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Raising the barcode: improving medication safety behaviours through a behavioural science-informed feedback intervention. A quality improvement project and difference-in-difference analysis

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ABSTRACT

Barcode medication administration (BCMA) technology can improve patient safety by using scanning technology to ensure the right drug and dose are given to the right patient. Implementation can be challenging, requiring adoption of different workflows by nursing staff. In one London National Health Service trust scanning rates were lower than desired at around 0–20% of doses per ward. Our objective was to encourage patient safety behaviours in the form of medication scanning through implementation of a feedback intervention. This was informed by behavioural science, codesigned with nurses and informed by known barriers to use. Five wards were selected to trial the intervention over an 18-week period beginning August 2021. The remaining 14 hospital wards acted as controls. Intervention wards had varying uptake of BCMA at baseline and represented a range of specialties. A bespoke feedback intervention comprising three behavioural science constructs (gamification, the messenger effect and framing) was delivered to each intervention ward each week. A linear difference-in-difference analysis was used to evaluate the impact of our intervention on scan rates, both for the overall 18-week period and at two weekly intervals within this timeframe. We identified a 23.1 percentage point increase in medication scan rates (from an average baseline of 15.0% to 38.1%) on the intervention wards compared with control ($p<0.001$) following implementation of the intervention. Feedback had most impact in the first 6 weeks, with an initial percentage point increase of 26.3 ($p<0.001$), which subsequently plateaued. Neither clinical specialty nor number of beds on each ward were significant factors in our models. Our study demonstrated that a feedback intervention, codesigned with end users and incorporating behavioural science constructs, can lead to a significant increase in the adoption of BCMA scanning.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ There are known difficulties in adopting barcode medication administration technology, as significant changes to nurses' workflow are required. These difficulties occur despite the widely acknowledged potential benefits of the technology for patient safety.

WHAT THIS STUDY ADDS

⇒ We demonstrate that it is possible to meaningfully increase the rate of medication barcode scanning through implementation of feedback interventions that incorporate behavioural science constructs. It is likely that similar healthcare settings will also benefit from the application of behavioural science when exploring how to improve uptake of patient safety behaviours.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The results of this study suggest that using behavioural science principles to inform the design of interventions aimed at improving uptake of patient safety behaviours such as barcode scanning may increase their effectiveness.

INTRODUCTION

Medication errors can have fatal and significant consequences for patients.[1] Barcode medication administration (BCMA) technology can help nursing staff reduce the incidence of errors during medication administration.[2 3] This requires barcodes on both the patient's wristband and the

medication to be scanned, crosschecking against the medication ordered to ensure that the correct drug, dose and formulation are administered.[4 5] Direct observations of medication administration demonstrate that BCMA can significantly reduce the rate of potential adverse drug events, with one study showing a reduction in potential adverse drug events from 3.1% to 1.6%,[6] and another a reduction in medication errors from 6.3% to 1.2%.[7] A number of systematic reviews (incorporating both directly observed and self-reported medication errors) conclude that BCMA can reduce the incidence of medication error.[8–10]

Many studies have described the barriers associated with implementing and achieving high uptake of BCMA. These include inadequate training, perceived negative changes to workflow, poor equipment and staff resistance to new systems.[11–14] Most studies originate from the USA, where medication is typically supplied in 'unit dose' packaging, with each dose individually packaged and barcoded.[15] This is likely to facilitate higher rates of medication scanning—studies often report over 90% compliance[16 17] which improves further with interventions such as 'nursing champions' and 'incentives'.[18] In the UK, medication scanning rates are typically lower, which may be partly due to medication packaging differences. Use of multiple dose packs and patients' own drugs means not all medications can be scanned, requiring nurses to default to alternative administration methods, developing 'workarounds' to BCMA. There is a significant literature gap on successful implementation and adoption of BCMA outside the USA, with a handful of studies originating from elsewhere including Iran,[14] the Netherlands[19] and Lebanon.[20]

At the study site, a large National Health Service (NHS) trust with three main hospitals in central London, BCMA technology was implemented in one hospital with between 20% and 30% of all scannable medication doses being scanned each week by nursing staff in 2018–2019. However, rapid changes to working practice and overwhelming demands on the service during the COVID-19 pandemic led to a reduction in BCMA use. By mid-2021 BCMA was resumed, with an initial target of 50% of all scannable doses being scanned, and an eventual target of 95% (in line with Healthcare Information and Management Systems Society targets[21 22]). However, following changes in practice during the pandemic, BCMA reuptake was lower than desired, with many nursing staff scanning less medication than before pandemic. After pandemic, analysis of medication data for 2022 demonstrated that 68% of all medications were not being scanned. In this time period, 41% of wards were scanning less than 20% of all medications each week (between 2% and 19%), with some wards occasionally scanning 0%. This low rate of medication scanning had persisted despite ongoing trust-wide initiatives to improve BCMA uptake.

Given the literature demonstrating links between implementation of BCMA technology and a reduction in medication errors, it was perceived that designing an intervention to improve the rates of medication scanning within the trust could meaningfully improve patient safety, especially in the context of such a low baseline medication scanning rate.

