Open & Act: Tracking Healthcare Team Response to EHR Asynchronous Alerts

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Abstract

Purpose
To identify factors related to timely opening of alerts and first responsive action, and to describe the immediate relevant PCP actions following alert opening and assess the relationship between timely first responsive action and key patient outcomes.

Scope
Asynchronous alerts are a form of clinical communication delivered to physicians' secure InBaskets within EHRs. Delayed alert review can impact patient safety and compromise care.

We analyzed study-generated alerts, that represent a subset of all urgent InBasket notifications, sent 3 days post-discharge to 75 PCPs across a multisite healthcare system that highlighted actionable medication concerns for older patients (2010-2011).

Methods
Using EHR logs, we tracked alert opening, physician behavior following opening, and responsive actions for 799 alerts. We performed bivariate and multivariate analyses calculating associations between various factors, alert opening within 24 hours, and likelihood of subsequent PCP action.

Results
More notifications (>157 notifications) in the PCP InBasket at the time of alert delivery (OR 0.27 [CI 0.14-0.51]) and Saturday alert delivery (OR 0.16 [CI 0.08-0.33]) were associated with lower likelihood of opening within 24 hours. It was significantly more likely for medication recommendations to be followed by medication-specific action (4.97[2.10-11.76]) and recommendations for orders to be followed by lab-specific action (2.71[1.76-4.16]). Alerts recommending medication changes (4.0[1.7-9.7]) or test orders (2.1[1.4-3.3]) were more likely to be followed by EHR viewing compared to information-only alerts. The mean total time spent viewing patient-related information ranged from 20.5 to 116.15 seconds.

Key words
Electronic Health Records, Health Information Technology, Healthcare communication, Health Services Research

Purpose

To perform a secondary data analysis with the following specific aims:

1. Identify contextual factors, types of alerts and characteristics of providers, patients and hospital discharges that relate to timely opening of alerts following receipt.
2. Identify contextual factors, types of alerts and characteristics of providers, patients and hospital discharges that relate to timely first responsive action following receipt and opening of the alerts.
3. Track and describe the sequence of relevant actions taken by the healthcare providers immediately following alert opening.
4. Assess the relationship between timely first responsive action following opening of alerts and key patient outcomes, including completion of an office visit, rehospitalization, ER visits, urgent care visits, and adverse drug events.

Our overarching goal is to gain a deeper understanding of drivers and barriers to the timely completion of relevant HIT-based actions following delivery of EHR-based alerts in order to improve the design and implementation of future systems.

Scope

Background

Electronic Health Record (EHR)-based asynchronous messaging is a form of secure, email-style message exchange used widely by healthcare teams to communicate time-sensitive patient information without requiring sender and receiver to engage simultaneously. Asynchronous alerts are messages whose primary goal is to prompt timely, relevant healthcare team action aimed at improving patient outcomes. Unlike alerts that interrupt users mid-task, asynchronous alerts are delivered to a secure electronic "InBasket" where they wait to be opened.

While numerous studies describe interruptive alerts, little is known about the use, impact and risk of asynchronous alerts. Alerts are intended to improve patient outcomes, but little data exists on factors influencing alert effectiveness or on the potential risks incurred when alerts remain unopened. This is an important gap. Often asynchronous alerts serve as the only notification to healthcare team members of time-sensitive issues; unopened alerts represent a potentially dangerous communication breakdown. Through previous AHRQ funding (R18 HS017203) we implemented a post-hospital-discharge alert intervention notifying primary care teams of medication safety concerns and the need for close office follow-up post hospitalization. Automated asynchronous alerts were sent following 1282 hospital discharges of elderly patients but we found no evidence of an impact on patient outcomes. Preliminary review showed that 40% of staff-directed alerts and 19% of primary care provider alerts remained unopened at the end of day 1 post-delivery. A variety of sociotechnical factors likely influenced alert opening and subsequent actions. We compiled a rich collection of data with detailed information on alerts, the discharges triggering those alerts, contextual factors (e.g. number of unopened messages in the recipient's "InBasket" at the time of alert delivery), patient and provider characteristics, and clinical outcome data. We enriched this data with electronic tracking data ("digital crumbs") recording the date and time of the creation and review of EHR data elements.

Context

Through previous AHRQ funding (R18 HS017203) we implemented an alert intervention notifying primary care teams of medication safety concerns and the need for close office follow-up post hospitalization. For patients randomized to receipt of the intervention, automated asynchronous alerts were sent following 1282 hospital discharges of elderly patients between 2010 and 2011; of these, 799 highlighted medication concerns and were the focus of our study (others notified staff of the need for a follow-up office visit). Medication concerns included warnings about selected drug-drug interactions, recommendations for consideration of dose changes, need for laboratory monitoring for high-risk medications and notification of new medications at discharge for which PCP awareness was clinically important. Alerts were designed to convey actionable time-sensitive concerns; all had the heading: "[Hospital Name] Discharge Alert." Over four months prior to implementation, two physicians from the healthcare system reviewed every alert generated and suggested modifications to ensure that alerts would be perceived as necessary, useful and brief. Upon implementation, alerts were automatically triggered on day 3 following hospital discharge and were sent to the Test Results Folder within primary care provider EHR InBaskets, arriving at 10 am.

Settings

The hospital-to-home transitional care EHR alert intervention was carried out in the setting of a large multispecialty group practice. The group practice employs 265 physicians. The practice has used an electronic health record since 2006 (Epic Systems Corporation). The group provides care to approximately 25,000 senior plan members of an associated health plan, with which the group shares financial risk.

Participants

A total of 799 alerts for 713 patients highlighting actionable medication concerns were sent to 75 primary care physicians. Additionally, five providers from the multispecialty group practice participated in a focus group related to workflow patterns surrounding message opening.

Methods

Study Design

Overview: For **Aim 1,** an analysis was conducted to understand the use and impact of asynchronous EHR alerts delivered in the context of our post-hospital transitional care intervention. We used data elements derived from our previous study to investigate provider and staff opening of time-sensitive EHR alerts. In **Aim 2,** we examined whether there was an association between (a) contextual factors; (b) types of messages; and (c) provider, patient or hospital discharge characteristics and completion of first responsive healthcare team action. In **Aim 3,** we tracked the sequence of relevant healthcare team actions taken in the critical period (5 minutes) post-alert opening. Finally, for **Aim 4**, we examined whether timely first responsive action following timely alert opening was associated with better patient outcomes.

