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Original Research Paper

Improving medication safety through behavioral nudges: An evaluation of unit sales trends following a pharmacy-based intervention

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ABSTRACT

Background: Over-the-counter (OTC) medication misuse among older adults is a patient safety concern, exacerbated by limited patient engagement about potential risks. Senior Safe™, a pharmacy-based intervention using human-factors engineering and participatory design,specifically, shelf signage, product repositioning, and patient engagement to nudge safer choices. Despite its safety intent, and demonstrated effectiveness, it was important to determine the intervention's impact on its financial sustainability.

Methods: This study evaluated Senior Safe's effect on daily unit sales of OTC analgesic, sleep, and cough/cold/allergy products across 65 community pharmacies in a Midwestern health system. Using Generalized Linear Mixed Model regressions with Poisson distribution, the analyses compared daily unit sales pre- and post-intervention trends for products marked with Green Banners (safer), Red Stop Signs (high-risk), or Behind-the-Counter (BTC) signage (very high-risk), controlling for pharmacy type, size, location, open hours, and staff hours.

Results: Senior Safe was associated with increased sales of safer analgesics and cough/cold/allergy medications (IRR = 1.064 and 1.106), along with significant decreases in unit sales of BTC and Red Stop Sign products (IRR = 0.424-0.869). These findings suggest a substitution effect, where patients chose safer alternatives rather than forgoing OTC purchases. Operational factors, such as longer open hours and higher staffing levels, were positively associated with safer product unit sales.

Conclusions: Senior Safe successfully shifted consumer behavior toward safer OTC medication use without reducing overall sales volume, suggesting patient safety interventions can be financially sustainable in retail pharmacy settings. These results support broader implementation of low-cost, system-level interventions that align safety with business operations.

1. Introduction

Integrating patient safety interventions into healthcare systems often is impeded by the common assumption that enhancing patient safety will incur higher costs, which contradicts the typical business model emphasizing cost mitigation.[1] Healthcare leaders often hesitate to invest in implementation strategies when the return-on-investment is unclear.[2] However, evidence suggests that many quality improvement initiatives can drive meaningful behavior change without adding financial burden.[3] Understanding both intended and unintended downstream costs effects of these interventions is essential to achieve sustainable integration and securing stakeholder support.[4]

An important and often-overlooked area in patient safety involves the misuse of over-the-counter (OTC) medication misuse among older adults (age 65 or older), a major yet underrecognized public health concern.[5] In a realistic pharmacy simulation study with 144 older adults, nearly 80% misused OTCs—most commonly through selection or dosing errors and frequent drug-drug or drug-label interactions.[5] With over 59.3 million older adults in the United States,[6] and nearly half using OTCs, often with prescriptions or supplements,[7] more than 29 million older adults may misuse OTCs. Beyond these, the older adult population is projected to be 82 million by 2050.[8] Since OTC medication do not require a prescription, healthcare providers and pharmacists have limited visibility into their patients' OTC usage patterns, which leads to insufficient oversight and increased likelihood of misuse.[9]

Addressing this misuse requires strategically designed interventions

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that mitigate clinical risks and align with organizational sustainability. Human factors engineering (HFE) applies a system approach to intervention design, representing a promising method to achieve such goals. It has been successfully applied to healthcare contexts, with evidence showing that HFE-driven patient safety interventions can significantly reduce harm while saving costs.[10] In practice, improving safety through systems design yields measurable economic benefits.[11,12] Strengthening infection control is one clear example: investments in hand-hygiene programs (e.g., ensuring adequate supplies, training, and workflow design) have drastically cut hospital-acquired infections at low cost, with one hospital reporting a net benefit of over $5 million, roughly a $23.7 return for every $1 spent on its initiative.[11] Similarly, HFE-designed fall-prevention protocols not only reduced inpatient falls and injuries but also lowered expenses; a multi-hospital study of the FALL TIPS program documented $14,600 in avoided costs per 1000 patient-days (about $22 million saved over five years) and projected $1.8 billion savings nationwide.[12] At the national level, system-wide safety improvements have led to substantial cost reductions, for instance, the U.S. Medicare- Acquired Condition Reduction Program prevented an estimated 25,000 deaths and saved $7.7 billion in three years by reducing infections, adverse drug events, pressure ulcers, and other preventable harms at a system level. Prioritizing patient safety through an HFE and systems lens is a high -value strategy: safer care translates into fewer cost, aligning with the goals of value-based care.