Barriers to BCMA use were previously explored at the study site through qualitative interviews with nursing staff and patients.[23] Elicited themes included culture and accountability, time efficiency, patient safety, staffing and environmental ergonomics. These barriers informed two codesign workshops with subject matter experts, behavioural scientists and frontline staff. The development and refinement of ideas within the workshop were framed around the behaviour change wheel (COM-B [capability, opportunity, motivation - behaviour])[24] (online supplemental file 1—logic model and codesign process).

The codesign process led to the selection of a 'feedback' intervention, implemented as a motivational nudge. The intervention incorporated several behavioural science constructs, with a focus on relaying positively framed information regarding each ward's performance. It is known that feedback interventions can lead to effective behaviour change, particularly in the short term and across a wide range of behaviours, including reducing excessive alcohol drinking in students[25] and a reduction in antibiotics prescribing by general practitioners.[26] Offering positively framed feedback has been effective in clinical settings; for example, high-quality positive feedback was associated with higher performance and greater levels of self-evaluation in nursing students.[27]

Our research question was as follows: can implementation of regular positively framed feedback to nursing staff improve the uptake of medication scanning? Our objectives were to implement a feedback intervention aimed at improving BCMA scanning rates on selected wards and to evaluate its impact over time using a difference-in-difference (DID) analysis.

METHODS

We conducted a quality improvement study using longitudinal measurement on intervention and control wards; the study is reported in line with the Standards for Quality Improvement Reporting Excellence 2.0 guidelines.[28]

Study setting and target wards

We selected five wards at the study hospital to be our intervention wards, based on available resources and feasibility of delivering the intervention. We selected wards with a range of BCMA uptake (from very low baseline scanning rates of 5% to higher rates of 25%), a range of clinical specialties (surgical, acute admissions and medical) and different numbers of beds. We also used engagement of ward managers with the

Table 1 Characteristics of included wards at the study site

Variable	Control wards (n=14)	Intervention wards (n=5)
Clinical specialty		
Surgical	3	2
Medical	8	3
Rehabilitation	2	0
Mixed	1	0
Number of beds		
0–10	1	0
10–20	7	1
20–30	6	3
>30	0	1

study team and appetite for the study as criteria for inclusion, although this was not measured formally. The remaining 14 wards using BCMA at the hospital acted as controls. The control wards included medical, surgical and rehabilitation wards. Characteristics of these wards can be viewed in table 1. Most wards had similar baseline rates of scanning at the start of the study (between 0% and 25% of all scannable medications scanned by nursing staff), but two wards within the control group were performing particularly well (60–80%) as a result of previous ward-based quality improvement projects. Trust-wide initiatives to improve BCMA (such as the inclusion of scanning rates on their ward accreditation scheme, widespread training in BCMA and an increase in trust-wide BCMA support staff) were equally available to all wards at the study site throughout our study period.

Design and development of the intervention

Data on BCMA rates for each ward and nurse were available on QlikView,[29] a business intelligence reporting tool for data integration and analytics. The application within QlikView shows anonymised data on medication scanning obtained from the patient's electronic health record, as an interactive dashboard demonstrating the BCMA rates across the Trust.

Data points used to create the intervention and evaluate its effect were the number of medications that *could* have been scanned each week, the number of medications that *were* scanned and a calculated percentage of medication scan rates for the week. These data are routinely available for any trust employee to view. For the purposes of this study, we focused on medication scanning rates, rather than patient scanning rates. While both are important, medication scanning was the trust's immediate priority, and we had identified specific barriers to medication scanning in previous qualitative work.[23] Our feedback intervention had been codesigned with two key components.

First, the ward matron/manager on each intervention ward was sent a weekly email constructed by the study team that comprised four elements of feedback: (1) the ward's scanning rate for the previous week and their target for next week (set at a change of 10 percentage points above their current rate that week to feel achievable); (2) the names of two nurses with the highest scanning rates that week; (3) the names of the two nurses with the most improved scan rates that week; (4) a 'top tip' promoting the benefits of BCMA scanning. These 'top tips' included highlighting the benefits for patient safety or time efficiency for the user and were iterated and refreshed each week. Only scanning rates over 70% were incorporated numerically to minimise the risk of backfire (eg, if the top scanning nurse only scanned 10%, highlighting this might risk this being viewed as acceptable). If a 'top-scanning' or 'most-improved' nurse had scanned less than 70% of doses, only their name was included. We requested that this feedback was read out by the ward manager/matron every morning and night at the nursing handover meeting for 7 days, aiming to ensure the message was heard by every nurse working a shift that week. The mechanism of delivering this verbal feedback was also considered, as it was anticipated this may influence the success of the intervention. In addition to standard handover information (staffing, patient numbers, clinical concerns), a framework known as 'the big four' had been developed at the study site; this allowed four key safety issues to be highlighted at staff handover each day, within a structured framework. We gained approval to incorporate our verbal feedback script as one of the 'big four', helping to ensure its delivery each day. This was incorporated into the wards' standard method of delivering the 'big four'—either via an established proforma or on a manually created handover agenda.

