more at a distance of 2 metres or less.

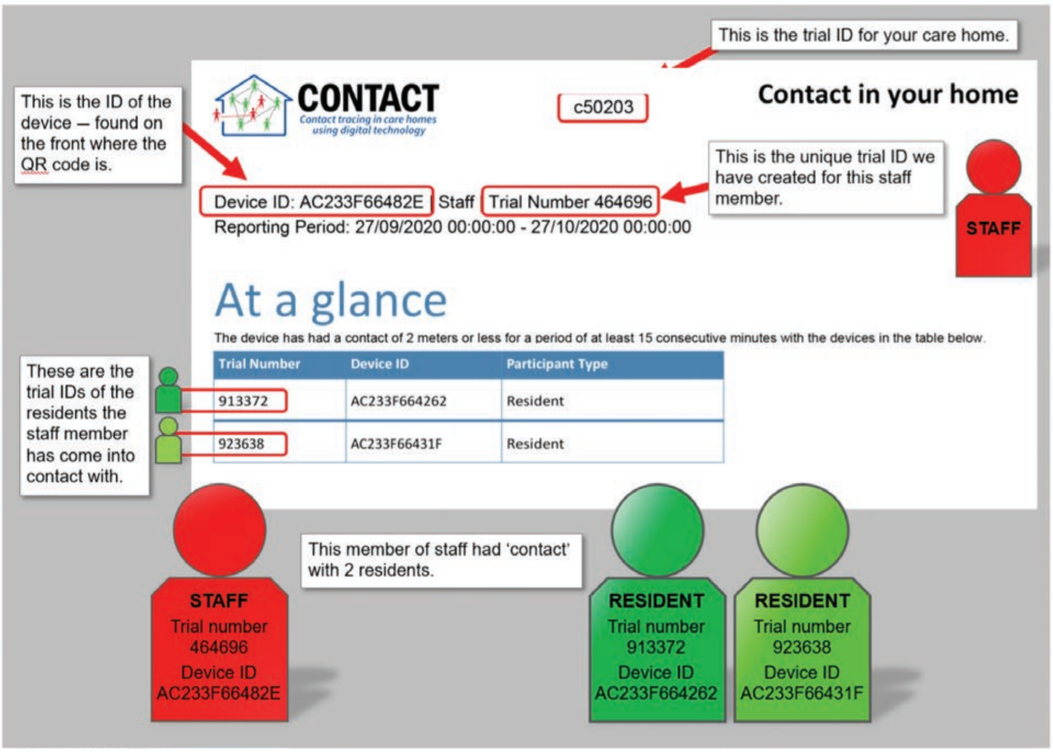
This report provides you with a breakdown of those contacts.

The first page/s provide you with a general 'at a glance' quick summary of the headlines. It tells you who has come into contact with who, how many times and where. This type of information can help you to identify 'hot' areas where a lot of people might be coming into close contact with each other. The device IDs are already matched up to residents, staff and visitors. You can use your Master Device Log to find out more specific information about which device belongs to which person.