2. Senior Safe™

A pharmacy-based intervention (called Senior Safe™) was developed using HFE and participatory design frameworks to help mitigate older adults' misuse of particularly high-risk OTC medications used to treat pain, cough/cold/allergy and sleep symptoms.[13–15] The overall project was based on a randomized control trial (RCT) design in which 10 intervention and 10 control pharmacies were randomly selected and paired based on pharmacy and area characteristics (representing the RCT phase). Implementation timing was determined colligatively with pharmacy leadership to ensure operational feasibility. After that, system-wide adoption across all remaining 45 pharmacies to assess longer-term integration (representing a Sustainability phase).[9,13] Results from two studies led to two determinations. First, the presence of Senior Safe reduced the potential for a variety of OTC misuse for older adults determined from a hypothetical use scenario, including drug-age, drug-drug, and drug-disease interactions, when treatment sites were compared to control sites without the intervention.[13] Second, these OTC misuse reductions did not significantly increase over a predetermined three-month period.[16]

Senior Safe's success likely depends on two intervention features: (1) safety signage and (2) prompts to facilitate medication safety discussions between patients and pharmacy staff (e.g., pharmacists and technicians). HFE-based Red Stop Signs were designed to designate relevant OTC products that are considered higher risk according to the Beers criteria and were placed in front of those products as a "soft barrier" to prompt recommendations for alternative products and encourage patient engagement with pharmacy staff.[17] As an added feature, Red Stop Sign products were placed on lower shelves as an ergonomic barrier to easy product accessibility for older adults. Alternatively, Behind-the-Counter (BTC) Signage is located on the lowest shelves in place of extremely high-risk products that have been repositioned to behind the pharmacy counter. In this way, BTC Signage is considered a "forcing function", since patients can access the medications only after a discussion with a pharmacist.[18] Finally, Green Senior Safe Banners designate products with higher safety profiles for older adults, which typically are located within shoulder height or at eye level. Cumulatively, this signage, along with pharmacy staff's promotion of safer products, is designed to reduce use of potentially harmful OTC medications. Color-coded safety-related signage based on HFE principles has been found to be effective in other pharmacy settings for different outcomes and aligns directly with Senior Safe's visual cues and shelf zoning components.[19]

The intervention was conceptualized for and implemented in community pharmacy sites that were part of a large midwestern health system where patient safety is a foundational organizational philosophy.[16] However, the health system also is a not-for-profit entity that nevertheless relies in part on medication sales for its revenue profile. Although reduced sales of high-risk OTCs support the organization's central patient safety mission, concomitant purchases of lower-risk products would offset Senior Safe's deleterious fiscal impact and support an intervention that is both functional and financially sustainable. It was important, therefore, to evaluate the impact of Senior Safe on the frequency of OTC product sales immediately upon its implementation only in treatment sites during the RCT phase and then when system-wide adoption occurred during the Sustainability phase described above. In addition, such examination should consider a variety of site characteristics that have the potential to influence Senior Safe effects, such as size, number of staff hours worked, and geographic location.

3. Objectives

This study's primary objective is to assess Senior Safe's impact on the unit sales of OTC medications within pharmacies, specifically analyzing how the categorization and re-shelving of medications influence the unit sales of products designated with Green Banners, Red Stop Signs, or BTC signage. This assessment aims to determine whether the intervention can decrease the unit sales of potentially harmful medications (Red Stop Signs and BTC Signage), while concomitantly increasing unit sales of safer alternatives (Green Banner), without negatively impacting the overall pharmacy business model.

4. Method

4.1. Data collection

These analyses assess the impact of Senior Safe on daily unit sales the three medication classes (i.e., pain, sleep, and cough/cold/allergy products) within a network of 65 community pharmacies affiliated with a large not-for-profit health system in the Midwest. Of the system's 67 pharmacies, two newly opened sites in 2022 were excluded because they did not provide a complete 26-month data record. All other sites were continuously operational during the observation period, with no closures, additional openings, or mergers. This evaluation focuses on assessing the changes in the frequencies of unit sales of these OTC medications contained in the Green Banner, Red Stop Sign, and BTC Signage categories before and after the intervention's implementation. Comprehensive sales data were collected for the June 1, 2022-July 31, 2024 period. The dataset includes the daily units sold for each medication class and signage category (Green Banner, Red Stop Signs, and BTC Signage), Senior Safe installation date and additional operational and demographic covariates also were collected to control for potential confounders.

4.2. Data acquisition

To evaluate the impact of Senior Safe, we acquired three key datasets that addressed variables relevant to both the study objectives and the modeling framework from our healthcare organizational partner.

