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Nurses' Behaviors and Visual Scanning Patterns May Reduce Patient Identification Errors

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Patient identification (ID) errors occurring during the medication administration process can be fatal. The aim of this study is to determine whether differences in nurses' behaviors and visual scanning patterns during the medication administration process influence their capacities to identify patient ID errors. Nurse participants ($n = 20$) administered medications to 3 patients in a simulated clinical setting, with 1 patient having an embedded ID error. Error-identifying nurses tended to complete more process steps in a similar amount of time than non-error-identifying nurses and tended to scan information across artifacts (e.g., ID band, patient chart, medication label) rather than fixating on several pieces of information on a single artifact before fixating on another artifact. Non-error-indentifying nurses tended to increase their durations of off-topic conversations—a type of process interruption—over the course of the trials; the difference between groups was significant in the trial with the embedded ID error. Error-identifying nurses tended to have their most fixations in a row on the patient's chart, whereas non-error-identifying nurses did not tend to have a single artifact on which they consistently fixated. Finally, error-identifying nurses tended to have predictable eye fixation sequences across artifacts, whereas non-error-identifying nurses tended to have seemingly random eye fixation sequences. This finding has implications for nurse training and the design of tools and technologies that support nurses as they complete the medication administration process.

Keywords: medication administration, medication error, patient identification, eye tracking, nursing

The purpose of this study is to test empirically whether nurses who identify patient identification (ID) errors exhibit different behaviors and visual scanning patterns during the medication administration process than those of nurses who do not identify patient ID errors. By the patient ID process, we mean the series of steps that nurses conduct to ensure that a medication is given to the patient for whom it is intended.

The Institute of Medicine (IOM; 1991) defines health care quality as "the degree to which health services for individuals and populations *increase the likelihood of desired health outcomes* and are consistent with current professional knowledge" (italics added; p. 232). Medical errors are therefore one of the major threats to health care quality because they decrease the likelihood of desired health outcomes. Unfortunately, medical errors are relatively common, with the IOM (1999) suggesting that medical errors cause 44,000–98,000 deaths each year. The IOM (2007) also reports that medication errors are one of the most significant types of medical errors, with hospitalized patients experiencing approximately one medication error per day of their stay.

During the medication administration process, nurses serve as the last shield to prevent patients from the risk of medication errors, with one study reporting that nurses intercept the majority (85%) of potential medication errors (Leape et al., 1995). However, nurses are not always ready to identify potential medication errors. In a recent experimental study, 39% of the study nurses who administered a medication misidentified the patient and administered the medication to the wrong patient (Henneman et al., 2009).

Lane, Stanton, and Harrison (2006) have provided a detailed hierarchical protocol outlining the ideal medication administration process. In their protocol, regardless of the type of medications that nurses administer, they must "check patient ID wristband" and "check [patient] chart" before giving medications to patients, thus fixating their eyes on these two artifacts (p. 674). Visual scanning patterns are also a key component of how nurses identify patient ID errors—to ensure that the right medication is administered to the right patient. According to Henneman et al. (2009), most steps in the patient ID protocol involve nurses visually scanning patient identity information (e.g., name, date of birth [DOB], medical

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record number [MRN]) across various artifacts (e.g., patient ID band, medication label).

There are a significant number of studies acknowledging the importance of the relationship between care providers' cognitive processes (e.g., visual scanning patterns) and medical errors. Zhang, Patel, Johnson, and Shortliffe (2004) have provided a comprehensive cognitive taxonomy of medical errors. Their taxonomy covers cognitive error types related to individuals' goals, intentions, action specifications, action executions, perceptions, interpretations, and evaluations. These cognitive errors are often affected by factors external to the individual, including interruptions and distractions, unfriendly human–technology interfaces, inadequate staffing, and ineffective health care provider communication (Alper et al., 2006; Alper et al., 2008; Carayon et al., 2007; Koppel, Wetterneck, Telles, & Karsh, 2008; Patterson, Rogers, Chapman, & Render, 2006).

More recently, Grundgeiger and Sanderson (2009) systematically reviewed research examining the nature of the relationship between one external factor, interruptions, and medical errors. They noted that much of the research in this area is descriptive, and they suggested that future research use cognitive theories as a basis for empirical research and that researchers study situations leading to both positive (nonerroneous) and negative (erroneous) outcomes (Grundgeiger & Sanderson, 2009). Using an eye tracking device in a simulated clinical setting, Grundgeiger, Sanderson, Venkatesh, and MacDougall (2010) used two cognitive theories—memory for goals and prospective memory theories—to study empirically how long it takes nurses to resume clinical tasks after being interrupted. This work is important in that it is one of the few studies explicitly linking internal cognitive processes with an external factor (i.e., interruptions).

Eye tracking devices, such as that used by Grundgeiger et al. (2010) are typically used to record visual scanning data, which can provide insights into the visual, cognitive, and attention aspects of human performance. A comprehensive review of methods to analyze visual scanning data is in Jacob and Karn (2003). Throughout these studies, researchers have developed common definitions for visual scanning behaviors. Broadly, an eye *fixation* occurs when the eye-in-head position is stable and focused on a specific reference point for at least 100–200 ms. A *saccade* is the rapid shift of the eye from one point of fixation to another, typically lasting less than 50 ms.