Second, we created a poster displaying the four elements of the feedback intervention visually, with the colours and designs adapted weekly to maintain engagement in a busy ward environment.

This two-part feedback intervention used three behavioural science constructs. The *messenger effect* was employed,[30] with the most senior nurse (ward manager/matron) delivering the verbal feedback each day, as it was hypothesised by the study team that the nurses working on the wards would be more likely to change their behaviour if instructed to do so by their most senior member. The intervention used *gamification*[31] by challenging nurses to see who could be the best/most improved each week. Finally, the intervention used *gain framing*,[32] demonstrating the positive aspects of the decision to use BCMA scanning, such as reduction in the likelihood of a medication error. Examples of feedback scripts can be viewed in online supplemental file 2.

Implementation of the intervention

To generate support for our intervention, the study team ensured that the ward managers/matrons on each intervention ward were engaged in the project,

understood its purpose and perceived the intervention to be acceptable. This was achieved through early engagement with the ward teams, meeting regularly to elicit their feedback. We also ensured they were represented during our earlier qualitative research into the barriers to use of BCMA, at the codesign sessions and in the later discussions regarding results and iteration of the feedback.

The intervention was first launched on two of the five intervention wards for 2 weeks in August 2022 to allow for identification of any unintended consequences. The study team had weekly meetings with each ward manager to ensure there were no concerns about the delivery of the intervention, and to discuss any external factors that might affect scanning rates (eg, a broken scanner). Additionally, scan rates were monitored weekly to ensure there was no 'backfire'—scanning rates suddenly falling as a consequence of the intervention. The intervention was launched on the remaining three wards immediately after this initial test period and ran for a total of 18 weeks. Updated data on BCMA rates were accessed weekly and used to update and iterate the feedback emails and posters.

Study team

The team implementing this project was a multidisciplinary group of behavioural scientists (KG, AB, CM, HB, AA, SH) (five of which had a clinical background (KG, AB, CM, AA, SH)). This team all have prior experience of conducting behaviourally informed research in the clinical setting. These team members were supported by a senior pharmacist (BDF), senior clinician (AD), a designer (AG), statistician (RFC) and a clinical informatics nurse (JB).

Data analysis

Data on scanning rates were published on the trust's QlikView app each Sunday. Preintervention data on baseline scanning rates were captured on all 19 wards from Sunday, 27 March 2022. Two intervention wards 'went live' with the intervention after 18 weeks of baseline data capture, the week commencing 1 August 2022 (with the effect of the intervention available from 7 August 2022). These two wards ran the intervention for a total of 18 weeks. The remaining three intervention wards 'went live' with the intervention on 14 August 2022 (with a total of 20 weeks of baseline data capture) and ran the intervention for a total of 16 weeks. All 14 control wards had data collected for the full 36-week period with the exception of one that was missing data for the 10 initial weeks of the baseline period due to a later launch of BCMA. Missing values for this ward were imputed to facilitate the creation of the chosen statistical model. While the linear DID model did not require this, given the missing data were only located in the control arm (for one ward), this was done to minimise the risk of bias and allow comparison of the same number of wards before and after intervention. The mean value for the ward was imputed in order to maintain the ward's scanning rate central tendency. No additional imputation was required for other wards.

A linear DID analysis was conducted to evaluate any change in the rate of medication scan rates following the feedback intervention, comparing the five intervention wards to the 14 control wards. This method of analysis was selected to allow for evaluation of the rate of change on our intervention wards in relation to improvement in other wards (as we were aware of ongoing trust-wide work to improve medication scanning, and wanted to ensure any improvement as a result of our intervention could be identified). This was achieved by creating a linear mixed-effects model in which the percentage of medications scanned per week was the outcome variable, and the number of weeks since the study started, the number of beds on the ward, ward specialty and a 'difference-in-difference' estimator (indicating whether the intervention had started in the intervention wards) were used as covariates. Individual wards were included as a random effect in the model.

In addition to evaluating the impact of the intervention over linear mixed-effects model for the entire intervention period, the data were also analysed in two weekly units of time to provide information on the effect of the intervention over the course of the study. This was achieved by creating separate models which included all data prior to the start of the intervention, and 2, 4, 8, 10, 12, 14 and 16 weeks after intervention, respectively. This unit of time was selected based on the observed rate of change by the study team as the intervention was being delivered. Additionally, the implementation of the intervention was assessed informally throughout the study through regular check-ins with the ward teams.

Using the UK Health Research Authority decision tool,[33] this work was deemed 'improvement' and approval granted to run the study as a quality improvement project by the study trust (registration number 652).

RESULTS

The feedback intervention was successfully launched on all five wards, with no unintended consequences identified. The numbers of medication doses prescribed and administered were consistent on each ward before and after intervention, ranging from 500 to 2000 medications administered per week per ward with variation relating to the number of beds, patient acuity and clinical specialty. For the 18 weeks prior to intervention launch, the weekly median medication scan rate was 18% for the control wards and 15% for the intervention wards. For the duration of the intervention the weekly median medication scan rate was 27% for the control wards and 41% for the intervention wards.