We provide here a visual overview of the Alert-Response Pathway and the points along this pathway which we proposed to study (see Figure 1).

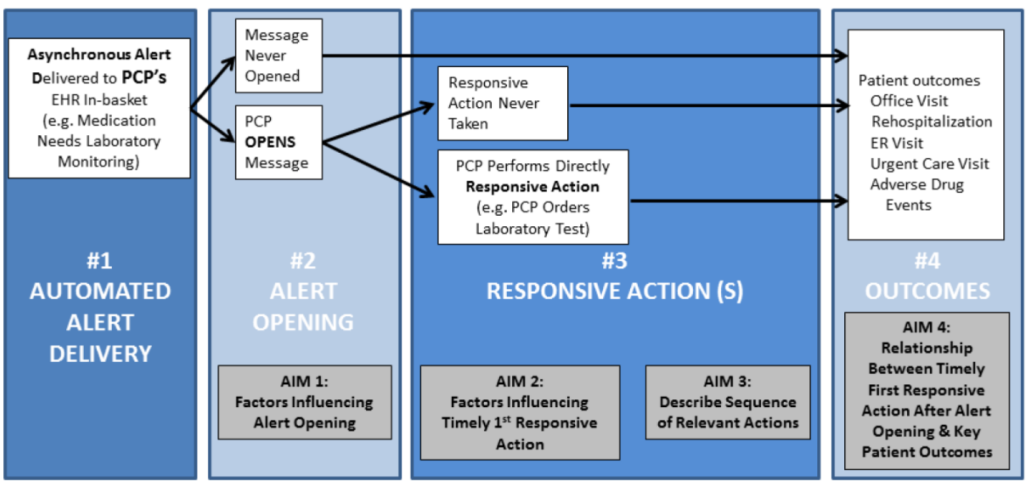

Figure 1. Diagram of Alert-Response Pathway for an Electronic Health Record-based asynchronous alert delivered to the InBasket of a primary care provider.

Aim 1. Identify contextual factors, types of alerts and characteristics of providers, patients and hospital discharges that relate to timely opening of alerts following receipt.

Dependent variables. We used audit and access logs to capture time of alert opening which was incorporated into all 4 aims. For Aim 1, we calculated the percentage of alerts opened by PCPs within 24 hours. We focused on 24 hours for alert opening because this was an at-risk population (post-hospital discharge, aged ≥65 years) for whom new medication concerns had been identified that were deemed urgent (based on two-physician review during pre-implementation phase). We also performed a sensitivity analysis examining characteristics associated with 48 hour opening. Since all alerts were delivered at 10 am on the day of delivery, a 48-hour window included standard weekday clinic hours for all alerts.

Independent variables of interest. We classified patients' age (65-74; 75-84; ≥85 years) and gender. We used administrative data to examine patient-level variables including number of office visits (≤ 6, 7-11;

12-18 or >18 visits) and comorbid medical conditions. We created a modified Charlson comorbidity index score for patients (categorized as 0, 1, 2, and 3+) using data on medical diagnoses and procedures in the year prior to admission to the hospital(24) and gathered information on length of hospital stay (≤2, 3, ≥4 days).

PCP characteristics included in the analyses were age (<50 vs ≥50 years), gender, number of patient encounters in study year (quartiles), and specialty (internal medicine; family medicine; non-MD PCP such as nurse practitioner; and subspecialist acting as PCP).

Using data from audit logs and access logs, we identified the following variables and categorized each by quartile: number of total notifications (already opened notifications + unopened notifications) in the PCP's InBasket at the time of alert delivery; number of unopened notifications in the PCP's InBasket at the time of alert delivery; and number of notifications delivered to the PCPs InBasket in the 7 days prior to alert delivery. In addition, we analyzed number of total notifications in the PCP's InBasket as a continuous variable. We compared alerts delivered on Saturday to those delivered on all other days because those arriving on Saturday were the only alerts for which 24 hours post-delivery did not include any weekday time. We collectively refer to the above variables as contextual variables.

We also captured timing of log in to the EHR (logged in at time of alert delivery or within the 24 hours of delivery vs. not logged in); alert opening by (a) a physician who was not the PCP and (b) a staff member (opened within 24 hours vs. not); and opening of a follow-up notification by PCP or other physician (opened within 24 hours vs. not). Follow-up notifications are created by staff and contain a copy of the alert contents.

Statistical Analysis

Descriptive analysis. We performed descriptive analyses, calculating basic frequencies and percentages for patient and PCP characteristics and calculating frequencies, medians and interquartile ranges for all contextual variables. We then calculated time to PCP opening of alerts, using survival curves measuring time (in days) from the date of alert delivery (day 3 post hospital discharge) to 30 days post alert delivery. Survival curves were stratified for independent variables that demonstrated a statistically significant association with message opening in the multivariate analysis described below.

In an exploratory analysis of workflow, we calculated frequencies and percent of alerts opened by (a) the intended PCP and (b) another physician within 24 hours. We also examined frequencies and percent of alerts opened within 24 hours by a staff member and for these, we tracked frequency and percent of cases in which follow-up notifications were opened by PCPs or covering physicians within 24 hours of alert delivery. We were unable to capture surrogate assignment of InBasket coverage and therefore could not estimate the percent of alerts delivered on days where a covering clinician was assigned.

Bivariate Analyses – All PCPs. We used generalized estimating equations (GEE) with a logit link and a binomial distribution to estimate the bivariate association between PCP characteristics, patient characteristics, contextual variables and opening of the alerts within 24 hours. The GEE models account for clustering of measures within PCPs since some PCPs received multiple alerts over the one year period. In order to check for the existence of a linear trend in association with timely opening, we also examined the bivariate association between total number of InBasket notifications (using this variable as a continuous measure) and alert opening within 24 hours.

Multivariate Analyses – All PCPs. We performed multivariate analyses using GEE equations as described above, studying the association between covariates of interest and PCP alert opening within 24 hours. Covariates included in the multivariate models encompassed all PCP characteristics, patient characteristics and contextual variables. All PCPs were included in this analysis.

Multivariate Analyses –PCPs logged in at time of alert delivery. We also constructed multivariate GEE models using the approach described above but limiting our population to PCPs who were logged in at the time of alert delivery or who logged in within the 24 hours following.

Analyses were carried out using the SAS package version 9.3 (SAS Institute, Cary NC, USA) and STATA version 13.1 (STATA Corp., Texas, USA).

Aim 2. Identify contextual factors, types of alerts and characteristics of providers, patients and hospital discharges that relate to timely first responsive action following receipt and opening of the alerts.