Two studies analyzing individuals' visual attention to specific information in an environment are presented in Fitts, Jones, and Milton's (1950) pioneering work addressing the design of an aircraft instrument panel and in Goldberg and Kotval's (1999) work addressing the design of a computer interface. Fitts et al. (1950) analyzed pilots' frequencies of eye fixations on each aircraft instrument, pilots' lengths of fixations on each instrument, and pilots' patterns of eye movements between instruments. Goldberg and Kotval (1999) used a fixation:saccade ratio to capture individuals' time spent processing (fixations) information within computer interface components to the time spent searching (saccades) for the components. Higher ratios indicated that individuals tended to do more information processing than searching for information when using the interface components.

Another two studies demonstrate the use of eye fixation data to differentiate between groups of individuals. In one experiment, novice and experienced drivers drove along three types of roads (rural, suburban and dual-carriageway) in a simulated setting (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003; Underwood, Phelps, Wright, Van Loon, & Galpin, 2005). Researchers then analyzed the drivers' eye fixation data to identify differences in the drivers' scanpaths (i.e., sequences of fixations) throughout the drive that could be associated with skill acquisition and that could indicate sensitivity to road type. Ratwani, McCurry, and Trafton (2008) used eye fixation data to predict the probability of a participant making what they termed a *postcompletion error* (e.g., forgetting to remove your ATM card) during a computer-based task in which participants had to order two different types of sea vessels. Given the participant's total number of eye fixations and whether the participant fixated on a specific area of the interface during the process, Ratwani et al. (2008) could predict with 98% accuracy whether the participant would make a postcompletion error (i.e., confirming the order). Their goal was to generate a system that would monitor users' eye fixations and alert users who had a 75% or greater chance of committing the error.

In our study, we extend the use of eye tracking technology and existing visual scanning measures to analyze differences in nurses' visual scanning patterns based on whether the nurses identified a patient ID error. As in other studies, we used predefined areas of interest in the visual field relevant to the medication administration process, specifically the ID band, patient chart, and medication label.

In our study, we used Fitts et al.'s (1950) measures to capture which artifacts nurses fixate on most frequently while administering medications, which artifacts the nurses fixate on longest while administering medications, and whether nurses fixate on artifacts in a specific order during the medication administration process. We used Goldberg and Kotval's (1999) measure to capture whether nurses have different patterns of processing and searching for information across artifacts during the medication administration process. We also use similar comparative approaches to those used by Underwood et al. (2003, 2005) and Ratwani et al. (2008) to test empirically whether nurses who identify patient ID errors exhibit different visual scanning patterns during the medication administration process than nurses who do not identify patient ID errors. With this knowledge, we may be able to revise current training guidelines for nursing students and design simulated training experiences to better prepare them for real clinic settings.

Several studies have shown that attention-based training programs can successfully change individuals' attention patterns. Transportation researchers, for instance, have shown that attention-based training can increase older and younger drivers' probabilities of looking for roadway hazards (Fisher, Pollatsek, & Pradhan, 2006; Pollatsek, Narayanaan, Pradhan, & Fisher, 2006; Pradhan, Pollatsek, Knodler, & Fisher, 2009; Romoser & Fisher, 2009). Pollatsek et al. (2006) and Pradhan et al. (2006) showed that attention-based training can be effective even when hazards are different than those addressed in the training and that the effects of the attention-based training persist over time. Similarly, Hubert-Wallander, Green, and Bavelier (2010) and Anderson and Bavelier (2011) have shown that video games can be an effective mechanism for training attention patterns.

If we understand nurses' behaviors and visual scanning patterns, we may also be able to anticipate how nurses will adapt to and use new technologies as they complete the medication administration process. For instance, a recent text edited by Roda (2011), titled *Human Attention in Digital Environments*, explicitly addresses the importance of accounting for attention in technology design and how technology can be used to support human attention.

Study Approach

In the study presented in this article, we specifically address two hypotheses. Hypothesis 1 (H1) is that nurses who identify patient ID errors will be more efficient in the process by which they administer medications. This hypothesis is motivated by the findings from existing analyses, showing that medication errors increase with factors such as interruptions (Grundgeiger & Sanderson, 2009; Grundgeiger et al., 2010). We used three analysis methods to test this hypothesis. The first method measures overall process efficiency, the second method focuses on interruptions that may affect process efficiency, and the third method focuses on the efficiency of the nurses' eye fixations:

1. Nurses who identify a patient ID error may take fewer seconds to complete each step of the medication administration process than nurses who do not identify the patient ID error because they are more focused on the task at hand.

2. Nurses who identify the patient ID error may engage less in a specific type of interruption—off-topic discussions with patients—than nurses who do not identify the patient identification error. Other studies have found face-to-face interactions to be a common type of work interruption (Alvarez & Coiera, 2005; Coiera, Jayasuriya, Hardy, Bannan, & Thorpe, 2002; Coiera & Tombs, 1998; Spencer, Coiera, & Logan, 2004) and that most work interruptions occur during direct patient care (Hedberg & Larsson, 2004). This type of interruption may affect nurses' overall efficiency as measured in the first method.