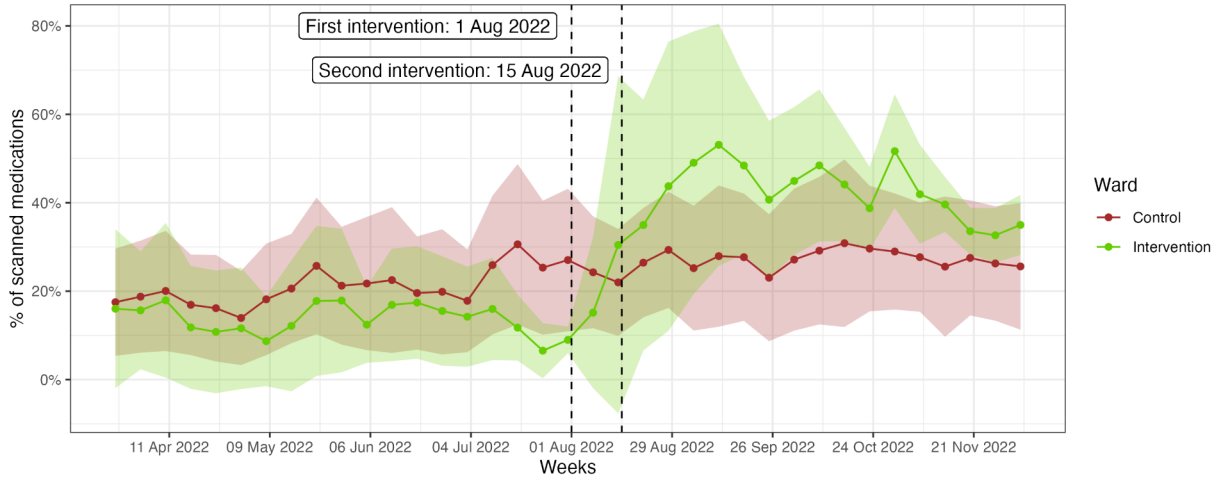

Figure 1 Absolute changes in percentage of medication doses scanned each week over the trial period (18 weeks before intervention and 18 weeks after intervention).

Overall, across the study period, DID analysis suggests that the implementation of the feedback intervention led to an increase of 23.1 percentage points in scan rates on the intervention wards compared with the control wards ($p<0.001$) (from an average baseline of 15%). A separate model excluding the two high-performing control wards showed an increase in scanning rates of 23.8 percentage points associated with the intervention (online supplemental file 3).

The absolute changes in percentage of medication doses scanned each week over the trial period can be viewed in figure 1.

When analysed at two weekly intervals, there was an increase in scanning on the intervention wards of 21.6 percentage points ($p<0.001$) by week 2, a 25.8 percentage point increase by week 4 ($p=0.004$) and a 26.3 percentage point increase by week 6 ($p<0.001$) when compared with the control wards. This then plateaued at an approximate 25 percentage point increase in scanning rates for the remaining weeks of the intervention, with slight reduction in the size of the increase towards the end of the intervention period. This decrease was also noted when plotting the data in a p-chart (online supplemental file 3). The last data point in the postintervention analysis fell outside the control limits for this segment, indicating that there may be a decrease in the effect of the intervention towards the end of the intervention period.

Beyond the impact of our intervention, neither clinical specialty nor number of beds on each ward were significant factors in our model. However, we noticed a non-statistically significant trend towards larger wards having lower scan rates (−0.9 percentage point change); and when rehabilitation and surgical wards were compared with medical wards, they demonstrated 3.5 percentage point and 3.6 percentage point lower scanning rates, respectively (note, rehabilitation wards were only present in the control group). Overall model data for the entire intervention period can be viewed in table 2. The two weekly units of time analysis data can be viewed in online supplemental file 3.

DISCUSSION

Key findings

Our study demonstrated that a behaviourally informed positively framed feedback intervention can significantly improve the rate of use of BCMA by nursing staff. As such, we highlight the potential benefits of using positively framed feedback to engage staff in patient safety initiatives within the healthcare setting, knowledge that can subsequently be applied to other patient safety behaviours.

These effects were achieved through an extremely low-cost feedback initiative, highlighting that our intervention would be suitable for scaling across healthcare environments with limited resources.

