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Increasing Recognition of Wrong-Patient Errors through Improved Interface Design of a Computerized Provider Order Entry System

Meirav Taieb-Maimon Ph.D.1,2, Catherine Plaisant Ph.D.2, A. Zachary Hettinger M.D.3,4, Ben Shneiderman Ph.D.2

1 Department of Software and Information Systems Engineering, Ben-Gurion University of the Negev, Israel
2 Human-Computer Interaction Lab, University of Maryland, College Park, Maryland, USA
3 National Center for Human Factors in Healthcare, MedStar Health, Washington, DC, USA
4 Department of Emergency Medicine, Georgetown University School of Medicine, Washington, DC, USA

Corresponding author: Meirav Taieb-Maimon, Department of Software and Information Systems Engineering, Ben Gurion University of the Negev, POB 653, Beer Sheva, Israel, 84105. Tel: 972-523918555; fax number: 972-774030277; meiravta@bgu.ac.il

Running Title: Increasing Recognition of Wrong-Patient Errors

ABSTRACT

Wrong-patient errors from inadvertent menu selections while using computerized provider order entry (CPOE) systems could have fatal consequences. This study investigated whether the manipulation of CPOE interface design could improve healthcare providers’ ability to recognize patient selection errors and also decrease the time to error recognition. Using a 2x2 design, 120 participants were randomly assigned to one of four groups, interacting with different versions of a simulated CPOE: (1) control- standard version; (2) highlighted selection- the selected patient
row was highlighted for two seconds, by blanking the rest of the screen; (3) photographs of patients’ faces were displayed in all screens; (4) combined- with photo and highlighted selection. Each participant navigated through five case scenarios. On the last scenario, an error was simulated by directing the participant to a wrong patient. Recognition rates of the wrong-patient error and times to error recognition were significantly improved for the highlighted selection, photo, and combined groups, relative to the control group. These results suggest that the addition of patient photos and highlighted selection could substantially reduce errors in CPOE systems and other applications.

Keywords: Wrong-patient Errors, Slips, Menu Design, Photos, Highlighting, Computerized Provider Order Entry Systems, Patient Safety, Interface Design, Human-Computer Interaction

1. Introduction

Computerized Provider Order Entry (CPOE) systems are computer-based systems that allow a physician or other ordering authority (nurse practitioner, physician’s assistant, etc.) to directly enter orders for medications, tests, or other medical procedures, for a specific patient. Although CPOE systems are often recommended to reduce medication errors (e.g., Radley et al., 2013), reports of CPOE usage indicate that it can introduce or facilitate new errors, which can compromise patient safety (Schiff et al., 2015; The Joint Commission, 2008).

Patient identification is a common reason for CPOE errors (Schiff et al., 2015) and can occur when a user selects an incorrect patient by slipping off a menu during the selection process. CPOE systems typically employ order screens with little differentiation, beyond the
patient demographic information located in a header at the top of the screen, which is outside where the users are directing their attention. Previous research has demonstrated that close to 75% of users do not verify that they are on the correct patient record after making a selection (Henneman et al. 2008, Hettinger & Fairbanks 2012), potentially leading to patient harm or a delay in care for the intended patient. We hypothesized that the design of an improved user interface could help to prevent wrong-patient errors, by making it easier for clinicians to recognize the selection error and make a correction before it could reach the patient.

This study examines whether the recognition of wrong-patient errors could be increased through an improved interface design of a CPOE system. The impact of three design manipulations was investigated: 1) highlighting the selected patient chosen from a list by blanking the rest of the screen; 2) inclusion of the patient’s photo; and 3) a combination of both methods (highlighted selection and photo). We conducted a user study to compare the three suggested designs against a standard CPOE system design (control). Our goal was to evaluate the three interface manipulations in terms of their effectiveness in increasing recognition of wrong-patient errors and efficiency in reducing the time interval from error occurrence to error recognition. We propose the following hypotheses:

Hypothesis 1: The error recognition rates will be significantly higher when using the designs with highlighted selection or photo than when interacting with the standard CPOE system (control).
Hypothesis 2: Recognition time intervals (the time interval between error introduction and error recognition) will be significantly shorter when using highlighted selection or highlighted selection plus photo, when compared to the non-highlighted versions (i.e., control or photo only).