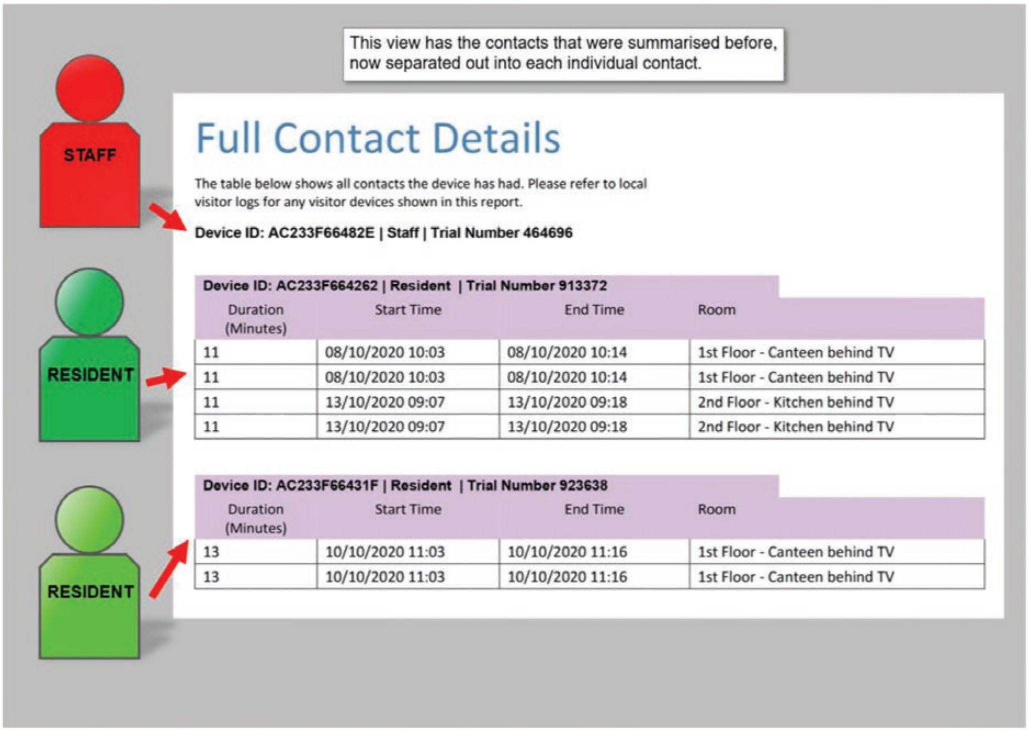
The 'detailed report' provides a more detailed breakdown of the 'at a glance' summary. This tells you about who came into contact with who, how long the contact was, what time the contact started, when it ended, and where the contact took place.

A quick reminder on how to interpret the report:

Page 1



Page 2



Full Contact Details

The table below shows all contacts the device has had. Please refer to local visitor logs for any visitor devices shown in this report.

Device ID: AC233F66482E | Staff | Trial Number 464696

Device ID: AC233F664262 | Resident | Trial Number 913372			
Duration (Minutes)	Start Time	End Time	Room
11	08/10/2020 10:03	08/10/2020 10:14	1st Floor - Canteen behind TV
11	08/10/2020 10:03	08/10/2020 10:14	1st Floor - Canteen behind TV
11	13/10/2020 09:07	13/10/2020 09:18	2nd Floor - Kitchen behind TV
11	13/10/2020 09:07	13/10/2020 09:18	2nd Floor - Kitchen behind TV

Device ID: AC233F66431F | Resident | Trial Number 923638			
Duration (Minutes)	Start Time	End Time	Room
13	10/10/2020 11:03	10/10/2020 11:16	1st Floor - Canteen behind TV
13	10/10/2020 11:03	10/10/2020 11:16	1st Floor - Canteen behind TV

Appendix 3 CONTACT costs

Cost item	Cost (£)	Fixed/variable cost
Equipment		
Wearable devices[a] *(365 fob devices, 148 card devices)*	36,936	Variable
Location markers and wave scanners (78 location markers, 38 wave scanners, adhesive, connectivity and spare straps/keyrings)	1123.20	Variable
Scanner gun	50	Fixed
Remote set-up fee[b]	550	Fixed
Shipping and handling	695	Fixed
Batteries *(Fob devices only)*	616.85	Variable
Equipment installation		
Planning *(Floor map plans)*	132.75	Fixed
Device preparation *(Tagging, aligning with floor plans and device management)*	265.50	Fixed
Installation	280.25	Fixed
Logs and inventory	132.75	Fixed
CONTACT training		
Training *(Main training, micro training and visitor training)*	51.63	Fixed
CONTACT care home set-up		
Consent *(Screening, resident and staff consent)*	1152.89	Variable
Registration	57.65	Variable
Device distribution	260.63	Variable
Device maintenance		
Device-related activities *(Ensuring the devices are activated, replacing missing devices, ensuring they are being worn correctly, changing batteries and cleaning)*	6131	Variable
Infection reporting *(COVID daily reporting and case reporting)*	2041.92	Variable
Visitor devices *(Allocating visitor devices, signing devices in and out, etc.)*	543.24	Variable
Additional activities *(Liaising with care home manager, weekly calls, scheduled report interpretation, etc.)*	1761.84	Variable
Total	£52,783	

a Wearables devices cost £72 per person per year. For the CONTACT study, both the wearable fob and key card devices cost the same; however, key card fobs usually cost more.
b A one-time 50% discount was applied.