Dependent variables. For the 799 alerts studied in Aim 1, EHR audit logs were tracked to identify actions taken by the provider after opening the alert. Responsive actions were categorized as 1) general action which included viewing any patient information within the electronic medical record; 2) medication-specific action which includes viewing the patient's medication list or ordering a medication, and 3) laboratory-specific action which included viewing or ordering labs. Medication-specific actions and Laboratory-specific actions are subsets of the General action category.

The window for a responsive action was 'same or next day', i.e. occurring at or after 10 am on the day of delivery (the time at which alerts were delivered) through midnight the day following alert delivery. The reason for this choice was to allow for inclusion of a broad range of potential responsive actions, some of which were recorded with time stamp and some of which only included a date. In our Aim 3 analysis (described below) we narrowed the time window to study just the 5 minutes post alert-opening (for those alerts where PCPs opened the alert).

Independent variables used in this analysis included all those listed in the Aim 1 analysis; additionally, alert opening and alert type were also included.

Bivariate and multivariate analysis was carried out studying the relationship between responsive action following alert opening and alert type, timing of alert opening, person opening (PCP or other), provider characteristics (age, gender, number of patient encounters in a year, and specialty), patient characteristics (age, gender, number of office visits in the past year, Charlson Comorbidity score, and length of hospital stay), and contextual factors (total number of messages in InBasket at time of alert delivery, number of unopened messages in InBasket at time of alert delivery, message count in 1 week prior to alert delivery, and day of the week alert sent).

Aim 3. Track and describe the sequence of relevant actions taken by the healthcare providers immediately following alert opening.

Dependent variables. We accessed clickstream data from the EHR audit logs to track physician actions during five minutes following opening of the alert to determine whether the immediate next action (dependent variable) was viewing of electronic information about the patient of interest or not. Actions which we categorized as viewing relevant patient information included opening a section of the patient's medical record or using one of several clickable buttons on the alert that served as direct links to summaries of components of that patient's record. Actions which we categorized as not viewing relevant patient information included opening a notification related to a different patient, opening a section of a different patient's medical record, or doing nothing further in the EHR for five minutes. We calculated the total time that the physician accessed information on the relevant patient, starting from opening of the alert and continuing through viewing of EHR sections related to the patient until the physician moved away from that patient's information or the end of the five-minute period. We categorized viewed sections of the EHR as being primarily related to medications, laboratory, orders, results, encounters, demographic information, other clinical information, non-clinical information, or information entry.

We assessed the impact on the first action following alert opening of alert type, physician characteristics (gender and number of patient encounters in the previous 12 months), comorbidity of the patient using the Charlson Comorbidity Score categorized as 0, 1 and 2+, timing of alert opening categorized as within 1 hour of receipt, within 24 hours or >24 hours, whether the alert was opened within office hours defined as 8AM to 5PM Monday through Friday, and contextual factors including the number of active notifications in the inbox as well as the number of unopened notifications and the total number in the past week.

We performed descriptive analyses, calculating frequencies and percentages for first actions following opening of the alerts for each alert type, physician and patient characteristics, timing of alert opening and context. In multivariable logistic regression analyses assessing the impact of these factors on whether the first action was viewing of any information on the relevant patient, we used generalized estimating equations with a logit link and binomial distribution to account for clustering within primary care physicians.

Among alert openings that were followed by any further action within five minutes, we calculated the total time in seconds spent on the alert plus EHR views for each alert type and for each type of first action and calculated mean, minimum, maximum, median and 25^{th} and 75^{th} percentiles.

Among physicians who viewed any portion of the patient's EHR, we calculated the percent that included sections relevant to the alerts, including those related to orders, medications, laboratory and results.

We tracked the sequence in which sections of the relevant patient's EHR were viewed and produced icicle graphs displaying the first 12 views.

Aim 4. **Assess the relationship between timely first responsive action following opening of alerts and key patient outcomes, including completion of an office visit, rehospitalization, ER visits, urgent care visits, and adverse drug events.**

Dependent variables. Patient outcomes examined in relation to timely first responsive action following alert opening included (a) rehospitalizations and (b) adverse drug events. ER visits and urgicare visits were examined but we determined that capture of these events was not sufficiently consistent for meaningful use in this analysis.

We excluded all outcomes preceding alert delivery and all outcomes where the time of occurrence overlapped with the time during which a responsive action was measured (e.g. 'same or next day'). Thus, outcomes occurring between 10 am on the day of delivery (the time at which alerts were delivered) through midnight the day following alert delivery were excluded.

Independent variables. Analysis of timely alert opening, responsive action, and patient outcomes focused on a comparison of '**timely opening with action**', defined as the PCP opening the alert within 24 hours AND taking a responsive action 'same or next day', compared to all other situations. We also conducted a sensitivity analysis extending the alert opening window to 48 hours.

With the index time set at midnight on the day post-alert delivery, a crude survival analysis reviewing hazards ratios and significance for alert type, patient characteristics, provider characteristics, and contextual factors was performed to predict the likelihood of 1) rehospitalizations within 30 days and (in a subset of cases) 2) adverse drug events within 45 days. To adjust for clustering of patients within providers, we used a robust sandwich covariance matrix in SAS analytics software version 9.3 (SAS Institute, Cary NC, USA).