2. Background and Literature Review

2.1. Patient Safety Issues Related to CPOE Systems

Medical errors have a known and significant impact on the delivery of healthcare in the United States (Institute of Medicine, 1999). Despite the national effort to reduce medical errors, a significant number of errors have been reported (Leape and Berwick, 2005; Longo et al., 2005; Wachter, 2010; Wachter, 2004). CPOE systems have been recommended (Institute of Medicine, 2001; Institute of Medicine, 2007; The Leapfrog Group, 2012) as one of the means for improving patient safety and the use of CPOE systems is credited with the reduction of medical errors (Ammenwerth et al., 2008; Bates et al., 1998; Bates et al., 1999; Kaushal, Shojania and Bates, 2003; Mekhjian et al., 2002; Reckmann et al., 2009). However, the current literature shows mixed results from the introduction of CPOE systems regarding their safety and efficiency, placing doubt upon the efficacy of CPOE systems to “do no harm”.

The Joint Commission (2008) issued an alert regarding technology-related (including Electronic Medical Records (EMRs), CPOE and clinical decision support systems) adverse events, with the majority of the problems attributed to CPOE and other data entry systems. Related research (Ash Berg & Coiera, 2004; Ash et al., 2007; Bowman & Rhia, 2013; Campbell et al., 2006; Doggett et al., 2017; Dunn and Moga, 2010; Harrison, Kopel & Bar-Lev, 2007; Kim
et al., 2016; Koppel et al., 2005; Lin & Stead, 2009; Sittig & Ash, 2010; Zhan et al., 2006; Walsh et al., 2006) highlighted unintended consequences of technological solutions, including use errors by clinicians. Use errors often stem from the lack of attention to human-computer interaction and have potential negative implications for patient safety (Garber et al., 2015; Sparnon & Marella, 2012). Therefore, the implementation of human-computer interaction techniques while integrating computerized technology in clinical practice is encouraged (Chan, 2002; Chan et al., 2011; Horsky Kaufman and Patel, 2003; Horsky et al., 2003; Horsky Zhang and Patel, 2005; Jalloh and Waitman, 2006; Johnson, 2006; Khajouei and Jaspers, 2008; Khajouei, de Jongh and Jaspers, 2009; Khajouei and Jaspers, 2010; Nadzam and Macklis, 2001; Russ et al., 2014; Sengstack, 2010).

2.2. Wrong-Patient Errors

Wrong-patient errors are a specific type of use errors, defined as actions (orders or documentation) which are performed for one patient that were intended for another patient (Schumacher et al., 2011). This might occur for a number of reasons, including confusing one patient with another or inadvertently selecting the wrong patient from a list by mis-clicking. The latter error is termed a juxtaposition error and is part of a category of errors which occur during the performance of familiar tasks, and not as a result of lack of training or knowledge (Embrey, 2007). Such errors are referred to as slips, defined as the performance of an action that was not intended (Norman, 1981; Norman, 1983). In daily life, individuals can recover from slips using the context of the information seen after the selection has been made. For example, if a user makes a selection error of an email from a list, it is immediately evident to the user when the
wrong content appears. With CPOE systems, ordering screens are very similar, with the exception of patient information that is typically placed in a header on the top of the screen, out of the user’s directed attention. This is in contrast to paper charts, which may be in different physical locations and inside charts that have different colours and sizes. The orders themselves will be written in different colour ink with different penmanship that would make it obvious to the user if they have previously written orders on a given patient. Theses contextual cues are missing for the CPOE user, making wrong-patient errors easily missed, especially when providers are working quickly, handling interruptions, and coping with multiple tasks.

As mandated by the Joint Commission (2012), at least two patient identifiers such as name, date of birth and medical record number must be used for patient identification. However, Henneman et al. (2008) found, using eye tracking in a simulated environment, that 77% of medical providers missed wrong-patient errors while using CPOE systems because they frequently did not review the patient’s identifying information. Furthermore, when they did check the patient information, they may not recognize errors in medical record numbers, dates of birth or spellings of names. Hettinger and Fairbanks (2012), using a simulated CPOE environment, found a similar rate of 76% of providers that did not recognize a simulated wrong-patient error. Although they did not find an improvement with the addition of contextual written information in a small number of providers, they did observe that 82% of recoveries occurred during the order entry phase where users entered data. We hypothesized that the inclusion of patient photos and highlighting the selected patient by blanking the rest of the screen would draw the physician’s attention to the patient identifiers and therefore improve recovery from wrong-patient selection errors.
2.3. Inadvertent Item Selection Errors

Menus are easy to use and provide considerable functionality by conveniently grouping items from which to select (Hall and Bescos; 1995). Many studies have been conducted regarding optimal menu designs (e.g., Kim, Jacko & Salvendy, 2011). One known difficulty associated with the use of menus is inadvertently slipping off a menu item while trying to select it. Several causes have been suggested to explain an item slip. Brewster and Crease (1999) suggested that the release of the mouse button can move the mouse itself. Users may also start moving the mouse to the location of the next action before the mouse button is released. Because the menu is removed immediately after an item has been chosen, this can be hard to detect. Another explanation stems from the fact that item selection is a simple action which is very familiar to users and performed automatically, and therefore they do not monitor the feedback closely (Reason, 1990; Lee 1992). Alternatively, users might experience a feeling of closure when the desired item is highlighted, as they perceive the task as being completed (Dix et al., 1993). However, the task is not completed until the mouse button is released.