Table 2 Results of difference-in-difference analysis: increase in uptake of scanning on control wards versus intervention wards (percentage point increases)

	Percentage point change	95% CI (low)	95% CI (high)	P value	SE
Increase in barcode scanning (intervention ward) (%)	23.1%	19.0%	27.2%	<0.001	2.1%
Covariate					
Number of beds	−0.9%	−2.8%	1.0%	0.336	0.9%
Specialty—rehabilitation	−3.5%	−38.7%	31.7%	0.834	16.4%
Specialty—surgery	−3.6%	−26.2%	19.1%	0.741	10.6%

We found that the intervention was well received by nursing staff on the intervention wards, with positive reports being received and noted by the study team in the form of informal conversations and emails. 'Gamification' of the feedback was reported as helping maintain interest, and the study team observed different nurses' names appearing within the feedback each week. Anecdotally, we received stories of nurses clapping at handover when the top scanners were read out. We also noted that as our intervention wards were now doing well, this was recognised and rewarded by hospital management with high-performing wards receiving praise from senior management in the form of posters and mentions on the trust's social media platforms. A limitation of these perceptions is the lack of the formal collection of staff feedback, something which could be incorporated into future work.

There are several reasons why this feedback intervention may have been successful.

First, the study team (both through their own clinical experience and insight from the codesign process) understood the clinical setting that the study was to be delivered in, knowing that staff are under extreme pressures and that the ward environment is often very cluttered with lots of visual stimuli. With this in mind, we purposely ensured the visual feedback posters were different each week, changing colour and format. We also ensured the intervention would add minimal extra time and effort during handover, creating an intervention that would be feasible long term.

Second, the study team were engaged in the project delivery throughout, visiting the intervention wards each week to ensure the feedback script was received and that posters were displayed. This action could also be considered as a prompt for senior nursing staff to prioritise use of BCMA. We established good relationships with the ward managers, supporting enduring 'buy-in' and intervention fidelity. Additionally, support from the project stretched beyond the nursing team, with clinical educators and ward clerks engaging with and promoting the feedback intervention.

Finally, there was ongoing improvement work to encourage BCMA uptake across the trust—which may have accounted for some of the increase in scan rates. However, the DID analysis suggests that even though medication scan rates were increasing across all wards, our intervention significantly increased this rate of uptake.

Our feedback intervention had a marked initial improvement, peaking around weeks 10–12 of the intervention. There was still a significant improvement in the scanning rate by the end of the study period, demonstrating a persistent positive effect, even though reduced. It may be that once the 'novelty' of our intervention wore off, barriers associated with BCMA use (such as time pressures, or having to use heavy drug trolleys with a cumbersome design) were again more difficult to overcome. Second, while we noted that different nurses were present in the 'top two' or 'most improved' each week, some individuals may have felt that if they were not in either of these categories after a few weeks, that ongoing attempts to do so would have been futile, potentially leading to reduced engagement.

Relationship to existing research

Our results concur with other studies that have implemented feedback to change behaviour. A 2016 review identified several initiatives where providing endoscopists with a feedback summary of their performance led to an improvement in clinical outcomes.[34] A randomised controlled trial (RCT) compared the effect of a feedback intervention (compared with routine practice), and demonstrated a moderate but sustained improvement in hand hygiene compliance.[35] Additionally, a study evaluating the effect of feedback interventions on opioid prescribing in clinicians showed a significant decrease in prescribing when both individual and peer comparison feedback was implemented.[36]

Our findings in relation to the success of our intervention are consistent with existing research on BCMA implementation. Our intervention framed the adoption of BCMA as positive for patient safety (one of the highlighted benefits of BCMA used throughout delivery of the intervention), this is corroborated by work done to overcome the barriers in implementing digital technologies that demonstrated the benefit of prioritising patient safety.[37] Our intervention also helped communicate the *need* for BCMA—a key feature of successful implementation identified in a 2019 literature review.[38] A US study distributed reports on BCMA rates to nurse managers, improving compliance from 95% to 98%,[16] supporting our rationale for the success of using the ward manager as the messenger for our intervention.

Strengths

While the use of feedback in this way is not an original concept, there are several novel elements within our study. Our feedback ensured the information within it was framed in a positive manner, only highlighting what went well each week. We therefore demonstrate that this approach can be successful in the healthcare setting, without the requirement for negative values or rhetoric regarding potential negative repercussions. We used an existing feedback practice (the 'big four') to deliver our intervention, thereby improving its chance of being sustained as a practice and increasing its suitability for scale. A further strength is that we designed our feedback intervention using the behaviour change wheel,[24] ensuring that behaviour change constructs were included within our intervention—something that is reported as often missed in feedback interventions.[39]

Limitations

First, we did not randomise wards to receive the intervention. This, along with a lack of resource within

the study team, led to the uneven numbers of wards in control and intervention groups. We selected five wards to act as intervention wards based on engagement, study feasibility and to ensure busy inpatient specialties were represented. As such, the wards in control and intervention groups were not matched in terms of size, nursing ratios or patient admissions, and there may have been confounders (such as the utilisation of temporary staffing that may have affected how many staff were familiar with BCMA) that were not represented equally in both groups. However, on review of all wards, we did not identify any significant differences that we feel would have affected our conclusions.

Second, we included two readily available covariates in our model: number of beds and the ward's clinical specialty. However, data on factors such as the use of temporary staffing, annual leave or seniority of nursing staff were not available. The nurse manager/matron was crucial to our intervention, as they were delivering the feedback and using the *messenger* effect. It was observed that occasionally this individual would not be present on the ward that week (due to ill health, holiday, etc), which may have affected our results. As such, it is possible that other factors not included in the model may partly explain the differences seen in our analysis.