3. Nurses who identify the patient ID error may transition their eye fixations across artifacts more frequently than nurses who do not identify the patient ID error. If a nurse transitions his or her eye fixations between artifacts more frequently, he or she may be lessening his or her working memory burden by immediately comparing a specific patient identifier (i.e., name, DOB, MRN) across the three artifacts on which patients' ID information is located (i.e., ID band, patient chart, medication label), rather than fixating on all identifier information on a particular artifact before transitioning to the next artifact. Eye fixations are one key component of the patient ID process and so may affect nurses' overall efficiency as measured in the first method.

Hypothesis 2 (H2) is that nurses who identify patient ID errors will have more consistent eye fixation patterns than nurses who do not identify patient ID errors. This hypothesis is motivated by the presumption that nurses may be following Lane et al.'s (2006) medication administration and/or Henneman et al.'s (2009) patient ID protocols more closely. We used two analysis methods to test this hypothesis. The methods complement one another, as the first method measures consistency in fixation locations, whereas the second method measures consistency in fixation transitions across artifacts:

1. Nurses who identify the patient ID error may primarily fixate on the same artifact across the three trials, demonstrating consistency in how they value information on each artifact. If a nurse fixates on an artifact for a large number of steps, his or her transition ratio will decrease, meaning fixation lengths indirectly affect eye fixation efficiency. This measure, however, identifies the specific artifacts on which the nurses fixate.

2. Nurses who identify the patient ID error may have predictable (as opposed to random) visual scanning patterns, with the scanning patterns including all artifacts (i.e., ID band, patient chart, medication label). Whereas the third method measures the efficiency of eye fixations across artifacts, this method measures transitions of eye fixations across artifacts.

Method

Participants

We conducted the experiment at a 600-bed, urban, Level-1 trauma, pediatric, and tertiary referral center in Western Massachusetts with an annual emergency department (ED) census >100,000. During the experiment, we observed ED nurses (n = 28) as they completed the medication administration process in a simulated patient care setting while wearing an eye tracking device. Henneman et al. (2009) provided an overview of the study.

Participants volunteered to participate in the study during one of their day or evening shifts. We told participants that the purpose of the study was to evaluate how expert nurses use visual cues to perform common, patient care processes. Study participants did not know that we were studying the patient ID process and medication errors. The hospital's institutional review board approved the study, and all participants read and signed an informed consent form, having any questions answered by a study researcher. We asked the participants to not discuss the study with any colleagues while we conducted the study.

Participants wore an eye tracking device during the study. The ASL Mobile Eye (Applied Science Laboratories, Bedford, MA) is a tetherless eye tracking device that can be worn by participants who must move freely through a study environment. The eye tracking device weighs 76 g, includes a scene camera, optics, and reflecting mirror all mounted on safety glasses. To calibrate the eye tacking device for each participant, we had the participants look at 12 specific reference points in their field of view, with marks of their fixations adjusted to correspond to the reference points. Once calibrated, the Mobile Eye software program overlays crosshairs on a video showing the exact locations in a scene where the individual is gazing throughout the scenario.

Procedure

Each participant administered a medication to the same three researchers acting as patients. We asked each participant to perform the process the same way he or she does every day in the ED except for giving an actual medication. A researcher led the participant to the simulated patient rooms and gave the participant a list of patients in each of the rooms. For each of

the 3 patients, the researcher gave the participant a clipboard with an order sheet and a documentation page (i.e., patient chart), and an intravenous medication bag. The patient chart and medication bag were labeled with a patient's name, DOB, and MRN. The medication label was also labeled with the medication name and dose, as shown in Figure 1.

We labeled all materials with patient-specific information in exactly the same way. We designed the labels to look realistic yet allow for the eye tracking device to differentiate the specific ID information that the participant was viewing; and we placed the patient's name, DOB, and MRN on different vertical and/or horizontal axes on the labels.

Each patient, including the patient with the ID error, would state his or her correct name and DOB if asked. The patient's stated name and DOB matched the name and DOB on the ID band the patient was wearing. However, the DOB and MRN on the ID band were both different from the DOB and MRN on the medication label, so the participant could identify a DOB error and/or MRN error. A summary of this approach is described in Marquard et al. (2009).

Two research team members independently reviewed all eye tracking videos, using standardized steps names to code the steps that each participant took to complete the medication administration process. The reviewers developed a standard coding policy and focused on the participants' verbal steps (e.g., ask name, ask DOB, and ask allergies), action steps (e.g., give medication), and visual steps (e.g., look at name, DOB, MRN, and age on the ID band, medication label, and patient chart). Their kappa score for the agreement between the two independent team members reviewing the eye tracking data regarding which patient identifiers the participant looked at during the trials was 0.77. Three researchers resolved disagreements between the two initial coders. The research team members determined that a participant looked at a specific patient identifier if the crosshairs on the video were within a 1-cm^2 box that covered the patient identifier information for 120 ms on the calibrated video. A shortened sample process execution with only visual steps is shown in Figure 2.