Previous research offered different solutions to the problem of an item slip. Most of the techniques were designed to help the user to get the cursor onto the target more easily. For example, Walker et al. (1991) increased the point size of menu items as their distance from the top of the menu increased, i.e., increasing the size of the target area. It did, however, also make the distance to the target greater. The original area cursor (Kabbush and Buxton, 1995) was developed to facilitate selection, by using an area cursor, rather than point. Yet, it degenerated to a point cursor when it was over more than one target. The bubble cursor improves upon area
cursors by dynamically resizing its activation area depending on the proximity of surrounding targets, such that only one target is selectable at any time (Grossman and Balakrishnan, 2005). However, it degenerated with closely-packed targets. Many of these solutions were targeted to help elderly users and users with motor impairments (e.g., Hwang et al., 2003; Trewin et al., 2006; Wobbrock et al., 2009; Wobbrock and Gajos, 2008; Worden, A., 1997). Findlater et al. (2010) for example, presented and demonstrated improved usability of two enhanced area cursors that use goal crossing instead of clicking and two cursors that provide magnification to ease selection. The main design goals were to reduce the need for corrective-phase pointing, to lessen the effects of small targets on acquisition difficulty, and to reduce the need for accurate, steady clicking.

Another approach to mitigate the problem of an item slip is providing feedback on selection. This enables verification of a correct selection, or recognition of an error. According to Norman (1991), user interfaces should provide feedback to users confirming selection and informing them of progress. Brewster and Crease (1999) claimed that the graphical feedback indicating this (either by highlighting the menu item the user slipped on to (while the mouse hovers over it), or the removal of the highlight) is not demanding enough to grab the user’s attention, and therefore the error will not be noticed. They emphasized the need for more salient feedback and used sound to solve these problems. They showed a significant reduction in the subjective effort required to use new sonically-enhanced menus along with significantly reduced error recovery times and error rates. However, they acknowledged that sound can be a source of annoyance both to the user whose machine is making the noise (the primary user) and/or annoying to others in the same environment who overhear it (secondary users). Our study
investigated the effect of a more salient visual feedback, using three interface manipulations: 1) highlighting the selected item after the selection is made. This strategy blanks the rest of the screen and leaves only the selected item visible briefly, before the next screen appears; 2) providing visual feedback of related information, i.e., a photo, to provide additional opportunities to validate the choice or to detect errors; and 3) a combination of both methods (highlighted selection and photo).

The suggested interface manipulations could have payoffs for many consumer and business applications, in which selections of people (passengers, college applicants, patients etc.), products (books, films, etc.), or services (flights, shipping, etc.) are made. However, the consequences of an item slip might have very different implications in different areas. Sending an email or message to the wrong person might cause embarrassment, making a monetary transaction to the wrong account by a bank teller might be disturbing, but ordering a test or a medication to the wrong patient could be fatal.

2.4. Rationale Behind Suggested Interface Manipulations

On the limited display area of a computer screen, animation can be used to make something more distinctive, to promote a section within a site, or to illustrate editorial content more effectively (McGalliard, 1998; Ware, 2012; Chevalier et al., 2016). The human-computer interaction literature clarifies that one function of animation is attracting users’ attention to specific information on the screen (Chimera and Shneiderman, 2004; Nielsen, 2000). However, animation has also been recognized (McCormick, 1970; Nielsen, 1997; Spool et al., 1999; Stewart, 1976) as being “distracting”, “annoying” and “fatiguing” and therefore it should be used
cautiously by designers (Hong, Thong and Tam, 2004). For example, the results of the study of Hong et al. (2004) confirmed that flashing (often termed blinking) does attract users’ attention and facilitates quicker location of the flashed target item in tightly packed screen displays. Nevertheless, they also found that flashing had negative effects on users’ focused attention and that users have less favourable attitudes towards using a website when the flashed item was irrelevant to their information search task. Zang (2000) found that irrelevant animation can reduce information seeking performance, because it distracts users’ attention from the task. Therefore, in the present study, we did not use flashing to signal a patient’s name to remind the physician to verify the patient’s identifiers. Instead, our highlighted selection strategy keeps the selected item on the screen while the rest of the screen is blanked for two seconds, thereby briefly attracting users’ attention to the selected row, before moving to the next screen. No previous study has examined the effect of the suggested highlighted selection technique on error recognition.