Data Sources/Collection and Measures

Alert Opening	In the previous study (R18 HS017203), we generated tracking reports of automated asynchronous alerts. We used these reports to identify date and time of alert delivery into provider and staff electronic InBaskets. Using data from access logs, we identified the date and time of opening for every opened alert.
Contextual Factors	We identified contextual factors surrounding the delivery of alerts into provider InBaskets. These contextual factors include the total number of messages in the InBasket at the time of alert delivery, the number of *unopened* messages in the InBasket at time of alert delivery, the day of the week the alert was sent, and the number of new messages received in the week prior to alert delivery.
Alert Types	There were three types of alerts: 1) **notification** about new and high risk medications at the time of hospital discharge, 2) recommendations to **change medications** (cancel or dose change) and 3) recommendations to **order tests** to monitor the impact of high risk medications or titrate their doses.
Provider Characteristics	We used information from our provider database to characterize primary care providers according to age, gender, and specialty. Encounter data provided information on number of patient encounters per study year, a proxy for patient panel.
Patient Characteristics	We used claims and medical group encounter data to identify potentially relevant characteristics of discharged patients whose provider received one or more alerts. Characteristics included age, gender, number of hospitalizations and of office visits during the prior year, and Charlson comorbidity index.
Sequence of Relevant Actions	We accessed clickstream data from EHR audit logs to track physician actions during five minutes following opening of the alert to determine whether the immediate next action was viewing of electronic information about the patient of interest or not. Actions included viewing or documenting relevant patient information within the electronic medical record, discontinuing a medication or changing the dose, and ordering a lab, eye exam, or dose titration.
Responsive Action	General action includes viewing any relevant patient information in EHR. Medication-specific action includes medication list viewing, ordering or discontinuing a medication, or changing the dosage. Laboratory-specific action includes viewing laboratory results, ordering labs or eye exams, or titrations for a dose change. Medication-specific actions and Laboratory-specific actions are subsets of the General action category.
Outcomes	Patient outcomes examined in relation to timely first responsive action following alert opening included (a) rehospitalizations and (b) adverse drug events. Rehospitalizations were identified using administrative claims data. Adverse drug events were assessed for a subset of alerts. In the previous study (R18 HS017203), comprehensive medical chart reviews were conducted by three trained clinical pharmacists for 1000 consecutive hospital discharges from August 26, 2010 to December 27, 2010. To identify adverse drug events during an observation period of 1-45 days post hospital discharge, pharmacists reviewed hospital discharge summaries, emergency department visit notes, office visit notes, telephone encounters and other EHR-documented encounters that occurred between the patient and the Medical Group providers.

Physician Focus Group. We conducted a single physician focus group intended to inform our research regarding factors influencing InBasket management . Email invitations were sent to 100 PCPs in the medical group and 5 respondents were recruited. A one-hour session (audio recorded and professionally transcribed) addressed strategies for managing EHR InBaskets and factors influencing speed of notification opening including a discussion of the subject header for the alerts in this study. The transcript was reviewed for major themes by two authors (LB, SC).

Results

Principal Findings

Aim 1. The seventy-five PCPs received 799 automated alerts over the one-year period. The median number of alerts per PCP over the entire one-year period was 9 with an interquartile range (IQR) of 3-16. To place these alerts in context, the median number of total notifications in PCP InBaskets at the time of alert delivery was 68.7 (IQR 41.3, 156.3). The median number of notifications arriving in PCP InBaskets during the 7 days prior to alert delivery was 379.8, IQR (295.0, 492.0).

Characteristics of patients for whom alerts were triggered and PCPs to whom the alerts were sent are described in Table 1. Distribution of alerts by PCP and patient characteristics and for contextual variables is shown in Table 2. Overall, 47.1% (n=376) of alerts were opened by the intended PCP within 24 hours (Table 2). An additional 2.0% (16) were opened by covering physicians and, in some cases, staff members opened messages and generated follow-up communication. These follow-up communications were read by the intended provider (2.8%, N=22 messages) or a covering provider (0.9%, N= 7) within 24 hours of delivery. Overall, 41.1% of these time-sensitive messages were not opened by anyone within 24 hours; an additional 6.3% were opened by staff within the first 24 hours with no evidence that communications were passed along within the EHR. 59.5% were opened within 48 hours and 77.2% were opened at the end of 30 days (not shown in table).

Rates of opening within 24 hours were inversely related to size of InBasket at the time of message delivery, with 61.8% of messages opened within 24 hours among providers whose total number of InBasket messages were in the bottom quartile (≤42 messages), dropping to 28.1% of providers whose total number of InBasket messages were in the top quartile (>157 messages); $p<0.0001$.

In bivariate analysis accounting for clustering by PCP (Table 2), there were no significant bivariate associations between alert opening at 24 hours and either PCP characteristics or patient characteristics. On analysis using total number of InBasket notifications as a continuous variable, we found that for each additional notification in a PCP InBasket, there was a small but statistically significant decrease in likelihood of alert opening in 24 hours (OR 0.50 (95% CI 0.50, 0.50).

In a multivariate model controlling for physician, patient and InBasket characteristics, compared to alerts delivered into InBaskets whose message volume was in the bottom quartile, alerts delivered into InBaskets whose message volume was in the top 2 quartiles were less likely to be opened in 24 hours (>157 messages: OR 0.27 (95% CI 0.14-0.51); 69-156 messages: OR 0.39 (CI 0.21-0.75). Alerts delivered on Saturdays were less likely to be opened than those delivered on any other day OR 0.16 (CI 0.08-0.33).

For alerts sent to PCPs who were logged in at the time of or within 24 hours of alert delivery (Table 3), alerts sent for patients aged 75-84 were significantly less likely to be opened compared to alerts for patients under 75. Patients with a Charlson comorbidity score of 1 were significantly more likely to have their alerts opened than those with a score of zero but there was no apparent trend by comorbidity score.

Aim 2. Of the 799 alerts, 74.2% were notifications about newly started medications for which a potential issue was identified, 4.6% contained instructions to discontinue or change a medication dose, 21.2% contained instructions to order tests (labs or other tests related to medication use). Compared to the notification group, those told to order tests were significantly more likely on bivariate and on multivariate analysis to take any action (adjusted odds of action 1.66, 95%CI 1.08-2.54), to take a medication-specific action (OR 1.71, CI 1.09- 2.68)) or to take a lab-specific action (OR 2.75, CI 1.73- 4.38). Compared to the notification group, those told to change meds were significantly more likely to take a medication-specific action (OR 5.59 (2.42- 12.94) or a lab-specific action (OR 7.38 (3.64- 14.97)).

Aim 3. Of the 799 alerts, 616 were opened by 64 physicians. For 208 alerts, the first action following alert opening included viewing electronic information related to the relevant patient (Table 4). More than 50% of alerts were followed by the physician's opening of a notification related to a different patient, while 8.3% were followed by opening of a section of the EHR for a different patient and 4.7% had no additional actions for the five minutes tracked. Alerts that recommended cancelling a medication or reducing the dose were more likely (54.9%) to be followed by viewing the patient's EHR or a summary of patient information, compared to alerts recommending test orders (43.4%) and alerts containing medication information alone (28.1%).

During the sequence of views of the patients EHR, 108 (70%) view sequences included at least one of the following four sections that were directly relevant to the alerts: an order section (64%), a medication related section (24%), a laboratory section (25%), and a result section (23%). The total time spent viewing patient-related information differed widely across alert types and across the first actions after alert opening. The mean times ranged from 20.5 seconds to 116.15 seconds.