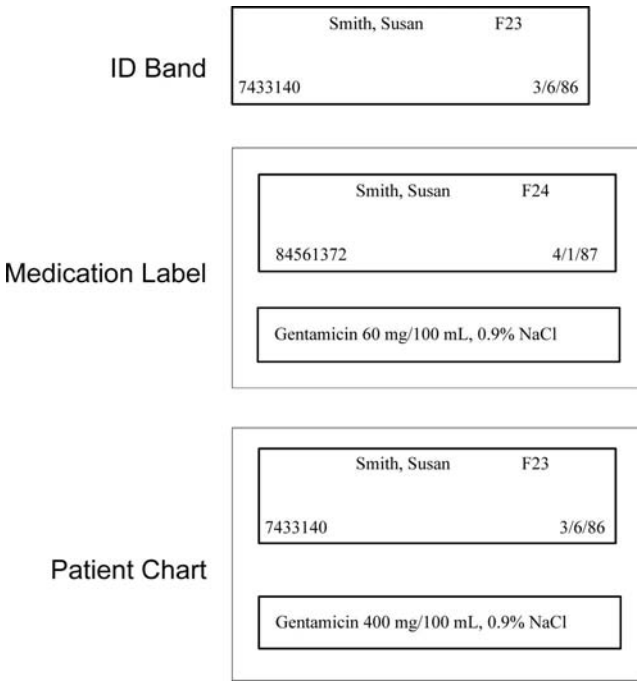

Figure 1. Example of experiment artifacts.

For Trial 3 with the ID error, we separated the process steps for each participant into two time frames: steps completed before the participant identified the error and steps completed after the participant identified the error. For this analysis, we disregarded the steps after the participant was confident that he or she identified the error, as (for the trial with the patient ID error) these steps were only present for the subgroup that identified the error.

We also assessed whether participants were consistent across the three trials to ascertain whether their behaviors and visual scanning patterns in Trial 3 were anomalous. If the behaviors and visual scanning patterns were consistent across trials, it may be that some participants exhibited systematically different behaviors and visual scanning patterns from other participants. If the behaviors and visual scanning patterns in Trial 3 are anomalous, it may be that identifying the patient ID error resulted somewhat from happenstance.

We used the following data to analyze H1—that nurses who identify patient ID errors will be more efficient in the process by which they administer medications.

1. We measured the average number of seconds it took participants to complete one process step, on the basis of their total number of process steps divided by their total process duration. We included visual, verbal, and action steps in this analysis.

2. We measured participants' engagement in off-topic discussions as the total duration of their off-topic discussions over the duration of the trial. We reasoned that discussions between the patient and the participant placed a higher cognitive load on the participants than statements made by only one individual, so single statements were not included in the analysis. For example, statements such as, "I am going to hang the medication on you," and "Hello, I am [Jane], one of the nurses here" were not included in the analysis. A typical example of an off-topic discussion was as follows:

Patient: "How long is the hospital open?"

Nurse: "24 hours a day."

Discussion durations were recorded as the time from the start of the first question or statement to the end of the final response.

3. We measured participants' eye fixation transitions across artifacts by means of a transition ratio, the average number of identifiers on an artifact that participants fixated on before transitioning their eye fixations to another artifact, to understand how frequently the participants shifted their fixations between the three different artifacts important in the medication administration process (i.e., ID band, patient chart, medication label). We then calculated a transition ratio between artifacts (Q) for each participant, where

$$Q = \textit{Transitions}/\textit{Steps}.$$

Only visual steps were included in this analysis. A visual step occurred when an individual fixated on a specific artifact (e.g., looked at ID band), and a transition occurred when an individual's eye fixation changed from one artifact to another (e.g., looked at ID band then looked at patient chart). Figure 3 shows

Nurse ID	Nurse 1
	Looked at DOB on Patient Chart
	Looked at DOB on ID Band
	Looked at Name on ID Band
	Looked at Name on Patient Chart
Event	Looked at Name on ID Band
Sequence	Looked at Name on Patient Chart
	Looked at MRN on Patient Chart
	Looked at MRN on ID Band
	Looked at Name on Medication
	Gave Medication to Patient

Figure 2. Example of shortened process execution. DOB = date of birth; MRN = medical record number.

participants' eye fixation patterns and transition ratio calculations for two sample trials; the top trial is for a participant who identified the error, and the bottom trial is for a participant who did not identify the error. The transition ratio, Q, represents how frequently a participant switched his or her eye fixations from one artifact to another, with higher numbers signifying more transitions.

We used the following data to analyze our second hypothesis—that nurses who identify patient ID errors will have more consistent eye fixation patterns than nurses who do not identify patient ID errors.

4. We measured participants' largest number of consecutive eye fixations on each artifact on the basis of the largest number of identifiers on an artifact that participants fixated on before transitioning their fixation to another artifact. In the sample of participants' eye fixation patterns in Figure 3, the top participant's largest number of consecutive fixations was three (on the patient chart), and the second participant's largest number of consecutive fixations was four (on the medication label).

5. We measured participants' two-fixation scanpaths (e.g., ID band → medication label) as the probability of transitioning their eye fixations from one artifact to another, as compared with random transitions. We generated transition frequency matrices reflecting the possible two-fixation transitions between the three artifact types for those participants who identified the error and for those who did not. We evaluated the transition frequency matrices using a binomial test, which assumes the two possible transit states have an equal probability of occurring, meaning the participant fixated on the artifacts in a seemingly random order. If a nurse visually scans across artifacts randomly, the transition probability from one artifact to each of the other two should each be 0.5. This procedure identifies which two-fixation scanpaths that occur more frequently than would be expected by chance.