Previous studies have also shown that attention may be preferentially directed to faces and engaged longer by them, to the detriment of other visual stimuli (Bindemann et al. 2005; Bindemann et al. 2007; Cerf et al. 2008; Cerf, Frady and Koch, 2009; Mack et al., 2002; Ro, Russell and Lavie, 2001; Theeuwes and Van der Stigchel, 2006; Vuilleumierm, 2000). One conclusion of these experiments is that attention is captured by the face similar to the way attention is captured by a true exogenous event, such as an unexpected conspicuous visual stimulus. Because faces capture attention, one has to assume that faces are discriminated by some “preattentive” or unconscious processing (Theeuwes and Van der Stigchel, 2006). Upon discerning the face, focal attention is directed towards the location of the face in an automatic
way, and thus the processing of a subsequent target at that location is facilitated. Cerf et al. (2009) demonstrated that in natural scenes, faces are 1.49 times more likely to be attended to than text. Beymer, Orton and Russell (2007) investigated how pictures influence online reading and found significant influences on fixation placement and duration when images were placed next to text content. The inclusion of photos in radiographs was shown to be instrumental in increasing the detection rate of simulated wrong-patient errors (Tridandapani, Olsen and Bhatti, 2015; Ramamurthy et al., 2014). Only one recent study investigated the incorporation of patient pictures within a CPOE system in a children’s hospital (Hyman et al., 2012). Based on analysis of voluntary reporting of error events by staff and providers, it was concluded that an order verification screen requiring single click confirmation, including the patient’s photograph, is an effective strategy for reducing the risk that orders will be placed in an unintended patient’s electronic medical record. Our study investigated the effect of photos of mature patients on wrong-patient error recognition in terms of both error recognition rates and times to error recognition.

2.5. Challenges of Evaluating and Reducing Wrong-Patient Errors

Sopan et al. (2014) suggested that careful design of the user interface can help mitigate wrong-patient errors, but found few empirical evaluations of relevant user interface design guidelines. There are a number of challenges that arise in the evaluation of wrong-patient errors and the methods to reduce these errors. First, it is difficult for human-computer interaction researchers to simulate a hospital environment. Wrong-patient errors are often only detected when reported by pharmacists or nurses, sometimes after the patients have suffered the
consequences of the errors. Spontaneous errors are rare and unlikely to occur in laboratory settings.

An additional challenge is that some studies rely on voluntary reporting and self-corrections. For example, Hyman et al. (2012) admitted that the most significant limitation of their study is its reliance on voluntary reporting of events that are recognized, as well as the possibility of unrecognized occurrences resulting in errors, events, and near misses. Wilcox (2011), Adelman (2013) and Green (2015) used self-corrections to estimate the number of errors made, i.e., orders placed that were retracted rapidly and then reordered by the same provider on a different patient within a short period after retraction. Their method was beneficial for estimating near miss errors, but they did not measure errors that reached the patient and caused harm. To address this challenge, we used the technique of simulating a selection error which enabled us to monitor both detections and misses.

Another challenge of evaluating CPOE systems is the availability of clinicians to perform usability studies. Previous research (Liu, 2009) investigated the effect of user profiles on usability evaluation results, providing practical advice on the choice of users as test subjects when conducting usability evaluations of medical devices. Liu’s analysis implied that when interacting with a simple medical user interface, expert users are not superior to novice users in performance. In other words, expert users appear similar to novice users in terms of task completion (e.g., number of errors and task completion time). However, expert users outperformed novice users when interacting with a complex medical user interface. In addition, naive users are recommended for experimental tests to avoid the bias of previous experiences.
and habits (e.g., Chapanis, 1959). When there is a big difference between previously used interfaces and a new or unknown interface concerning information organization, expert users’ old mental models or previous use experience can have negative effects on their interaction (Liu, 2009). Therefore, for simple user interfaces, it is recommended to involve novice users in usability evaluation for investigating interaction or interface aspects.

Studies have been performed to compare physicians and other professional and non-professional workers with regard to attitudes toward their acceptance of IT technologies (Hu et al., 1999; Chrismar & Wiley-Patton, 2003). They investigated whether the technology acceptance model (TAM) applied to physicians just as well as to other types of workers. The results suggested that TAM was able to reasonably predict a physician’s intention to use telemedicine technology (Hu et al., 1999). Specifically, it was found that like other workers, physicians are willing to adopt and use Internet-based health applications if they perceive them as being useful to their work (Hu et al., 1999; Chrismar & Wiley-Patton, 2003).

Several studies pointed out the challenges that arise from the strategies for reducing wrong-patient orders. One strategy includes using electronic decision support to verify the patient identification before placing orders or alerting providers when orders are not consistent with the diseases in the patient’s problem list (e.g., Galantar et al., 2013). However, these interventions can be distracting, costly, dependent on the type of CPOE system, and their effectiveness may diminish over time due to alert fatigue (Ash et al., 2007).