1. Sales Dataset: The first dataset consisted of daily unit sales records from 65 community pharmacies within the health system, which provided the frequency of medications sold. These records captured the frequency of analgesic, cough/cold/allergy, and sleep categorized by Green Banner, Red Stop Signs, and BTC Signage. These records were sourced directly from the health system's internal unit

sales tracking system and represent the primary outcome variables in the analysis.

2. Staff Roles and Work Hours Dataset: A second dataset provided information on pharmacy staff roles and associated work hours per month. Pharmacists and technicians, who directly engage in medication dispensing, were identified and included in the analysis. Non-clinical roles, such as administrative and managerial staff, were excluded from the dataset to maintain a focus on those staff members who directly impacted medication unit sales. The refined staff list was validated with the project leader who has a pharmacist background (MAC) to ensure accuracy and consistency in role identification.
3. Pharmacy Site Characteristics Dataset: The third dataset contained pharmacy site-level characteristics. Characteristics included pharmacy type (traditional vs. remote dispensing (RD)), size (small, medium, large), geographic location (urban vs. rural), weekly pharmacy open hours. In addition, this data set recorded the study phase for each site (Pilot, RCT and Sustainability).

4.3. Aggregation of sales data

To prepare the data for analysis, the raw unit sales records were aggregated by matching pharmacy site, date, medication category, and signage type. For each pharmacy, daily counts of unit sales were summed separately for products categorized as analgesics, cough/cold/allergy, and sleep, and further stratified by Green Banner, Red Stop Signs, and BTC Signage. To preserve the continuity and integrity of the time series, all calendar dates within the 26-month study period were represented for each site, regardless of whether unit sales occurred. When no unit sales were recorded for a specific category on a given date, a value of zero was inserted to maintain a complete time series. There were no missing data in this unit sales trend, either a relevant OTC medication was sold or not. The resulting dataset provides a comprehensive daily snapshot of OTC medication unit sales across all sites over the study period.

4.4. Merging of datasets

Following data acquisition and aggregation, the three core datasets were merged using pharmacy site identifiers as linking variables. This merging process created a unified analytic dataset that integrated outcome with relevant operational and contextual covariates.

5. Data analysis

All statistical analyses were conducted using RStudio Version 2024.12.0 + 467. To evaluate the effect of the Senior Safe intervention on medication unit sales, Generalized Linear Mixed Model (GLMM) regression with Poisson distribution was applied, which accounted for the low count nature of the sales data. Separate models were constructed for each medication category (analgesics, cough/cold/allergy, and sleep aids) and signage type (Green Banner, Red Stop Signs, and BTC), resulting in six model specifications. Model results are presented as Incidence Rate Ratio (IRR) with corresponding p-values. The IRR expresses the ration of the expected count of unit sales post-intervention to that of the pre-intervention period. An IRR greater than 1 indicates an increase in unit sales, while an IRR less than 1 indicates a decrease. There were no analgesics stop sign products because relevant ingredients had such a high potential for unsafe use for older adults that they warranted BTC categorizations. Alternatively, there were no unsafe sleep products identified.[20] Each model accounted for both fixed and random effects to account for site-level and temporal heterogeneity (Table 1).

Table 1
Summary of data covariates.

Variable Description	Category	Details	Fixed or Random Effect
Senior Safe Installation Date	Categorical	Pre-intervention, Post-intervention	Fixed
Pharmacy Type	Categorical	Traditional, Remote Dispensing	Fixed
Pharmacy Size	Categorical	Small, Medium, Large	Fixed
Geographic Location	Categorical	Urban, Rural	Fixed
Total Daily Open Hours	Continuous	Total hours open per day	Fixed
Staff Working Hours per day	Continuous	Daily working hours of staff(s)	Fixed
Site ID (store)	Categorical	Unique pharmacy identifier	Random intercept
Study Phase	Categorical	Pilot, RCT, Sustainability	Random slope

Fixed effects included covariates that were theorized to influence sales outcomes and control for operational and contextual differences across pharmacies. These included the intervention indicator (pre-intervention vs. post-intervention), pharmacy type (traditional vs. RDs), pharmacy size (small, medium, or large), geographic location (urban vs. rural), total daily open hours, and staff working hours per day. Staff working hours were converted from monthly to daily values, while pharmacy open hours were converted from weekly to daily values, for inclusion in the model to improve interpretability and numerical stability. In addition, random effects were used to adjust for unmeasured variability at the site and time levels. Specifically, there was a need to account for pharmacy site-level differences in baseline unit sales and operational characteristics, as well as for the phased implementation of the intervention.