Third, this study was conducted in one hospital within one NHS trust. As such, our findings may not be generalisable to other settings. While the factors that affect uptake of barcode scanning (as identified in our qualitative work[23]) may be present in other similar clinical healthcare environments (such as short staffing, high patient acuity and rapid patient turnover), we would suggest caution when generalising the findings of our intervention without a prior exploration of the specific barriers to BCMA at other sites. We also acknowledge that while trust-wide initiatives to improve BCMA use were available equally across all wards included in this study, we did not have data on the uptake of these. It is possible that such opportunities could have been used differently between control and intervention groups, which may also influence the generalisability of our findings.

Finally, we tested three behavioural science concepts within this intervention; as such, it is impossible to conclude which one was most effective, or whether the result was an additive effect. We did not design the study to test which specific iteration was more effective, or if in fact the combination of behavioural science concepts was essential for a positive effect to occur. Understanding this further would provide an opportunity for future work.

Opportunities for future work

There are several opportunities for future work. The intervention could be broken down according to the three behavioural science constructs, and these tested separately in different arms of an RCT, alongside our composite intervention. It would also be of interest to trial this intervention in different wards and hospitals to provide further support for the effectiveness of our intervention. This could lead to recommendations for improving the implementation and uptake of BCMA technology using feedback being written into local policy. While our intervention was effective at increasing the rate of BCMA scanning, further work should look to increase this further, aiming to get closer to the ultimate target of 95%. Further qualitative work could be conducted to understand the barriers that remained even with our intervention, in order to further future improvement work. It would also be of value to evaluate the change in medication scanning rates for a longer period after intervention, to further explore the effect of our intervention over time.

CONCLUSION

The implementation of a positively framed feedback intervention that used three behavioural science constructs—the messenger effect, gamification and gain framing—was effective at increasing the rates of medication barcode scanning in our target population. The intervention led to improvement despite the presence of significant existing barriers to the use of the technology, including short staffing, challenging equipment and a perceived lack of time. This study highlights that low-cost, behaviourally informed simple feedback interventions, implemented alongside extensive stakeholder engagement, can be extremely effective, leading to a 23.1 percentage point increase in the rate of medication scanning during the intervention. This learning can be applied to similar patient safety behaviours within the healthcare setting.

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Supplementary File 1: Logic Model for the development of our intervention: Co-Design Workshops and Development of Behavioural Science Informed Intervention.

Goal

The long-term impact of this study was to contribute to the increased uptake of barcode medication scanning by nursing staff, thereby contributing to a reduction in the incidence of medication errors and potentially leading to increased patient safety.

Inputs

In order to develop the behavioural science informed intervention, a co-design process with frontline NHS staff (all familiar with using barcode medication administration (BCMA)) was planned. The design of this process was informed by qualitative research findings exploring the barriers and facilitators to BCMA conducted previously by this research group (1).

Activities

The intervention was developed primarily through the conduct of two co-design workshops, in which ideas were generated and subsequently refined. The two co-design workshops were held with members of the hospital's BCMA implementation team, behavioural science experts, frontline nursing staff, pharmacists and the academic study team.

Co-design 1: Understanding the behaviours and ideation

The first workshop reviewed the barriers and facilitators to using BCMA, according to eleven themes identified in a previous thematic analysis, utilising data obtained through qualitative interviews and ethnography. These 11 themes were 'time efficiency', 'culture and accountability', 'equipment', 'training', 'effect on patient interactions', 'patient safety', 'staffing and workload', 'ergonomics – BCMA trolley', 'ergonomics – ward layout', 'infection control' and 'drug related'. Previous interventions to improve BCMA as identified in the literature were also reviewed. Participants then engaged in an activity designed to generate as many potential interventions as possible, all individually entering their ideas into a shared cloud-based workbook. We asked participants to use the COM-B framework when generating ideas. Following this, each participant was asked to rate all the ideas generated by the group according to their perceived impact and feasibility.

Co-design 2: Refining ideas, assessing feasibility and impact

These ideas were reviewed and ranked by the study team based upon the scores provided by the co-design participants on perceived impact and feasibility. This led to the creation of a shortlist that was presented at the second co-design workshop. Careful consideration was given to the specific behaviour these interventions targeted, and each potential intervention was mapped to the relevant elements of the COM-B framework (2). These shortlisted interventions were presented to the attendees, who subsequently reviewed and ranked each idea according to each intervention idea's potential for impact and feasibility of implementation in small groups.

Post-workshop synthesising and development of final intervention

The final intervention was refined by the study team and subject matter experts within the hospital, based upon perceived impact, feasibility and trying to minimise the risk of any

"backfires" or behaviours that would reduce the use of BCMA further and hence put patient safety at risk.