A second strategy for mitigating wrong-patient errors (Adelman et al., 2013) demonstrated that an ID-verify alert without photo (single-click confirmation of patient identity) reduced
wrong-patient electronic orders by 16%, while an active ID-reentry function (requiring active reentry of identifiers) achieved a 41% reduction. Although their ID-reentry function proved effective, it required an average of 6.6 additional seconds for every order session. Adelman et al. pointed out that this time (6.6 seconds) seems brief for one order session, but in the aggregate, it represents approximately 3300 hours per year at their medical institution. This additional time added to providers’ busy days may lead to varying types of unforeseen errors or less time spent in the care of patients. Hill, Sears and Melanson (2013) found that during a busy 10-hour shift, the total number of mouse clicks by medical providers using electronic health records approaches 4000. Our study investigated interface design manipulations aimed at increasing recognition of wrong-patient errors prior to order completion, while minimizing physical interaction (such as mouse pointing and clicking) and physicians’ time, without compromising patient safety.

3. Methods

3.1. Participants

We recruited 120 university students, faculty and staff. Participants included 68 women and 52 men whose ages ranged from 21 to 64 years. We did not use medical professionals because they have very little availability, are hard to recruit for a user study, and most importantly the simplified order entry task used in the study was simple enough to be performed by anyone with experience using a computer. All participants used computers on a daily basis for their work or academics.
Participants were not aware of the ultimate study’s goal. They were told that they would be “evaluating different screen designs for a medical data entry system”. Informed consent was obtained and the study was approved by the Institutional Review Board for the protection of human participants. The experiment was conducted over several days.

3.2. Study Design

A randomized between-groups experimental design was used in which participants were randomly assigned into one of four study groups: (1) control group- interacted with the standard version of the ordering system; (2) highlighted selection group- interacted with the version in which the selected row was highlighted for two seconds; (3) photo group- interacted with the version in which the patient photos was presented in all screens; (4) combined group- interacted with a version that included both the display of photo and the highlighted selection. The order of the first four test ordering scenarios, preceding the scenario including the embedded wrong patient selection error, was counterbalanced over participants to control for the impact of any order effects.

3.3. Apparatus and Materials

A simulated CPOE system was developed to allow users to navigate between pages, enter data and submit orders. It was designed to simulate the basic screens and procedures of a CPOE system used in a local hospital and representative of typical CPOE interfaces. The task was to order tests for simulated patients. The control version included five screens (see Figure 1a-e). Each screen represented a stage in the ordering process. The first screen (patient selection stage)
showed the list of patients, ordered alphabetically by last name, and provided their name, age, gender, medical record number, date of birth, admission date and attending physician.

Please insert Figure 1 about here

Upon selection of a patient name from the list a second screen appeared (medical summary stage), which included the patient’s medical data summary: vital signs, medical history, allergies and medications. Upon selection of “Orders/CPOE”, followed by “Write Orders” the third screen appeared (test selection stage). On this screen participants had to first select one out of five test categories: blood tests, urine tests, imaging, consultation, and more tests. Each category included a list of possible tests to choose from. For example, the imaging category included: “CT”, “MRI”, “Ultrasound” and “X-ray”. Upon selection of a test type another sub-list appeared which included the body part for which the test was needed. On the fourth screen (data entry stage) the type of test that was being ordered was displayed. The participant had to fill in the purpose of the test (for example: check for forearm fracture), the patient’s room number, and then sign the order with their initials. Pressing “OK” would introduce the fifth and final screen (order confirmation stage) confirming the specific order. The participant had to press the “Return to Patient List” button to order a test for the next patient. Throughout the process, once a patient was selected, there was a banner at the top of the screen (marked in Figure 1) showing the patient’s name (in bold), medical record number, age, gender, date of birth and their attending physician.

Three variations of the standard version of the simulated CPOE system were also developed: highlighted selection version, photo version, and combined version (photo and
highlighted selection). In the first screen of the highlighted selection version, when users click on a patient in the patient list, the entire selected row remains in place on the screen while the rest of the screen is blanked for two seconds (see Figure 2). This was designed to briefly attract the participants’ attention to the selected row before navigating to the next screen. We call this “highlighting on departure”. The rest of the interactions remained the same on subsequent screens. In the photo version, the patient’s photo is shown next to the patient name in the patient list of the first screen, and the photo also appears in the patient demographics banner of all subsequent screens (see Figure 3a and 3b). Finally, in the combined version both modifications are combined so users’ attention is directed to the row that was selected and the patient’s photo is displayed in all screens (see Figure 4).