6. Results

6.1. Participating pharmacies characteristics

Senior safe was implemented across 65 community pharmacies, differentiated by their operational models, sizes, and locations (Table 2). For the purpose of describing these findings, the term “pharmacies” will be used to generally refer to all sites, even though RD sites were part of the overall sample. There were more than twice as many traditional pharmacies as RD sites. In terms of size, about half of the pharmacies were classified as small, followed in frequency by medium-sized sites, with large pharmacies being the least common. Most pharmacies were in urban areas.

On average, pharmacies were open for about 8 h a day. The staff, comprising both pharmacists and technicians, cumulatively worked an average of 18.7 h per day. However, this average represents significant variability across sites (SD = 12.3 h), reflecting differences in

Table 2
Participating pharmacies characteristics.

Variables	Count	Percentage
Type		
Traditional	45	69.2
Remote Dispensing	20	30.8
Size		
Small	33	50.8
Medium	22	33.8
Large	10	15.4
Urban/Rural		
Urban	56	86.2
Rural	9	13.8
Variables	**Mean**	**Standard Deviation**
Total Weekly Open Hours (Original)	53.2	18.6
Total Daily Open Hours (Transformed)[a]	7.6	2.7
Staff Working Hours per month (Original)	562.4	367.2
Staff Working Hours per day (Transformed)[a]	18.7	12.3

[a] For the GLMM modelling purpose, we use the transformed data.

operational scale and service demand.

6.2. Descriptive summary of absolute monthly sales changed (Table 3)

Unadjusted mean monthly sales across all sites were compared to describe overall changes before and after the intervention (Table 3). Green Banner products exhibited mixed patterns in absolute monthly sales changes: cough/cold/allergy products increased by 1.86 units per month, while analgesics and sleep products showed slight declines of 0.15 and 0.40 units per month, respectively. In comparison, more pronounced reductions were observed for higher-risk categories, including BTC analgesics (−0.84), BTC cough/cold/allergy products (−0.89), and stop sign cough/cold/allergy products (−0.59) per month. These unadjusted descriptive findings suggest that, at the aggregate level, sales of potentially high-risk medications declined more noticeably than safer alternatives, though the magnitude of change was small. Because these absolute differences do not account for site-level variation, operational characteristics, or temporal trends, subsequent GLMMs were used to estimate adjusted IRRs and isolate the intervention effect while controlling for confounding and random factors.

6.3. Sales GLMM model analysis by medication category and Senior Safe intervention signage

The final analyzed dataset consisted of 75,205 daily unit sales records across the community pharmacy settings within a large Midwestern health system over 2 years. These analyses represent the results of six GLMM models, each corresponding to a different OTC medication category flagged under the Beers Criteria as either safe or potentially unsafe for older adults. The categories include analgesics (Green Banner and BTC), cough/cold/allergy (Green Banner, BTC, and Stop Sign), and sleep (Green Banner).

6.4. Analgesics medications – Green Banner (Table 4)

The installation of Senior Safe was associated with a significant increase in the unit sales of safer analgesics (IRR = 1.064, 95% CI [1.104–1.116], $p = 0.012$). Pharmacy operational factors, including pharmacy type and size, significantly influenced unit sales. Compared to RD sites, traditional pharmacies had higher unit sales of safer analgesics (IRR = 1.498, 95% CI [1.143–1.963], $p = 0.003$). Medium (IRR = 1.387, 95% CI [1.074–1.791], $p = 0.012$) and large pharmacies (IRR = 1.447, 95% CI [1.040–2.013], $p = 0.028$) showed significantly greater unit sales compared to small pharmacies. However, a site's location in urban or rural areas did not significantly predict safer analgesic unit sales. Sites that were open longer per day (IRR = 1.130, 95% CI [1.077–1.184], $p < 0.001$) and had greater staff hours (IRR = 1.026, 95% CI [1.014–1.037], $p < 0.001$) also contributed to increased safer analgesic unit sales.

6.5. Analgesics medications – BTC (Table 5)

Senior Safe significantly decreased the unit sales of BTC analgesics (IRR = 0.424, 95% CI [0.345, 0.522], $p < 0.001$), indicating a 57.6% reduction post-intervention compared to pre-intervention. While pharmacy type did not significantly affect BTC analgesic unit sales, pharmacy

Table 3
Absolute monthly change in mean unit sales before and after intervention.