Results

Of the 28 participants, 7 did not have eye tracking data of sufficient quality to judge what artifacts the participant was looking at. The reasons for the eye tracking failures included the following: no crosshairs on the video image, glare or poor focus obscuring the ID information, and an inability to wear the eye tracking device over participants' glasses. For the purpose of this study, we only included those participants with sufficient eye tracking data in the analysis. One other participant interacted with a patient whose ID band fell on the ground. This event may have influenced the participant's attention to the ID band, so we also excluded this participant's data (final $n = 20$). We believe that excluding these data is unlikely to influence our findings as a similar percentage of the excluded participants identified the error, as did the participants included in the analysis (62.5% of excluded participants identified the error vs. 62% of included participants). In some cases, it was not possible to determine with absolute certainty what identifiers each individ-

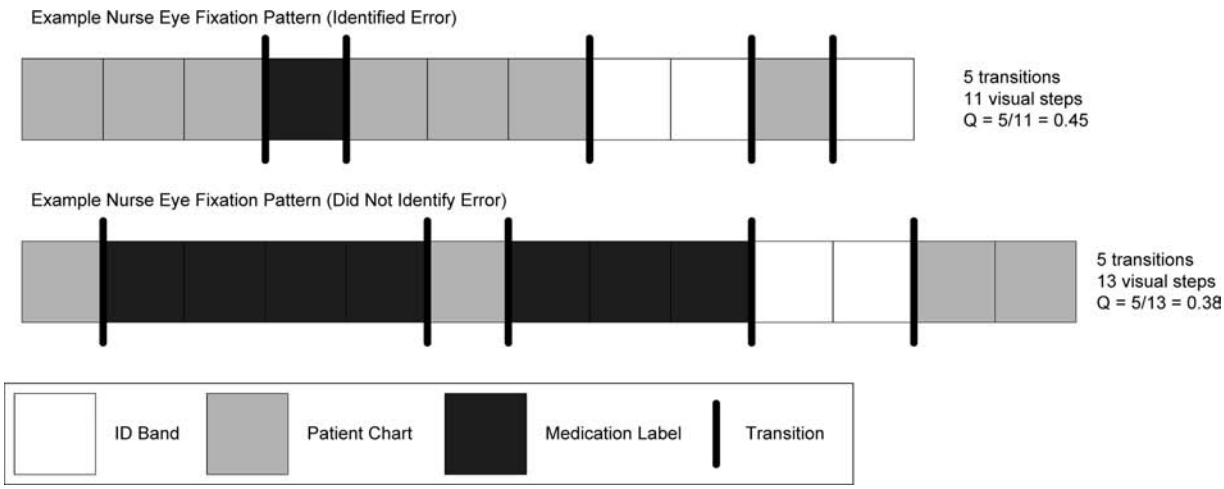

Figure 3. Example of eye fixation patterns. Q = transition ratio between artifacts.

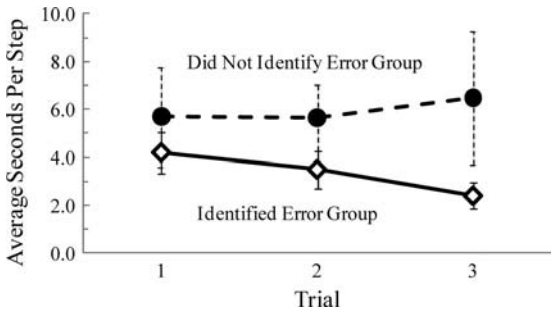

Figure 4. Average number of seconds to complete one process step, by trial.

ual looked at on the artifacts. Thus, we analyzed participants' visual steps at the artifact level. On the basis of participants' verbal statements at the end of the trials, 5 participants identified the DOB error, 6 identified the MRN error, and 1 identified both errors.

For each of the five measures, we analyzed the data in two ways. First, the consistency of the measure values across trials provided evidence as to whether participants were consistent in their behaviors and visual scanning patterns across trials or whether their behaviors and visual scanning patterns in Trial 3 were an anomaly. Second, the difference in measure values between the groups provided evidence as to whether the groups of participants exhibited different behaviors and visual scanning patterns. Together, these two analyses would suggest strategies that were important for identifying the patient ID error in Trial 3.

Figure 4 displays the average numbers of seconds the participants spent per process step. The error bars represent the 95% confidence intervals for the values. Table 1 shows the results of the two-factor analysis of variance (ANOVA), with repeated measures on one factor (trial). We observed a significant difference in this measure between the participants who identified the error and those who did not ($p = .006$). With individual t tests, the difference between groups was significant in Trial 2 ($p = .012$) and Trial 3 ($p = .012$). Although participants who identified the error did not tend to take less time to complete the process, they tended to complete more steps in the same amount of time. There was no significant difference across trials ($p = .293$), but there was a significant Group × Trial interaction effect ($p = .032$). For all trials, participants who did not identify the error tended to take longer to complete each process step than participants who identified the error, and this difference grew across trials. This interaction effect suggests that the difference between groups may have been increasing over the course of the trials.