Please insert Figures 2,3,4 about here

3.4. Pilot

Prior to the experiment a pilot study with ten participants was conducted aimed at investigating how many orders were necessary for participants to become comfortable using the simulated CPOE system. The results of the pilot showed that from the third order onwards the ordering times stabilized. Therefore, in order to simulate a scenario of a physician who is experienced in using the ordering system, the wrong-patient error was forced on the fifth scenario to reduce the effects of using a novel system.
3.5. Procedure

The procedure for each participant was carried out during an individual session which lasted approximately half an hour. A short break was set between sessions, so that participants would not meet each other. Following written informed consent, the participant's demographic data were recorded. Participants were asked to play the role of a physician working at an emergency room in a hospital, caring for 12 patients. They were given ten minutes during which they had to become familiar with their patients by reading 12 "medical files", each including the patient’s name, photo, date of birth, age, medical record number (MRN), room number, chief complaints and medical scenario. The medical scenarios and chief complaints (detailed in Table 1) were composed by an emergency medicine registered nurse and a physician. Common medical cases which are familiar to most people were used due to the lack of medical training of the participants.

Please insert Table 1 about here

Participants received a brief demonstration of the version of the simulated CPOE system to which they were assigned. During the study, participants were given clear directions to order specific tests for a patient, for example: “Please order neurology consultation for William Altman in room 14, who has been disoriented for three months”, or “Please order a neck X-ray (cervical spine) for Aboud Fateesh in room 12, to check for fracture”. Once given a direction, participants would have to select the patient and interact with the system to order the required test. Participants also received written instructions regarding the order for reference. However, the written instructions did not include patient photos.
After the demonstration the participants used the system on their own with a practice task. During the practice the system did not introduce any error artificially. Upon successful completion of the training task the participants were required to order tests for five patients, one at a time, following the procedure described above. During the selection of the fifth patient the system deliberately introduced an error, resulting in the selection of the adjoining patient’s record. The simulated error was the same for all participants. Specifically, on the fifth trial participants were asked to “order an abdominal CT scan” for “Fred Gomez” in room five to check for appendicitis. When the participants clicked on the row of “Fred Gomez” on the first screen, the record of “Danny Holmes” appeared instead in all of the remaining screens (including the photo of “Danny Holmes” in the photo and combined groups). In addition, in the highlighted selection group and the combined group, after choosing the row of “Fred Gomez” on the first screen, the row of “Danny Holmes” (including his photo in the combined group) appeared solely on the screen for two seconds before going to the second screen.

It should be noted that “Danny Holmes” (bald with light skin) looked very different from “Fred Gomez” (thick hair, dark skin). This was chosen on purpose, to test the extreme case in which the appearance of the patients was very different. The reason behind this was that if the error was not noticed in this extreme case (i.e., if no significant differences in error recognition rates could be found between the photo group and the control group), the chance that it would be noticed for patients who looked closer in appearance would be even smaller. The gender and ages of these two patients were chosen to be the same so that if the error was noticed it could not be associated with the different sex or age (which was indicated on every screen), but only with the different name or appearance.
Participant’s recognition of the simulated error was the primary outcome, with secondary outcomes of time-on-task and the order stage at which the error was recognized. Time-on-task was defined as the time from the moment the participants finished reading the order instruction (announcing: ‘ready’) until the time they clicked on the ‘Return to the Patient List’ button on the last screen. Recognition wrong-patient error was defined as participants verbally acknowledging the fact that this was not the required patient: “This is not Fred Gomez”, or seeing them returning to patient selection screen and choosing the correct patient. The recognition time intervals of the participants who recognized the error introduced at the fifth trial were recorded as well.

At the end of the session the participants were debriefed regarding their performance and experience during the experiment. If they had recognized the error, they were asked what helped them to do that. If they had not recognized it, the matter was brought into their attention and they were asked why, in their opinion, they had not recognized the error. Participants were asked not to speak with anyone about the goals of the experiment until the study was complete, to reduce the chances of bias.

4. Results

4.1. Error Recognition Rates

The average error recognition rate for all groups was 37.5%. The error recognition rates for each group are presented in Figure 5. Only 7% (95% CI 0-16%) of the participants of the control group (who interacted with the standard version of the system) noticed the occurrence of the wrong-patient error. The rates were 36% (95% CI 19-53%) for the highlighted selection
group, 43% (95% CI 25-61%) for the photo group, and 63% (95% CI 46-80%) for the combined group. To compare the error recognition rates of the different experimental groups, we first performed a chi-squared test. The result of the analysis showed the chi-square statistic was highly significant

\[ \chi^2 = 23.25 > \chi^2 (df=3) = 7.8147, p<0.0001. \]

This result indicated that at least one proportion was significantly different than the other three. Thus, paired comparisons between the error recognition rates of the different groups were conducted, using a chi square significance test for comparing two proportions with continuity correction. The results, which are presented in Table 2, show that the error recognition rates of the highlighted selection group (36%), the photo group (43%) and the combined group (63%) were each significantly higher than the error recognition rate in the control group (7%). The error recognition rates of the highlighted selection group and the photo group were not significantly different from each other. The error recognition rate of the combined group was significantly higher than the error recognition rate of the highlighted selection group, but not significantly higher than the error recognition rate of the photo group.