In multivariate analyses predicting viewing of the patient's electronic information, the only factor that reached statistical significance was the type of alert. The odds ratio for alerts that recommended cancelling or reducing the dose of a medication was 4.0 (95% confidence interval 1.7, 9.7) compared to alerts that simply provided information, and for alerts that recommended ordering a test it was 2.1 (95% CI 1.4, 3.3)

Aim 4. On bivariate and multivariate analyses, there was no significant association between 'timely opening with action' (e.g. PCP opening within 24 hours AND taking action) and likelihood of rehospitalization within 30 days (HR 0.89 [95% CI 0.52-1.53], p=0.68). Similarly, among the subset for whom ADE was assessed, there was no significant association between 'timely opening with action' and likelihood of adverse drug event within 45 days (HR 0.58 [95% CI [0.21-1.57], p=0.28). Sensitivity analyses looking at PCP opening within 48 hours for both of these outcomes also showed nonsignificant associations.

Physician Focus Group

Our focus group included 3 men and 2 women from several primary care specialties (pediatrics, family medicine, internal medicine), each from a different site within the healthcare system.

Themes that emerged in the general discussion about InBasket notifications included receipt of redundant and inactionable information and the need for better prioritization. The categories 'addendum' and 'cc' were cited as containing numerous low priority items; anxiety over associated risks was discussed. Physicians also discussed the high number of notifications and necessity of reviewing notifications after hours including evenings, weekends, and vacations.

Table 1. Patient and Primary Care Provider (PCP) characteristics

Characteristics of Participating Patients	**N (%)**
Age	
65-74 years	224 (31.42)
75-84 years	315 (44.18)
≥85 years	174 (24.40)
Gender	
Female	371 (52.03)
Male	342 (47.97)
Number of Office Visits w/in Prior 12 Months	
≤6 visits	195 (27.35)
>6 and ≤11 visits	201 (28.19)
>11 and ≤18 visits	173 (24.26)
>18 visits	144 (20.20)
Charlson Comorbidity Score	
0	72 (10.10)
1	88 (12.34)
2	106 (14.87)
3+	447 (62.69)
Length of Hospital Stay	
≤ 2 days	324 (45.44)
>2 and ≤4	251 (35.20)
>4 days	138 (19.35)
Characteristics of Participating PCPs	**N (%)**
Age	
<50 years	38 (50.67)
≥50 years	37 (49.33)
Gender	
Female	36 (48.00)
Male	39 (52.00)
Number of clinical encounters over 1-year study period	
>0 and ≤2326	19 (25.33)
>2326 and ≤2783	19 (25.33)
>2783 and ≤3173	19 (25.33)
>3173	18 (24.00)
Specialty	
Family Medicine	16 (21.33)
Internal Medicine	51 (68.00)
Non-MD PCP	6 (8.00)
Sub-Specialty	2 (2.67)

Table 2. Alert opening among PCPs receiving time-sensitive alerts delivered to their EHR InBaskets (Aim 1)

	Total # of EHR InBasket alerts	Total # & (%) of alerts opened by PCP within 24 hours	Crude Odds Ratios (95% CI)*	Adjusted Odds Ratios (95% CI)
	799	**376 (47.06)**		
PCP Characteristics				
Age				
<50 years	296	137 (46.28)	Ref	Ref
≥50 years	503	239 (47.51)	0.73 (0.39-1.37)	0.71(0.33-1.52)
Gender				
Female	264	99 (37.50)	Ref	Ref
Male	535	277 (51.78)	1.46 (0.8-2.66)	1.28(0.59-2.77)
Number of Patient Encounters in Study Year (quartiles)				
>0 and ≤2326	80	25 (31.25)	Ref	Ref
>2326 and ≤2783	163	63 (38.65)	1.03 (0.43-2.45)	1.58(0.52-4.79)
>2783 and ≤3173	247	104 (42.11)	1.33 (0.58-3.06)	1.99(0.76-5.18)
>3173	309	184 (59.55)	1.98 (0.80-4.90)	2.90(0.89-9.42)
Specialty				
Internal medicine	661	317 (47.96)	Ref	Ref
Family medicine	118	54 (45.76)	0.82 (0.41-1.66)	0.57(0.27-1.19)
Non-MD PCP	11	3 (27.27)	0.47 (0.13-1.61)	0.3(0.06-1.49)
Sub-Specialty	9	2 (22.22)	0.47 (0.14-1.58)	0.55(0.19-1.63)
Patient Characteristics				
Age				
65-74 years	255	133 (52.16)	Ref	Ref
75-84 years	349	150 (42.98)	0.76 (0.56-1.04)	0.77(0.55-1.08)
≥85 years	195	93 (47.69)	1.00 (0.70-1.43)	0.96(0.65-1.39)
Gender				
Female	418	182 (43.54)	Ref	Ref
Male	381	194 (50.92)	1.16 (0.86-1.56)	1.19(0.82-1.72)
Number of Office Visits w/in Prior 12 Months				
≤6 visits	205	95 (46.34)	Ref	Ref
>6 and ≤11 visits	219	101 (46.12)	0.92 (0.7-1.22)	0.96(0.7-1.3)
>11 and ≤18 visits	194	94 (48.45)	1.07 (0.8-1.44)	1.26(0.87-1.81)
>18 visits	181	86 (47.51)	0.9 (0.65-1.24)	1.03(0.69-1.54)
Charlson Comorbidity Score				
0	78	31 (39.74)	Ref	Ref
1	92	49 (53.26)	1.55 (0.94-2.54)	**1.79(1.02-3.14)**
2	118	56 (47.46)	1.31 (0.78-2.18)	1.56(0.88-2.76)
3+	511	240 (46.97)	1.14 (0.74-1.74)	1.04(0.62-1.77)