Figure 5 shows the average duration of off-topic discussions for each trial. The error bars represent the 95% confidence intervals for the values. Table 2 shows the results of the two-factor ANOVA for this measure. We observed no significant difference in this measure between the participants who identified the error and those who did not ($p = .225$). Additionally, there was no Group × Trial interaction effect ($p = .076$). Although the interaction was not significant, we conducted a group comparison for Trial 3 because this was the critical error ID trial. With an individual t test, the difference was significant in Trial 3 ($p = .032$), meaning that those participants who identified the error tended to engage in fewer off-topic discussions during Trial 3 than did those participants who did not identify the error. There was a significant difference in participants' durations of off-topic discussions across trials ($p = .000$), suggesting that participants' durations of off-topic discussion may have increased significantly across the trials.

Figure 6 shows the average transition ratios for each trial. The error bars represent the 95% confidence intervals for the values. Table 3 shows the results of the two-factor ANOVA for this measure. We observed a significant difference in this measure between the participants who identified the error and those who did not ($p = .013$). On the basis of this analysis, the participants who identified the error tended to consistently transition their eye fixations between different artifacts more frequently than the participants who did not identify the error. There was no significant difference in participants' transition ratios across trials ($p = 1.0$) and no significant Group × Trial interaction effect ($p = .780$). Although those who identified the error tended to have slightly higher transition ratios for all three trials, the transition ratios for both groups tended to be consistent across the trials.

The largest number of consecutive fixations across all trials ranged from 1 (no consecutive fixations on the same artifact) to 10 consecutive fixations. Figure 7 shows the percentage of participants who used each artifact as their primary reference artifact in each trial, meaning that their largest number of fixations in a row was on that artifact. Given that some participants had more than one artifact on which they fixated the longest, the percentages in Figure 7 may not sum to one. In our study, the groups did not significantly differ in the artifacts on which they fixated the longest: For Trial 1, $\chi^2(2) = 0.536$, $p =$

Table 1
Analysis of Variance for Average Number of Seconds to Complete One Process Step

Source	SS	*df*	MS	*F*	*p*	η^2
Between participants	275.720	19				
Participants who did vs. those who did not identify error (A)	95.120	1	95.120	9.480	.006	0.251
Participants within A	180.600	18	10.030			
Within participants	103.810	40				
Trials 1, 2, and 3 (B)	5.710	2	2.860	1.270	.293	0.015
A × B	17.000	2	8.500	3.780	.032	0.045
B × Participants Within A	81.100	36	2.250			
Total	379.530	59				

Note. SS = sum of squares; MS = mean squares.

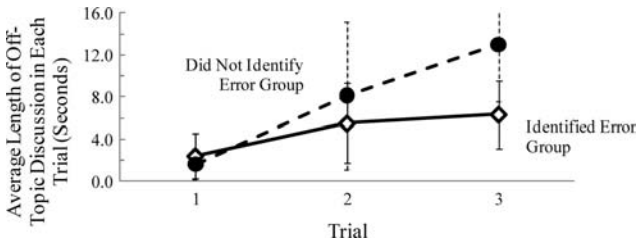

Figure 5. Average total duration of off-topic discussions, by trial.

.765; for Trial 2, $\chi^2(2) = 2.458$, $p = .293$; for Trial 3, $\chi^2(2) = 1.111$, $p = .574$.

Only those participants who identified the error tended to have more frequent than random scanpaths, and all nonrandom scanpaths included the patient chart. For the participants who identified the error, the transitions of ID band → patient chart ($p = .000$), patient chart → ID band ($p = .002$), and medication label → patient chart ($p = .033$) were all statistically overrepresented in the trials.

Discussion

Our analyses revealed several important findings about how nurses' behaviors and visual scanning patterns may affect their abilities to identify patient ID errors.

With regard to H1, it appears that nurses who identify patient ID errors may be more efficient in the process by which they administer medications. Participants who identified the error tended to complete more steps in a given time period (see Figure 4 and Table 1). By completing more steps in a given time period, participants may have been able to collect more information about the patient during the trial, potentially helping them identify the error. There was no significant difference across trials, meaning that this difference between groups may be consistent.

Participants who identified the error tended to engage in fewer off-topic discussions with the patient only in Trial 3, and—although not significant—there was a numeric difference in the same direction for Trial 2 (see Figure 5 and Table 2). Although neither group of participants tended to have consistent behaviors and visual scanning patterns across trials with regard to the total duration of off-topic discussions (see Figure 5 and Table 2), the Group × Trial interaction was significant, so it may be that participants who identified the error and participants who did not identify the error have different patterns in their engagement in off-topic discussions over the course of the trials; nurses who did not identify the error may have increased their amount of off-topic conversation more substantially with each trial. We expect this type of discussion to serve as a process interruption, affecting nurses' abilities to hold patient information in their working memory and increasing the chances that they miss the ID error. A larger sample size might produce stronger evidence that managing off-topic conversations is a factor associated with error ID.

Participants who identified the error tended to look at fewer items on one artifact before shifting their fixations to another artifact (see Figure 6 and Table 3). For instance, the participant may have only looked at the patient's name on the ID band and then the patient's name on the medication label, instead of looking at the patient's name, DOB, and MRN on the ID band before shifting his or her fixation to the medication label. We posit that immediately comparing a patient's information across different artifacts requires a nurse to store less information in his or her working memory, making it easier to notice the ID error. There was no significant difference across trials, meaning that this difference between groups may be consistent.