Category		Pre	Post	Absolute difference
Green Banner	Analgesics	18.91	18.75	−0.15
	Cough/Cold/Allergy	32.14	34.00	1.86
	Sleep	1.64	1.25	−0.40
BTC	Analgesics	1.39	0.55	−0.84
	Cough/Cold/Allergy	2.68	1.79	−0.89
Red Stop Signs	Cough/Cold/Allergy	3.13	2.53	−0.59

Table 4
Analgesics Medications – Green Banner unit sales.

			95% Confidence Interval	
	Incidence Rate Ratio	P-value	Lower Bound	Upper Bound
Senior Safe Installed				
Post-Intervention	1.064	0.012	1.014	1.116
Pre-Intervention	1			
Pharmacy Type				
Traditional	1.498	0.003	1.143	1.963
Remote Dispensing	1			
Pharmacy Size				
Medium	1.387	0.012	1.074	1.791
Large	1.447	0.028	1.040	2.013
Small	1			
Geographic Location				
Urban	0.772	0.105	0.564	1.055
Rural	1			
Daily Open Hours	1.130	<0.001	1.077	1.184
Staff Hours per Hours	1.026	<0.001	1.014	1.037

Values of 1 for each variable represent the statistical comparator group.

Table 5
Analgesics Medications – BTC unit sales.

			95% Confidence Interval	
	Incidence Rate Ratio	P-value	Lower Bound	Upper Bound
Senior Safe Installed				
Post-Intervention	0.424	<0.001	0.345	0.522
Pre-Intervention	1			
Pharmacy Type				
Traditional	1.232	0.474	0.697	2.177
Remote Dispensing	1			
Pharmacy Size				
Medium	1.856	0.028	1.068	3.224
Large	2.040	0.042	1.026	4.054
Small	1			
Geographic Location				
Urban	0.612	0.136	0.320	1.168
Rural	1			
Daily Open Hours	1.108	0.033	1.009	1.218
Staff Hours per Hours	1.041	<0.001	1.018	1.064

Values of 1 for each variable represent the statistical comparator group.

Table 6
Cough Cold Allergy Medication – Green Banner unit sales.

			95% Confidence Interval	
	Incidence Rate Ratio	P-value	Lower Bound	Upper Bound
Senior Safe Installed				
Post-Intervention	1.106	<0.001	1.050	1.166
Pre-Intervention	1			
Pharmacy Type				
Traditional	1.395	0.031	1.030	1.890
Remote Dispensing	1			
Pharmacy Size				
Medium	1.257	0.151	0.920	1.717
Large	1.514	0.041	1.018	2.253
Small	1			
Geographic Location				
Urban	0.888	0.501	0.630	1.254
Rural	1			
Daily Open Hours	1.134	<0.001	1.074	1.196
Staff Hours per Hours	1.027	<0.001	1.015	1.040

Values of 1 for each variable represent the statistical comparator group.

Table 7
Cough Cold Allergy Medication – BTC unit sales.

	Incidence Rate Ratio	P-value	95% Confidence Interval Lower Bound	Upper Bound
Senior Safe Installed				
Post-Intervention	0.607	<0.001	0.496	0.743
Pre-Intervention	1			
Pharmacy Type				
Traditional	0.954	0.873	0.535	1.700
Remote Dispensing	1			
Pharmacy Size				
Medium	1.684	0.043	1.106	2.792
Large	1.861	0.098	0.891	3.885
Small	1			
Geographic Location				
Urban	0.471	0.010	0.265	0.838
Rural	1			
Daily Open Hours	1.170	0.002	1.057	1.296
Staff Hours per Hours	1.034	0.007	1.009	1.060

Values of 1 for each variable represent the statistical comparator group.

Table 8
Cough Cold Allergy Medication – Stop Sign unit sales.

	Incidence Rate Ratio	P-value	95% Confidence Interval Lower Bound	Upper Bound
Senior Safe Installed				
Post-Intervention	0.869	0.003	0.792	0.953
Pre-Intervention	1			
Pharmacy Type				
Traditional	1.587	<0.001	1.216	2.072
Remote Dispensing	1			
Pharmacy Size				
Medium	1.217	0.132	0.943	1.571
Large	1.576	0.012	1.104	2.250
Small	1			
Geographic Location				
Urban	0.759	0.107	0.543	1.061
Rural	1			
Daily Open Hours	1.131	<0.001	1.073	1.193
Staff Hours per Hours	1.026	<0.001	1.016	1.037

Values of 1 for each variable represent the statistical comparator group.

Table 9
Sleep Medication – Green Banner unit sales.