	Total # of EHR InBasket alerts	Total # & (%) of alerts opened by PCP within 24 hours	Crude Odds Ratios (95% CI)*	Adjusted Odds Ratios (95% CI)
Length of Hospital Stay (tertiles)				
≤ 2 days	360	167 (46.39)	Ref	Ref
>2 and ≤4	281	136 (48.40)	1.09 (0.84-1.43)	1.05(0.77-1.44)
>4	158	73 (46.20)	1.19 (0.88-1.59)	**1.48(1.00-2.19)**
Contextual Factors				
Total Number of Notifications (opened + unopened) in InBasket at Time of Alert Delivery				
≤ 42.0	207	128 (61.84)	Ref	Ref
> 42.0 and ≤ 69.0	194	111 (57.22)	0.77 (0.55-1.10)	0.69(0.45-1.06)
> 69.0 and ≤ 157.0	199	81 (40.70)	**0.56 (0.34-0.92)**	0.39(0.21-0.75)
> 157.0	199	56 (28.14)	**0.38 (0.22-0.65)**	0.27(0.14-0.51)
Number of Unopened Notifications in InBasket at Time of Alert Delivery				
≤ 0	251	172 (68.53)	Ref	Ref
> 0 and ≤ 4.0	183	81 (44.26)	**0.57 (0.37-0.87)**	0.75(0.46-1.21)
> 4.0 and ≤ 9.0	185	67 (36.22)	**0.52 (0.31-0.88)**	0.87(0.48-1.58)
> 9.0	180	56 (31.11)	**0.50 (0.31-0.82)**	0.89(0.52-1.53)
Notification Count in 1 Week Prior to Alert Delivery				
≤ 344	200	86 (43.00)	Ref	Ref
> 344 and ≤ 453	201	88 (43.78)	0.96 (0.59-1.56)	0.98(0.59-1.62)
> 453 and ≤ 546	199	107 (53.77)	1.19 (0.81-1.76)	1.11(0.69-1.77)
> 546	199	95 (47.74)	1.07 (0.62-1.85)	1.14(0.61-2.15)
Day of the Week Alert Sent				
All Other Days	633	345 (54.50)	Ref	Ref
Saturday	166	31 (18.67)	**0.2 (0.10-0.41)**	**0.16(0.08-0.33)**

*Crude Odds Ratios account for clustering by PCP, using a GEE model.
†Adjusted Odds Ratios account for clustering by PCP using a GEE model and control for PCP characteristics, patient characteristics and contextual factors

Table 3. Factors associated with primary care provider (PCP) action (same or next day) within the EHR in response to EHR InBasket alerts. (Aim 2)

Multivariate analysis	**General Action** Adjusted Odds Ratios (95% CI)	**Medication-specific Action** Adjusted Odds Ratios (95% CI)	**Laboratory-specific Action** Adjusted Odds Ratios (95% CI)
Alert Types			
Medication Info Only	Ref	Ref	Ref
Medication Recommendation	2.02 (0.85- 4.80)	5.59 (2.42- 12.94)	7.38 (3.64- 14.97)
Recommendation for Orders	1.66 (1.08- 2.54)	1.71 (1.09- 2.68)	2.75 (1.73- 4.38)
Opened by PCP/other staff			
Opened by staff/provider other than PCP	Ref	Ref	Ref
Opened by PCP	1.41 (0.81-2.45)	2.13 (1.35-3.37)	1.65 (0.99-2.73)
Timing of alert opening			
Opened ≤24 hours after delivery	Ref	Ref	Ref
Opened >24 hours and ≤48 hours after delivery	1.22 (0.63- 2.37)	1.15 (0.70- 1.90)	1.12 (0.64- 1.97)
Opened >48 hours after delivery	1.24 (0.71- 2.19)	1.06 (0.63- 1.79)	1.42 (0.83- 2.42)
Provider Characteristics			
Age			
<50 years	Ref	Ref	Ref
≥50 years	0.96 (0.65- 1.42)	0.64 (0.37- 1.11)	0.61 (0.41- 0.91)
Gender			
Female	Ref	Ref	Ref
Male	0.61 (0.37- 1.02)	0.73 (0.41- 1.31)	0.45 (0.31- 0.65)
Number of Patient Encounters in Study Year (quartiles)			
>0 and ≤2326	Ref	Ref	Ref
>2326 and ≤2783	0.64 (0.30- 1.38)	0.52 (0.35- 2.80)	0.95 (0.42- 2.17)
>2783 and ≤3173	1.01 (0.50- 2.07)	1.50 (1.15- 8.01)	1.85 (0.87- 3.96)
>3173	1.52 (0.71- 3.29)	2.49 (1.46- 13.31)	2.71 (1.27- 5.78)
Specialty			
Internal medicine	Ref	Ref	Ref
Family medicine	0.70 (0.41- 1.18)	0.85 (0.40- 1.80)	0.58 (0.38- 0.89)
Non-MD PCP	0.33 (0.09- 1.16)	0.63 (0.21- 1.91)	0.62 (0.27- 1.39)
Sub-Specialty	3.03 (0.96- 9.59)	1.36 (0.35- 5.30)	2.06 (0.71- 6.01)
Patient Characteristics			
Age			
65-74 years	Ref	Ref	Ref
75-84 years	1.06 (0.72- 1.57)	0.75 (0.53- 1.05)	0.93 (0.63- 1.39)
≥85 years	0.87 (0.54- 1.41)	0.95 (0.61- 1.49)	1.00 (0.62- 1.63)

Multivariate analysis **Gender**	**General Action** Adjusted Odds Ratios (95% CI)	**Medication-specific Action** Adjusted Odds Ratios (95% CI)	**Laboratory-specific Action** Adjusted Odds Ratios (95% CI)
Female	Ref	Ref	Ref
Male	0.93 (0.67- 1.29)	1.11 (0.7735- 1.59)	1.28 (0.92- 1.77)
Number of Office Visits w/in Prior 12 Months			
≤6 visits	Ref	Ref	Ref
>6 and ≤11 visits	1.33 (0.87- 2.03)	0.92 (0.53- 1.60)	1.04 (0.63- 1.72)
>11 and ≤18 visits	2.13 (1.27- 3.58)	1.35 (0.81- 2.25)	1.36 (0.63- 1.72)
>18 visits	1.69 (1.05- 2.72)	1.17 (0.64- 2.14)	1.48 (0.89- 2.48)
Charlson Comorbidity Score			
0	Ref	Ref	Ref
1	0.68 (0.33- 1.38)	0.68 (0.28- 1.65)	1.29 (0.53- 3.14)
2	0.87 (0.43- 1.77)	0.72 (0.33- 1.57)	1.57 (0.64- 3.87)
3+	0.76 (0.41- 1.41)	0.64 (0.30- 1.33)	1.30 (0.61- 2.78)
Length of Stay			
≤ 2 days	Ref	Ref	Ref
3 days	1.43 (0.97- 2.13)	1.14 (0.80- 1.61)	1.22 (0.85- 1.74)
≥4 days	1.48 (0.88- 2.49)	1.33 (0.83- 2.12)	1.45 (0.89- 2.36)
Contextual Factors			
Total Number of Messages in InBasket at Time of Alert Delivery			
≤ 42.0	Ref	Ref	Ref
> 42.0 and ≤ 69.0	0.89 (0.54- 1.48)	0.88 (0.51- 1.52)	0.72 (0.45- 1.14)
> 69.0 and ≤ 157.0	0.70 (0.41- 1.20)	1.00 (0.55- 1.81)	1.39 (0.94- 2.05)
> 157.0	0.52 (0.28-0.97)	1.00 (0.73- 2.36)	0.92 (0.58- 1.47)
Number of Unopened Messages in InBasket at Time of Alert Delivery			
≤ 0	Ref	Ref	Ref
> 0 and ≤ 4.0	0.99 (0.66- 1.50)	0.84 (0.53-1.33)	0.90 (0.56- 1.45)
> 4.0 and ≤ 9.0	1.20 (0.73- 1.96)	0.69 (0.46- 1.02)	0.82 (0.48- 1.42)
> 9.0	1.49 (0.90- 2.45)	1.17 (0.78- 1.76)	0.77 (0.49- 1.20)
Message Count in 1 Week Prior to Alert Delivery			
≤ 344	Ref	Ref	Ref
> 344 and ≤ 453	0.66 (0.42- 1.04)	0.90 (0.58- 1.40)	0.64 (0.38- 1.09)
> 453 and ≤ 546	0.74 (0.48- 1.13)	0.61 (0.40- 0.94)	0.44 (0.25- 0.75)
> 546	0.69 (0.42- 1.13)	0.61 (0.36- 1.01)	0.58 (0.35- 0.95)
Day of the Week Alert Sent			
All Other Days	Ref	Ref	Ref
Saturday	1.25 (0.72- 2.17)	1.18 (0.72- 1.92)	0.94 (0.55- 1.61)