With regard to H2, it also appears that nurses who identified patient ID errors may have more consistent eye fixation patterns than nurses who did not identify patient ID errors. Although not significant, the participants who identified the error may consistently fixate longest on the patient chart to validate patients' data, a key component of Lane et al.'s (2006) standard medication administration protocol (see Figure 7). A larger number of participants could confirm or refute this finding. If true, one implication of this finding may be that training-specific visual scanning strategies may provide an effective way to implement these recommended procedures. Although not significant, neither group of participants appeared to fixate the longest on the medication label, which is interesting as this was the artifact that—if given to the wrong patient—would cause a medication error. These findings were not significant; however, they may be an important area for further study.

Additionally, only participants who identified the error tended to have nonrandom scanning patterns across the artifacts. The participants who identified the error more frequently than randomly tended to scan in the order of ID band → patient chart, patient chart → ID band, and medication label → patient chart, whereas the participants who did not identify the error

Table 2
Analysis of Variance for Average Total Length of Off-Topic Discussions

Source	SS	*df*	MS	*F*	*p*	η^2
Between participants	1,432.180	19				
Participants who did vs. those who did not identify error (A)	115.600	1	115.600	1.580	.225	0.040
Participants within A	1,316.580	18	73.140			
Within participants	1,494.000	40				
Trials 1, 2, and 3 (B)	489.430	2	244.720	10.120	.000	0.167
A × B	133.820	2	66.910	2.770	.076	0.046
B × Participants Within A	870.750	36	24.190			
Total	2,926.180	59				

Note. SS = sum of squares; MS = mean squares.

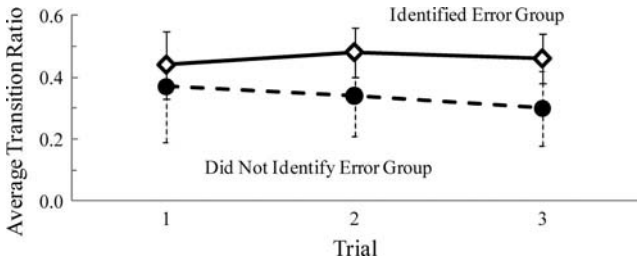

Figure 6. Average transition ratio, by trial.

tended to scan artifacts in a seemingly random order. This difference suggests that participants who identified the error may have more predictable (nonrandom) scanpaths, which nurses could potentially learn through recommended visual scanning protocols.

Limitations

There are several aspects of this study that limit our findings. Perhaps our most significant limitation results from the fact that this was a nonexperimental study in which we identified our groups of interest (i.e., those participants who identified the error and those who did not) post hoc. We consequently cannot state conclusively which factors led to participants identifying patient ID errors. The value of this study is therefore in determining possible visual scanning processes that may underlie nurses' abilities to identify patient ID errors, so that we can thoughtfully inform the design of future experimental studies.

Our sample size was fairly small ($n = 28$) and smaller once we excluded participants with insufficient eye tracker data and the participant who interacted with the patient whose ID band fell off ($n = 20$). We also conducted three scenarios per participant; a larger number of scenarios would result in more generalizable findings. Additionally, this study was conducted at a single hospital, whereas participants at other institutions may exhibit different behaviors or visual scanning patterns. We also did not control for other measures of participants' individual differences (e.g., gender, age, years of clinical experience) or the ordering of the three trials. Therefore, we do not know whether these differences in participants' visual scanning patterns are due to one of these underlying factors. Instead, we analyzed the data from all three trials to determine whether the participants' eye fixation patterns and behaviors were consistent across the three trials or whether the Trial 3 data with the ID error was an anomaly.

There are several limitations regarding the specific inferences we can draw from our analyses. With regard to our finding regarding the average seconds taken by participants for each process step, we did not analyze how this rate changed over time. For instance, those participants who identified the error might complete a number of rapid steps after they suspect an error, which would drive their ratio down. Similarly, we do not know where in the process participants engaged in off-topic discussions. It may be that some participants engaged in these discussions only at the beginning or end of the trial, whereas others engaged in discussions midway through the trial.

An additional limitation of our study is the potential effect of the simulated clinical setting on the participants' behaviors. However, we expect that nurses would be more careful when being watched, so we can posit that nurses may be even less likely to identify a patient ID error in a real clinical setting, as opposed to the 61% who identified the error in this study.

This study is one of the first to use an eye tracking device in a free-moving, simulated health care environment. Therefore, this approach has limitations that can inform the execution of future studies. The eye tracking device was calibrated at the beginning of the participant's task but occasionally may have shifted on the participant's head from its original position during the scenario. Although the participants were instructed to move their head position when looking at artifacts, at times the participants would look at an artifact in their peripheral vision. Additionally, there were aspects of the environment, such as the lighting, that were difficult to control; the lighting occasionally caused the artifact to become white. For these reasons, we were unable to consistently determine which identifiers on an artifact the participants were viewing. We therefore kept our analysis at the artifact level. In future studies, we will be able to glean much more discrete information about the process if we can be certain which identifiers the participants looked at throughout the process.

Finally, the analysis of the eye tracking videos is subjective. To address this limitation, we had two independent evaluators review the videos, with three evaluators reconciling discrepancies between the initial evaluators' coding of the process steps.