	Incidence Rate Ratio	P-value	95% Confidence Interval Lower Bound	Upper Bound
Senior Safe Installed				
Post-Intervention	0.812	<0.001	0.720	0.917
Pre-Intervention	1			
Pharmacy Type				
Traditional	1.840	0.001	1.277	2.651
Remote Dispensing	1			
Pharmacy Size				
Medium	1.266	0.178	0.898	1.783
Large	1.356	0.193	0.857	2.144
Small	1			
Geographic Location				
Urban	0.743	0.184	0.479	1.151
Rural	1			
Daily Open Hours	1.089	0.009	1.022	1.161
Staff Hours per Hours	1.019	0.007	1.005	1.034

Values of 1 for each variable represent the statistical comparator group.

size did: compared to small pharmacies, both medium and large pharmacies had significantly higher unit sales (IRR = 1.856, 95% CI [1.068, 3.224], p = 0.028 and IRR = 2.040, 95% CI [1.026, 4.054], p = 0.042, respectively). Daily operational characteristics also influenced outcomes. Longer daily open hours (IRR = 1.108, 95% CI [1.009, 1.218], p = 0.033) and greater staff hours per day (IRR = 1.041, 95% CI [1.018, 1.064], p < 0.001) were both associated with significantly increased BTC analgesic unit sales. Again, the geographic location was not a significant predictor of BTC analgesic unit sales.

6.6. Cough/cold/allergy medications – Green Banner (Table 6)

Senior Safe installation also was associated with a significant increase in the unit sales of safer cough/cold/allergy products (IRR = 1.106, 95% CI [1.050, 1.166], p < 0.001), reflecting a 10.6% rise in unit sales following the intervention. Compared to RD sites, traditional pharmacies had significantly higher unit sales of safer cough/cold/allergy products (IRR = 1.395, 95% CI [1.030, 1.890], p = 0.031). While medium-sized pharmacies did not show a statistically significant difference, large pharmacies demonstrated significantly greater unit sales compared to small pharmacies (IRR = 1.514, 95% CI [1.018, 2.253], p = 0.041). However, geographic location (urban vs. rural) did not significantly influence safer product unit sales. Increased unit sales were also found when sites had longer daily open hours (IRR = 1.134, 95% CI [1.074, 1.196], p < 0.001) and more staff hours per day (IRR = 1.027, 95% CI [1.015, 1.040], p < 0.001).

6.7. Cough/cold/allergy medications – BTC (Table 7)

Introducing Senior Safe contributed to a significant decrease in the unit sales of BTC cough/cold/allergy products (IRR = 0.607, 95% CI [0.496, 0.743], p < 0.001). Pharmacy operational factors, including pharmacy type, size and location, influenced unit sales. Compared to RD sites, pharmacy type did not significantly predict BTC product unit sales. Medium-sized pharmacies showed significantly greater unit sales compared to small pharmacies (IRR = 1.684, 95% CI [1.106, 2.792], p = 0.043), while large pharmacies did not reach statistical significance. A site's location in urban or rural areas was a significant predictor, with urban pharmacies showing lower BTC product unit sales than rural ones (IRR = 0.471, 95% CI [0.265, 0.838], p = 0.010). Sites that were open longer per day and had more cumulative staff hours also had increased BTC product unit sales (IRR = 1.170, 95% CI [1.057, 1.296], p = 0.002 and IRR = 1.034, 95% CI [1.009, 1.060], p = 0.007, respectively).

6.8. Cough/cold/allergy medications – Red Stop Signs (Table 8)

As with related BTC product, Senior Safe significantly decreased unit sales of Stop Sign cough/cold/allergy products (IRR = 0.869, 95% CI [0.792, 0.953], p = 0.003). Pharmacy operational factors, including pharmacy type and size, also influenced unit sales. Compared to RD sites, traditional pharmacies had significantly higher unit sales (IRR = 1.587, 95% CI [1.216, 2.072], p < 0.001). Only large pharmacies showed significantly greater unit sales than small pharmacies (IRR = 1.576, 95% CI [1.104, 2.250], p = 0.012). Unlike the effects found for BTC products, a site's urban/rural status did not significantly predict Stop Sign product unit sales. Significant increases for Stop Sign product unit sales were found for sites that were open longer per day (IRR = 1.131, 95% CI [1.073, 1.193], p < 0.001) and had higher staff hours (IRR = 1.026, 95% CI [1.016, 1.037], p < 0.001).