*General Action in EHR includes…
Medication-specific action includes medication list viewing and ordering.
Laboratory-specific action includes laboratory viewing and ordering.

Table 4. Sequence of Relevant Actions in the 5 minutes following alert opening by Primary Care Physician (Aim 3)

		First action related to patient in alert N=208 (33.76%)		First action not related to patient in alert N=408 (46.24%)		
	Total	**Opened specific EHR for patient**	**Opened summary info for patient**	**Opened other message**	**Opened EHR for other patient**	**No action in 5 minutes**
	N	**N(%)**	**N(%)**	**N(%)**	**N(%)**	**N(%)**
TOTAL	**616**	**156 (25.32)**	**52 (8.44)**	**328 (53.25)**	**51 (8.12)**	**29 (4.87)**
Alert Type						
Medication info only	445	91 (20.45)	34 (7.64)	257 (57.75)	43 (9.66)	20 (4.49)
Medication recommendation	31	14 (45.16)	3 (9.68)	14 (45.16)	0	0
Recommendation for orders	140	51 (32.69)	15 (10.71)	57 (40.71)	8 (5.71)	9 (6.43)
Time to Alert Opening						
within 1 hour	119	23 (19.33)	9 (7.56)	48 (40.34)	33 (27.73)	6 (5.04)
within 24 hours	252	63 (25.00)	25 (9.92)	136 (53.97)	13 (5.16)	15 (5.95)
>24 hours	245	70 (28.57)	18 (7.35)	144 (58.78)	5 (2.04)	8 (3.27)
Opening within Office Hours Y/N						
No: Opened - other (outside office hours)	312	87 (27.88)	23 (7.37)	180 (57.69)	7 (2.24)	15 (4.81)
Yes: Opened 8 to 5 Mon - Friday	304	69 (22.70)	29 (9.54)	148 (48.68)	44 (14.47)	14 (4.61)
Contextual Factors						
Total Number of Notifications (opened + unopened) in InBasket at Time of Alert Delivery						
≤ 42.0	159	30 (18.87)	12 (7.55)	83 (52.20)	26 (16.35)	8 (5.03)
> 42.0 and ≤ 69.0	152	33 (21.71)	17 (11.18)	78 (51.32)	15 (9.87)	9 (5.92)
> 69.0 and ≤ 157.0	153	50 (32.68)	12 (7.84)	74 (48.37)	8 (5.23)	9 (5.88)
> 157.0	152	43 (28.29)	11 (7.24)	93 (61.18)	2 (1.32)	3 (1.97)
Number of Unopened Notifications in InBasket at Time of Alert Delivery						
≤ 0	189	44 (23.28)	16 (8.47)	76 (40.21)	38 (20.11)	15 (7.94)

> 0 and ≤ 4.0	135	28 (20.74)	15 (11.11)	77 (57.04)	10 (7.41)	5 (3.70)
> 4.0 and ≤ 9.0	145	43 (29.66)	7 (4.83)	91 (62.76)	1 (0.69)	3 (2.07)
> 9.0	147	41 (27.89)	14 (9.52)	84 (57.14)	2 (1.36)	6 (4.08)
Notification Count in 1 Week Prior to Alert Delivery						
≤ 344	146	46 (31.51)	8 (5.48)	72 (49.32)	11 (7.53)	9 (6.16)
> 344 and ≤ 453	159	30 (18.87)	18 (11.32)	101 (63.52)	7 (4.40)	3 (1.89)
> 453 and ≤ 546	157	30 (19.11)	12 (7.64)	86 (54.78)	20 (12.74)	9 (5.73)
> 546	154	50 (32.47)	14 (9.09)	69 (44.81)	13 (8.44)	8 (5.19)
PCP Characteristics						
Sex						
Female	204	58 (28.43)	14 (6.86)	115 (56.37)	14 (6.86)	3 (1.47)
Male	412	98 (23.79)	38 (9.22)	213 (51.70)	37 (8.98)	26 (6.31)
Number of Patient Encounters in Study Year (quartiles)						
>0 and ≤2326	42	18 (42.9)	1 (2.4)	18 (42.9)	2 (4.8)	3 (7.1)
>2326 and ≤2783	115	23 (20.0)	10 (8.7)	76 (66.1)	3 (2.6)	3 (2.6)
>2783 and ≤3173	203	58 (28.6)	12 (5.9)	114 (56.2)	14 (6.9)	5 (2.5)
>3173	256	57 (22.3)	29 (11.3)	120 (46.9)	32 (12.5)	18 (7.0)
Patient Characteristics						
Charlson comorbidity score (0, 1, 2, 3+)						
0	58	13 (22.41)	5 (8.62)	37 (63.79)	2 (3.45)	1 (1.72)
1	67	13 (19.40)	7 (10.45)	37 (55.22)	5 (7.46)	5 (7.46)
2+	491	130 (26.48)	40 (8.15)	254 (51.73)	44 (8.96)	23 (4.68)

Discussion

In this study of time sensitive-alerts sent to PCP EHR InBaskets, more than half of the alerts remained unopened by the PCP at 24 hours and more than one-third were still unopened after 48 hours. In our analyses of all PCPs, patient characteristics were not associated with likelihood of timely alert opening. Alerts triggered by our most complex patients and by our oldest patients were no more likely to experience prompt review than were those for less complex and younger patients. PCP characteristics were not significantly associated with timeliness of alert opening.