Outcomes

Findings from Co-design workshops

Over 130 initial ideas were generated in co-design workshop one. When reviewed for duplicity / similarity there were 45 unique ideas, which were then refined to a shortlist of 11 for the second co-design workshop. These 11, and the corresponding element of the COM-B framework can be viewed in the following table:

COM-B Element	Intervention Idea	Examples of what this might look like
CAPABILITY	BCMA Champions	Individuals with increased training/knowledge Act as a point of contact for troubleshooting
	Increase Impact of Training	Drop in training workshops Dedicated "quick fire" guides
	Improve Troubleshooting	Highlight location of existing troubleshooting guides Dedicated pathway for reporting broken equipment
	Improve ergonomics of BCMA drugs trolley	Re-design trolley to enable height adjustment Lighter trolley
OPPORTUNITY	BCMA Software Improvements	Streamline scanning process by presenting "scannable" medications first Enable only scanning patient once at start of drug round
	Improved WiFi and Accessibility	More wireless scanners Increased routers for areas with poor Wifi signal
	Avoidance of workarounds	Enforced second person sign-off when medication not scanned Alternatives when medication can't be scanned e.g. dummy barcode
	Reduce number of unscannable medications	Increase number of scannable medications (new barcodes) Labelling of drugs that are not scannable
MOTIVATION	Promotion of benefits of BCMA	Display benefits throughout ward environment e.g. posters Benefits might include improvement in patient safety
	Feedback on BCMA use	Individual feedback on rates of usage Ward level feedback to matrons, with comparison to high scanning wards
	Reward / Incentives for high users	Monthly incentives for ward with highest use e.g. coffee vouchers Promote individuals with high level use via hospital communications

The final outcome of this process led to the selection of a feedback intervention, based on its perceived high impact and feasibility by the co-design team.

Impact

The study aims to see a measurable change in the rate of medication scanning by nursing staff on the wards where we launch our feedback intervention, in comparison to the control wards.

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Supplementary File 2: Example verbal feedback scripts

Below are some examples of verbal feedback "scripts" that were used during the study. The script was changed each week and updated with new BCMA scan rates.

Each feedback script has a few key points

- The overall ward scanning rate, and the change from the previous week
- Top scanners (with their actual scan rate *if over 70%)*
- A target scan rate, which we would advise should be 10% higher than the previous week's scan rate
- Most improved scanners
- A helpful "tip" or "motivator" to encourage BCMA use over the next week.

"*Last week, the medication scanning rate on our ward was XX%.*

The two people with the highest scanning rates on (ward name) last week were _____ who scanned xx% of medications and _____ who scanned XX%. _____ and _____ were the two nurses who had the largest increase in their medication scanning rate since last week.

This week everyone should focus on ensuring all oral medications are scanned."

Last week, the medication scanning rate on our ward was %. This is still a high scanning rate so well done, although let's aim to get back up to the XX% scanning rate of the week before!

The top two scanners on (insert ward) last week were _____ who scanned XX% of medications and _____, scanning XX% of medications. The following nurses also scanned more than 70% of their medications last week: _____. Keep going to try and hit 100% or more!

The two people who improved their scanning rate the most since last week were _____ and _____.

This week remember to scan medications on every shift, and scan all patients in your bay. The aim is to try for another ward record and get closer to our target of XX% of all medications scanned next week!"

"Last week, the medication scanning rate on our ward was XX%. This is another improvement – the previous week you scanned XX% - well done! You are getting even closer to our initial target of XX% (this should be 10% above last week's scan rate) - let's hit it next week.

The top two scanners on (ward name) last week were _____ who scanned XX% and _____ who scanned XX%. Remember, by scanning all medications and patients' own medications it is possible to achieve over 100%! The following nurses also scanned more than 70%: _____.

The two nurses who increased their scanning rates by the largest amount last week were ____ and ____. Well done!

More and more nurses are scanning each week - this week let's focus on getting the whole team scanning medications every time!

"Last week, the medication scanning rate on our ward was XX%. You are consistently scanning above XX% of all medications each week now, well done! Your target for next week is to scan XX% of all medications.

To reach our target of XX% we need every nurse to be scanning medications. Can we improve and get everyone scanning?

Have you noticed someone struggling to scan? Next time you see someone giving medications, can you help them get their rate up by passing on some tips? By encouraging each other, we can help beat this week's score!"

"Last week, the medication scanning rate on our ward was XX%. This is a huge improvement and you hit your target of XX%. Well done everyone! Now let's aim for XX% next week.

In order to hit this target we need everyone to scan medications as much as possible.

Last week four nurses on (ward name) increased their scanning rate. The two people who increased their scan rate by the largest amount were _____ and _____. Well done! If you haven't scanned recently why not try to scan the medications you give this week and have the greatest increase next week?

We know how busy you are and that you want your drugs round to be as efficient as possible. When we mapped a nurse's journey using BCMA and compared this to the old system we showed their walking route around the ward was much shorter. You could save up to 200 meters of walking per drug round using BCMA – over one month this would equate to nearly 5k!"