6.9. Sleep medications – Green Banner (Table 9)

Finally, modeling Senior Safe effects on safer sleep products showed results that were counter to intervention intention, by decreasing unit sales of these products (IRR = 0.812, 95% CI [0.720, 0.917], p < 0.001). Another finding that was inconsistent with all other GLMM models was the entirely non-significant effect of pharmacy size on Green Banner sleep products. Compared to RD sites, traditional pharmacies had significantly higher unit sales (IRR = 1.840, 95% CI [1.277, 2.651], p = 0.001). Controlling for all other variables, a site's location in urban or rural areas was not significant. As with every other statistical model, sites that were open longer per day and had greater staff hours were significantly associated with increased safer sleep product unit sales (IRR = 1.089, 95% CI [1.022, 1.161], p = 0.009 and IRR = 1.019, 95% CI [1.005, 1.034], p = 0.007, respectively).

7. Discussion

Senior Safe was not only related to significant reductions in its primary goal of medication misuse,[16] but these analyses demonstrated an association in its effectiveness at reducing unit sales of potentially harmful OTC medications while simultaneously increasing purchases of safer alternatives. That is, the separate statistical models showed implementing Senior Safe was associated with increased unit sales of safer (Green Banner) medications related to cough/cold/allergy and pain symptoms. There also were decreased unit sales of both high-risk (Red Stop Signs) cough/cold/allergy medications and higher risk (BTC) analgesic and cough/cold/allergy products (Table 10). As a result, it seems that more frequent purchases of safer OTC medications offset the reduced unit sales of unsafe products, at least approximating a net-neutral effect on total product unit sales. These findings suggest that the intervention effectively influenced consumer purchasing behavior and pharmacy-level unit sales trends. The significance of these results extends beyond the immediate effects of Senior Safe, addressing a fundamental concern in healthcare delivery, balancing patient safety with economic sustainability.

Cumulatively, these findings are not only consistent with the intervention's safety-driven intent, but also carry broader implications for the integration of safety-focused design into real-world pharmacy practice. In retail healthcare environments, interventions designed to reduce unsafe patient behaviors fail to conform to the business model. In contrast, Senior Safe's design facilitated a shift in pharmacy staff/patient interactions through environmental nudges – visual signage designating safety, with prompts for such interactions, and product positioning on the shelves, motivating patients to substitute for safer medications rather than forgo OTC products. The represents is a rare example of a system-level safety intervention that is behaviorally effective, sales neutral, and operationally feasible.

Senior Safe's impact for one product class – safer sleep products – ran counter to all other models. That is, the unit sales of Green Banner-designated sleep products decreased following Senior Safe implementation. A likely explanation for this result relates to the physical placement of these items. As noted in a prior study of site adherence to intervention-specific product and signage placement guidelines, many of the Green Banner sleep products were located below knee height, which did not align with intervention guidelines and may have made them less visible or accessible to older adults.[20] This design limitation contrasts with other categories, where Green Banner products were placed at shoulder or eye level, maximizing their visibility.[21] In addition, as noted by a participating system manager (JG), there has been a system-wide decline in sales across the entire sleep and vitamin category, which could contribute to the observed decrease independent of the intervention.

Table 10
Summary of senior Safe™ effects on unit sales by medication category and signage type.

Category		IRR	P-value	Effect Direction
Green Banner	Analgesics	1.064	0.012	Increase
	Cough/Cold/Allergy	1.106	<0.001	Increase
	Sleep	0.812	<0.001	Decrease
BTC	Analgesics	0.424	<0.001	Decrease
	Cough/Cold/Allergy	0.607	<0.001	Decrease
Red Stop Signs	Cough/Cold/Allergy	0.869	0.003	Decrease

When examining other effects on product unit sales, several variables showed significant predictive value. Traditional pharmacies and those with longer daily open hours and greater staff hours tended to have significantly higher unit sales across all signage types. Pharmacies with greater operational capacity may naturally experience higher overall sales volume, independent of the intervention. Medium and large pharmacies also showed significantly greater unit sales in several categories compared to small pharmacies. This aligns with the intervention's design, which aimed to encourage staff-patient interactions to support safer medication choices. Pharmacies with more available personnel, whether pharmacists or technicians, were more likely to engage patients in conversations prompted by the signage or relocation cues. As noted by a participating system manager (JG), the simplicity of the signage-based intervention may have boosted pharmacy staff confidence in initiating safety discussions, amplifying its impact where staffing was sufficient. In addition, staffing differences may have contributed to the variation in intervention impact across sites. Notably, eight RD sites in the sample operated without on-site pharmacists. While larger traditional pharmacies often had multiple staff present, the absence of in-person pharmacy professionals in RD sites likely reduced opportunities for patient engagement and intervention reinforcement. These operational differences help explain both the variability in site-level effects observed in remote or lower-staffed settings.