Perhaps our most important finding relates to contextual factors. PCPs with more notifications in the InBasket at the time of alert delivery were less likely to complete timely alert opening, even if logged in within 24 hours of alert delivery. This relationship was significant when measuring total InBasket notifications (opened + unopened) both as a continuous and as a categorical variable.

In our study, alerts contained time-sensitive material and were designed by study team members (practicing physicians in the healthcare system) to be delivered to a high priority InBasket folder; however, subject headings (uniformly referencing hospital discharge) may not have been interpreted as urgent by receiving PCPs who (in this medical practice) receive updates on patient discharges through a number of channels.

We found that PCPs receiving alerts on a Saturday had lower likelihoods of timely opening. While this is not surprising, we were concerned to find that it took approximately 3 days for the proportion of Saturday-delivered open alerts to catch up with the proportion of opened alerts delivered on all other days.

Our tracking of physician actions for five minutes after opening a notification that contained an alert found that fewer than half were followed by an immediate view of the relevant patient's information in the EHR. However, for alerts that recommended specific actions such as changes to medication doses, odds of viewing information were significantly greater and after recommendations for ordering monitoring tests the odds were also greater. None of the physician or patient characteristics or contextual variables were significantly related to immediate viewing of patient information. The total viewing times including time on the notification that contained the alert and time spent viewing the relevant patient's EHR ranged widely, but even for alert openings that were followed immediately by opening of a message about a different patient, the median viewing time was 15 seconds and less than a quarter of these spent fewer than 9 seconds on the alert. Seventy percent of the viewing sequences included a directly relevant portion of the patient's EHR with the most common section related to orders.

Alerts recommending specific actions including medication changes/discontinuation and test ordering were significantly more likely to generate responsive actions by the end of the day following alert delivery – this was true for assessment of any EHR-based action within the patient's chart, and also for medication or laboratory-specific action. However, when we looked at the combination of timely opening *with* responsive action, (i.e. those alerts that were opened promptly and were followed by responsive action) we found no significant association with rehospitalization or likelihood of an adverse drug event.

Limitations

This study has several limitations. The extent to which our results are generalizable to other health systems is hard to estimate. However, the research was conducted in a healthcare setting that uses Epic, an EHR in widespread use across the United States. We may not have captured all relevant variables explaining alert opening, which may lead to residual confounding. While our study does describe alert opening, we are unable to determine whether alerts were actually read.

Conclusions

We conclude that the number of total InBasket notifications and weekend delivery may impact opening of time-sensitive EHR alerts. In a high-risk older population, time sensitive alerts were not being opened in a timely manner, possibly because physicians were simply overwhelmed with high numbers of InBasket notifications. Further study is needed to support safe and effective approaches to care team management of InBasket notifications.

Once opened, more than half of alerts recommending *specific* actions (medication changes or test ordering) were directly followed by viewing of patient information. Alerts that were viewed by PCPs appear to have gained viewers' attention for a reasonable amount of time, suggesting that recommendations were likely to have been read and given some consideration. We were unable to show a clear connection between prompt viewing, responsive action within the EHR and clinical outcomes.

Significance

Efforts to promote timely review of urgent notifications must include system-level changes, not just feedback or punitive measures for clinicians. To date no comprehensive guidelines exist for commercial EHRs. Particularly in the VHA, where some filters and management tools are available, larger total numbers of InBasket notifications (in comparison to peers with similar panels) could indicate less effective use of available management functions. Targets for improvement relevant both for VHA and nonVHA settings include physician and staff training to improve familiarity with any available EHR InBasket management tools or strategies. Systems could also be developed that highlight or escalate unopened alerts after a designated period, transforming them to an interruptive mode or escalating to supervisors.

Implications

InBasket management is a complex task for PCPs, and alerts delivered asynchronously to secure EHR InBaskets compete for attention with numerous other notifications. Studies seeking to use this form of communication must understand its limitations. Future studies are needed to explore ways to improve asynchronous communication with PCPs. Use of audit and access logs for such research merits further investigation, as this is an underused opportunity to learn from data generated as a byproduct of routine care.

List of Publications & Products

Presentations

1. Tracking Healthcare Team Response to EHR Asynchronous Alerts: Role of InBasket Message Burden. Poster presentation. Health Care Services Research Network (HCSRN) (Formerly HMO Research Network) 22nd Annual Conference (April 2016), Atlanta GA.
2. The Electronic Health Record: A Platform For Communication. Invited presentation and teleconference. Center for Healthcare Organization and Implementation Research (CHOIR), U.S. Department of Veteran's Affairs (April 2016), Bedford MA.
3. The Electronic Health Record: A Platform For Communication. Invited presentation. University of North Carolina School of Medicine, Program on Clinical Informatics (February 2016), Chapel Hill NC.

4. The Electronic Health Record: A Platform For Communication. Invited presentation. Duke University Division of General Internal Medicine and Health Services Research Group (February 2016), Durham NC.
5. "It takes your whole life over" – PCP Perspectives on Electronic InBasket Notifications. Oral presentation at Society for General Internal Medicine Annual National Meeting (April 2017), Washington, DC.
6. Tracking Physician Activities in the EHR. Guest Presentation. Health Care Services Research Network (HCSRN) 2017 Fall Virtual Data Warehouse Implementation Group Meeting, Harvard Pilgrim Health Care Institute (September 2017), Boston MA.

Publications

1. Cutrona SL, Fouayzi H, Burns L, et al. Primary Care Providers' Opening of Time-Sensitive Alerts Sent to Commercial Electronic Health Record InBaskets. Journal of general internal medicine 2017 Nov;32(11):1210-1219. Epub 2017 Aug 14.

Manuscripts in preparation

1. Field TS, Fouayzi H, Sundaresan D, et al. Physician responses to automated non-interruptive alerts: actions immediately following alert opening.
2. Amroze, A, et al. EHR InBasket Alerts: Using Access and Audit Logs to identify physician actions following alert opening.