Table 3
Analysis of Variance for Average Transition Ratio

Source	SS	*df*	MS	*F*	*p*	η^2
Between participants	0.740	19				
Participants who did vs. those who did not identify error (A)	0.230	1	0.230	7.670	.013	0.110
Participants within A	0.510	18	0.030			
Within participants	1.350	40				
Trial 1, 2, and 3 (B)	0.010	2	0.000	0.000	1.000	0.005
A × B	0.020	2	0.010	0.250	.780	0.010
B × Participants Within A	1.320	36	0.040			
Total	2.090	59				

Note. SS = sum of squares; MS = mean squares.

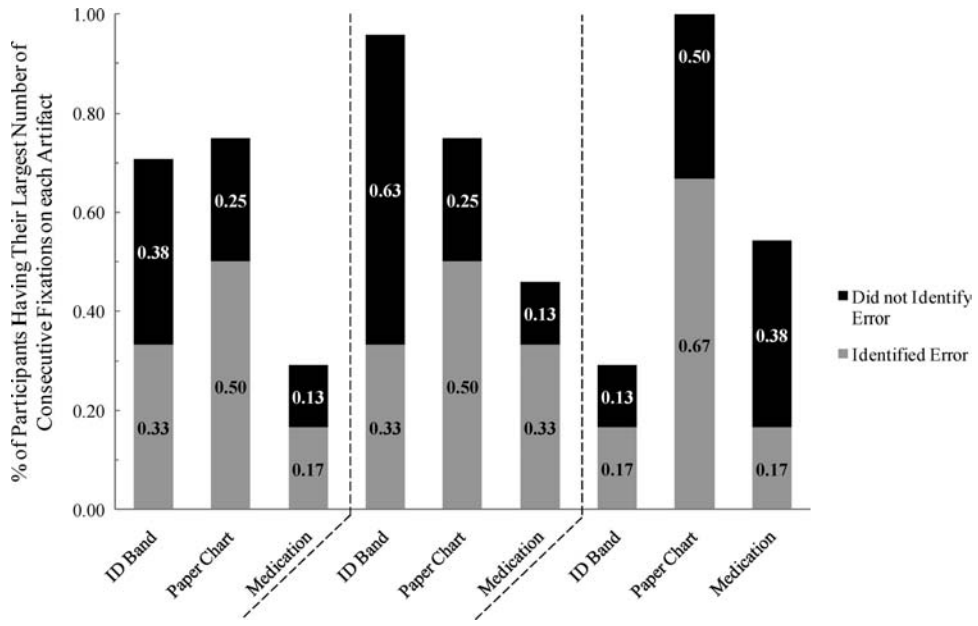

Figure 7. Percentage of participants having their largest number of consecutive fixations on a given artifact, by trial.

Practical Implications and Conclusions

The practical implications of this study are several. From this work, we are able to hypothesize that nurses who identify patient ID errors may exhibit different behaviors and visual scanning patterns during the medication administration process than nurses who do not identify patient ID errors. Those participants who identified the error tended to complete more process steps in the same amount of time as compared with participants who did not identify the error. This finding suggests that nurses may be able to be trained to be more thorough in completing the medication administration process without affecting the time it takes them to complete the medication administration process.

As shown in other domains such as transportation, attention-based training programs can successfully change individuals' attention patterns (Fisher et al., 2006; Pollatsek et al., 2006; Pradhan et al., 2009; Romoser & Fisher, 2009). On the basis of the results of this study, it may be beneficial for nurses to scan information across artifacts rather than sustaining their fixations on one artifact before transitioning their fixations to another artifact. It may be that a nurse cannot remember several pieces of information from a single artifact before transitioning his or her eye fixation to another artifact. Therefore, it seems logical that those nurses who fixate on fewer identifiers within an artifact before switching their eye fixations to another artifact may be better able to remember the identifier information and notice the ID error. It may be possible to train nurses to scan one identifier on many artifacts instead of many identifiers on one artifact. Additionally, on the basis of our findings, it seems important that this scanning across artifacts be done systematically as opposed to randomly.

As proposed by Roda (2011), if we understand individuals' behaviors and visual scanning patterns, we may be able to anticipate how they will adapt to and use artifacts and technologies during the process. Given that participants who identified the error tended to use the patient chart as their primary information source, special attention should be paid to the layout of the patient ID information on this artifact. For instance, the patient ID information on the chart—whether paper or electronic—should be prominently displayed. In the patient chart, this may mean displaying the patient's identity information in a larger format than what often appears on current labels placed at the top of the chart. In the electronic chart, this may mean displaying the patient's identity information in a prominent location on the screen at appropriate points during the medication administration process. In many electronic systems, the patient identifiers are in small print at the top of the computer screen.

In summary, these findings suggest a need for further study of behaviors and visual scanning patterns that may help nurses prevent medication and other types of medical errors. This study provides evidence for future studies that include more participants; address different types of errors; explore the effects of age, gender, and experience level on nurses' behaviors and visual scanning patterns; and include other institutions. We also see a need for more controlled laboratory studies to test whether specific scanning patterns increase nurses' abilities to identify patient ID errors and a need for more naturalistic studies to test whether these findings generalize to situations that include external factors such as interruptions.

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