One participant (from the control group) made an error in selection in one of the trials preceding the forced error on the fifth scenario. However, since he did not recognize the error we let him continue the experiment without mentioning this, until he finished the experiment.
4.2. Recognition Time Intervals and the Stage of Interaction at Which the Recovery Took Place

One-way ANOVA was conducted to examine whether there were significant differences among the different experimental groups in recognition time intervals of the embedded error in the fifth patient’s order. Recognition time interval was the dependent variable and the experimental group was the independent variable.

The results of the analysis showed that the effect of the group was significant (F(3, 41)=10.185, p<0.0001). A post-hoc Duncan’s Multiple Range Test for finding homogenous groups showed that the mean recognition time intervals of the participants who recognized the error in the highlighted selection groups (highlighted selection vs. combined) were not significantly different from each other (mean recovery time ± SD of 5.27±4.38 sec and 2.78±0.79 sec respectively), but significantly shorter (p<0.05) than the mean time intervals of both the photo group (mean ± SD of 13.77±11.98 sec) and the control group (mean ± SD of 22.5±0.70 sec). The mean recognition time interval of the photo group was significantly shorter than the mean time interval of the control group (p<0.05).

The analysis of the stage in the ordering process at which recognition occurred (corresponding to each of the five screens detailed above) showed that the error recovery took place at earlier stages of the interaction for the highlighted selection or combined groups relative to the control and photo groups. In the control group, the error recognition occurred at later
stages of the ordering process, specifically at the stages of data entry (fourth screen) and the final approval of the order (fifth screen). In contrast, in both highlighted selection groups approximately 90% of the participants who recognized the error, recognized it during the highlighted selection stage (while the row of “Danny Holmes” was shown alone on the screen instead of the row of “Fred Gomez” which was the intended selection). Most of the participants from the photo group (54%) recognized the error on the second screen (the first time the photo of “Danny Holmes” was presented instead of the photo of “Fred Gomez”), but many of them (38%) recognized the error at later stages of data entry (fourth screen) and final order approval (fifth screen).

4.3. Task Performance Times (Test Ordering Times)

Since the time of medical professionals is valuable, we also wanted to examine whether the inclusion of a photo or highlighted selection significantly affected the time it takes to order a test. A One-way ANOVA was performed to test whether there were significant differences in the ordering times among the different experimental groups. The ordering time was the dependent variable (average ordering times of the tests for the third and the fourth patients) and the experimental group was the independent variable. The results of the analysis showed no significant effect of the group on the test ordering time (F(3, 116)=1.06, p=0.37). The mean ordering times ± SD for each group were: 34.70±9.99 sec for the control group; 37.87±7.67 sec for the highlighted selection group; 35.52±9.66 sec for the photo group; and 34.38±5.37 sec for the combined group.
4. Discussion

4.1. Low Recognition Rate in Control Group

The results of the study indicated that only 7% of the control group participants, who interacted with the standard version of the CPOE system, noticed the occurrence of the wrong-patient error. This poor recognition rate is lower, but consistent with the results of Hettinger and Fairbanks (2012) who found an overall error recognition rate of 24% among emergency medicine physicians, using a simulated CPOE. They concluded that provider vigilance is not sufficient as a sole safety measure in monitoring for wrong-patient errors during the ordering process, and that a stronger safety net may be necessary. This is also supported by the findings of Henneman et al. (2008) who demonstrated using an eye-tracking device that providers seldom verified patient identity during CPOE use, or noted existing wrong-patient errors. Recent studies (Adelman et al., 2013; Wilcox, Chen and Hripcsak, 2011), which estimated a rate of approximately 50 wrong-patient errors per 100,000 electronic notes, also lead to the conclusion that a more active approach is essential for ensuring patient safety.

Participants who did not recognize the error and were debriefed after the experiment commonly said that they were focused on the task and especially on the specific part of the screen related to order completion (such as the order button on the left side). This corresponds well with Reason’s (1990) suggestion that two conditions must be met for a slip to occur: ‘The performance of some largely automatic task in familiar surroundings and a marked degree of attentional capture by something other than the job in hand’. In this case, the automatic task is
the menu selection (which most users are very familiar with) and the attentional capture comes from the main task that the user is performing (Brewster and Crease, 1999). In addition, the visual focus of the next action is at some distance from the target menu item and the cursor is required at the new focus (Dix and Brewster, 1994).