The single variable that showed the most consistent lack of predictive power was geographic location (urban vs. rural). In fact, a pharmacy's rural/urban status failed to achieve a statistically significant association with medication unit sales in all but one model (i.e., for BTC cough/cold/allergy products). It is possible that whether a pharmacy is situated in a rural or urban community, by itself, is just not an influence on most medication unit sales, but this seems counterintuitive. However, an alternative, and logical, explanation for these findings is that, within a multivariate modeling approach, the effect of a pharmacy's location may be better explained by its operational characteristics. That is, controlling for a pharmacy's type, size, number of staff, and hours opened could have cumulatively negated the influence of location for explaining OTC medication unit sales. Additional research can conceptualize an analytic design to evaluate the explanatory function of urban/rural status in relation to potentially related operating features.

7.1. Limitations

Despite the overall support for intervention effectiveness, this study has several limitations. First, medication unit sales volume data were accessible through the partner health system as a proxy for consumer behavior, rather than actual cost data or profit margins. Although these results suggest a net-neutral impact on unit sales, the financial impact or cost-neutrality of Senior Safe was not possible to determine. Future studies could incorporate product pricing and margin data to evaluate economic implications. A rigorous cost-effectiveness evaluation is warranted to account for opportunity costs and resource requirements, such as pharmacy personnel time and investments, necessary to maintain the intervention over time. Second, the analysis used unit sales as the outcome measure, which does not account for product strength, package size, or recommended daily dose. Since, medication-related risk can be dose dependent, the lack of strength/dose information could attenuate or exaggerate potential risk. However, it is not possible to link these results to clinical or health outcomes. Third, while the statistical models were adjusted for key operational characteristics (e.g., pharmacy size, type, staffing hours, and open hours), additional unmeasured variables, such as staff training quality, consumer demographics, or competitor closures, may have influenced outcomes and warrant further exploration. Fourth, there was variation in the duration of pre-intervention versus post-intervention periods across sites. Although all sites were observed over the same total time frame (1157 days), the number of post-intervention days ranged from 206 to 771, depending on the pharmacy. Still, all study sites had at least a six-month post-intervention period. Even with this ample post-intervention period, this variation may have reduced the ability to detect sustained changes in consumer behavior, especially for categories with slower adaptation curves. It is also possible that the intervention's impact could diminish over time – "effectiveness decay".[22] While initial implementation often promoted strong engagement and behavior change, prolonged exposure could lead to reduced visibility and patient responsiveness as patients became accustomed to the signage and engage in less behavioral reflection. As a result, a systematic process for periodic awareness and motivational strengthening, such as through regular updates or trainings, might be required. Finally, although the intervention specifically targeted older adults, analyses were conducted at the aggregate store-level using unit sales. It is not able to confirm that observed sales changes were primarily driven by older consumers rather than other consumers.

8. Conclusions

Regardless of these limitations, this study provides evidence that a patient safety intervention can be embedded into retail pharmacy practice in ways that are both behaviorally impactful and sustainable from a business perspective. The fact that unit sales of safer products increased concurrently with a reduction in high-risk purchases suggests that the design of Senior Safe not only influenced consumer decision-making but did so without compromising pharmacy business models—it negates a critical historical barrier to adopting patient safety intervention. Moreover, Senior Safe's adaptability across pharmacy types, sizes, and geographic locations reinforces its potential scalability. While the effects were more pronounced in larger, traditionally staffed, pharmacies, the presence of positive trends even in smaller or RD sites suggests that, with appropriate adjustments such as improved product placement, Senior Safe could be successfully deployed system wide. Finally, this work adds to the growing implementation science literature on how low-cost, system-level design changes can meaningfully improve health behaviors in real-world settings. As the healthcare system continues to shift toward patient-centered and preventive care, interventions like Senior Safe illustrate a promising path forward: one that enhances safety through thoughtful design and operational realities.

CRediT authorship contribution statement

Shiying Mai: Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Aaron M. Gilson:** Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Methodology, Formal analysis, Conceptualization. **Ronald E. Gangnon:** Validation, Software, Methodology, Formal analysis. **Jamie A. Stone:** Writing – review & editing, Resources, Project administration, Funding acquisition. **Kenneth D. Walker:** Resources, Project administration. **Joel D. Gollhardt:** Resources, Project administration. **Michelle A. Chui:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

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