"Last week, the medication scanning rate on our ward was XX%. We know that scanning medications helps reduce the risk of error. Let's get our scanning rate back to over XX% next week – you have done this before so let's get there again!

Last week three nurses on (ward name) increased their scanning rate. The two people who increased their scan rate by the largest amount were _____ and _____. Well done! Who will make it into the top two next week?

We asked patients what they thought of BCMA – they told us that it made them feel safer when they were in hospital and that a drug error was less likely to happen. Let's work together to keep patients safe by scanning as many medications as possible this week"

"Last week, the medication scanning rate on our ward was XX%. We know that scanning medications helps reduce the risk of error. You have improved so much since the start of this project, but we know you can scan over XX%. Let's hit this new target next week!

We are excited to say that the majority of (ward name)'s nurses are now scanning medications compared to when we started this project. This is brilliant! Last week four nurses on (ward name) increased their scanning rate. The two people who increased their scan rate by the largest amount were _____ and _____. Well done! The top two scanners last week were _____ who scanned XX% and _____ who scanned XX% of medications. Well done! Who will feature next week?

Patients were interviewed to see what they thought of BCMA. They felt it was less disruptive and they felt safer with this system being used. Join the majority of nurses using BCMA and let's work together to keep patients safe by scanning as many medications as possible this week"

Supplementary File 3 – Additional Analyses

Detailed statistical analysis at two-weekly intervals

Time post Intervention launch			**Percentage change**	**95% CI (low)**	**95% CI (high)**	**p value**	**Standard Error**
2 weeks	**Increase in barcode scanning (Intervention ward) (%)**		21.6%	14.7%	28.5%	<0.001	3.5%
	Co-variate	Number of beds	-0.9%	-2.8%	1.0%	0.31	0.9%
		Speciality - rehabilitation	-3.6%	38.7%	31.6%	0.834	16.4%
		Speciality - surgery	-2.4%	-25.0%	20.2%	0.82	10.6%
4 weeks	**Increase in barcode scanning (Intervention ward) (%)**		25.8%	20.1%	28.5%	<0.001	2.9%
	Co-variate	Number of beds	-0.9%	-2.8%	1.0%	0.35	0.9%
		Speciality - rehabilitation	-3.3%	-38.7%	32.0%	0.84	16.5%
		Speciality - surgery	-2.9%	-25.6%	19.9%	-0.76	10.6%
6 weeks	**Increase in barcode scanning (Intervention ward) (%)**		26.4%	21.3%	31.5%	<0.001	2.6%
	Co-variate	Number of beds	-0.9%	-2.8%	1.1%	0.35	0.9%
		Speciality - rehabilitation	-3.3%	-38.7%	32.1%	0.84	16.5%
		Speciality - surgery	-3.3%	-26.1%	19.5%	0.76	10.6%
8 weeks	**Increase in barcode scanning (Intervention ward) (%)**		25.4%	20.7%	30.2%	<0.001	2.4%
	Co-variate	Number of beds	-0.9%	-2.8%	1.1%	0.35	0.9%
		Speciality - rehabilitation	-3.3%	-38.7%	32.1%	0.84	16.5%

		Speciality - surgery	-3.4%	-26.2%	19.4%	0.75	10.6%
10 weeks	**Increase in barcode scanning (Intervention ward) (%)**		25.8%	21.3%	30.3%	<0.001	2.3%
	Co-variate	Number of beds	-0.9%	-2.8%	1.0%	0.34	0.9%
		Speciality - rehabilitation	-3.4%	-38.8%	31.9%	0.83	16.5%
		Speciality - surgery	-3.5%	26.2%	19.3%	0.74	10.6%
12 weeks	**Increase in barcode scanning (Intervention ward) (%)**		25.8%	21.3%	30.3%	<0.001	2.3%
	Co-variate	Number of beds	-0.9%	-2.8%	1.0%	0.34	0.9%
		Speciality - rehabilitation	-3.4%	-38.8%	31.9%	0.83	16.5%
		Speciality - surgery	-3.5%	26.2%	19.3%	0.74	10.6%
14 weeks	**Increase in barcode scanning (Intervention ward) (%)**		23.3%	19.2%	27.4%	<0.001	2.1%
	Co-variate	Number of beds	-0.9%	-2.8%	1.0%	0.33	0.9%
		Speciality - rehabilitation	-3.5%	-38.8%	31.7%	0.83	16.4%
		Speciality - surgery	-3.6%	-26.3%	19.0%	0.73	10.6%

Data from sensitivity analysis without two high performing control wards

		Percentage point change	**95% CI (low)**	**95% CI (high)**	**p value**	**Standard Error**
Increase in barcode scanning (Intervention ward) (%)		23.8%	19.8%	27.7%	<0.001	2.0%
Co-variate	Number of beds	-0.8%	-2.2%	0.6%	0.34	0.6%
	Speciality – rehabilitation	-29.2%	-62.3%	4.5%	0.08	15.3%

	Speciality – surgery	-12.2%	-30.0%	5.4%	0.15	8.1%

P-chart demonstrating the change in the effect of the intervention over the study period.