4.2. Significant Improvement in Error Recovery by Interface Manipulations

The study supported our hypotheses and demonstrated significant improvement both in error recognition rates and time to recognition, through interface design manipulations of a CPOE system. The error recognition rates of the highlighted selection group (36%) and the photo group (43%) were both statistically significantly higher than the recognition rate in the control group. This improvement was synergistic for the combined group (63%). These results are congruent with recent studies which showed that it is possible to reduce the risk and the frequency of providers entering orders in incorrect patient’s medical record via different interface manipulations of a CPOE interface. Wilcox et al. (2011) implemented a “pop-up” verification screen (without photograph) that reduced patient note mismatches by 40%. Similarly, Green et al., (2015) studied the effect of a verification dialog, which appeared at the beginning of each ordering session, requiring providers to confirm the patient’s identity after a mandatory 2.5-second delay. Although patient photographs were not available in the patient verification dialog, a male or female icon was displayed according to the patient’s sex. The use of this technique led to a 30% reduction in wrong-patient errors that was sustained over time, at a cost of 1.5 hours of mandatory physician time viewing alerts to prevent one error. Adelman et al. (2013) demonstrated that an ID-verify alert (single-click confirmation of patient identity)
reduced wrong-patient electronic orders by 16%, while an active ID-re-entry function (requiring active re-entry of identifiers) achieved a 41% reduction.

The time interval from error presentation to its recognition was significantly shorter and the recovery from the error took place at earlier stages of the interaction for the highlighted selection groups relative to the non-highlighted groups (control and photo). In our study, in the highlighted selection versions, when users click on a patient in the patient list, the entire selected row remains in place on the screen while the rest of the screen is blanked for two seconds. This highlighting briefly attracts users’ attention to the selected row before moving to the second screen, without the need of active pointing or clicking by providers. In both highlighted selection groups approximately 90% of the participants who recognized the error, recognized it during the highlighted selection phase. In the debriefing at the end of the experiment, participants in the highlighted selection groups who did not recognize the error stated that they were distracted by other things such as looking at the papers which included the order details, and therefore missed the highlighted selection phase.

In determining the interface manipulation which should be used in CPOE systems to minimize wrong-patient errors, the pros and cons of each method should be considered. Highlighted selection focuses attention on patient identifiers and does not require physical interaction, but if the user is distracted at that precise moment it can be missed. By comparison, a mandatory single-click confirmation of patient identity in a verification screen with a forced delay requires pointing and clicking, which is time consuming, and was criticized as being intrusive and frustrating for physicians (Wears, 1995). However, it ensures that the verification screen is not missed due to distractions or interruptions. Nevertheless, it is well documented
(Shah et al., 2006; Van der Sijs et al., 2006; Weissman et al., 2009) that providers override between 49% and 96% of alerts presented to them in the course of entering orders in the EMR and that alarm fatigue in general is a significant concern. In one study, physicians overrode 91.2% of drug allergy and 89.4% of high-severity drug interaction alerts; physician reviewers judged that 36.5% of the alerts were inappropriate (Weingart et al., 2003). Another recent study concluded that more awareness regarding the risks to patient safety from having too many alerts is required, for designers of clinical decision support tools and electronic safeguards for drug order entry (Carspecken et al., 2013). A literature review found little evidence from experimental studies about the most important design factors of computerized alerts and prompts for prescribing. The authors found no empirical studies that evaluated the effectiveness of different approaches to the design and display of alerts and prompts (Schedlbauer, 2009).

The distinct and interesting advantage of using a photo to capture the user’s attention is reflected in the results of our study. First, in the photo group the recognition rate was significantly higher and recognition time intervals were significantly shorter than in the control group. In the debriefing at the end of the experiment all the participants who recognized the error in this group specifically pointed out that it was the photo that made them recognize the error and not the patient’s name. Second, the recognition rate in the combined group was significantly higher than in the highlighted selection alone group, but not significantly higher than in the photo group. This implies that if designers use highlighted selection, it is better to combine it with a photo.

Our results support previous findings that photos are perceived directly and pre-attentively (Theeuwes and Van der Stigchel, 2006). Our findings are also congruent with the
conclusion of the study of Hyman et al. (2012), which was conducted in a children’s hospital, that an order verification screen, including the patient’s photograph, placed before the final signing of orders, is effective in reducing the risk that orders will be placed in an unintended patient’s EMR. Moreover, they mentioned that unlike other alerts in their system (which are ignored up to 80% of the time at their hospital), providers reported that the large, centrally placed patient picture on the verification screen was effective in capturing their attention when the picture was not of the child they were expecting. However, they noted as a limitation their ability to discern the differential impact between interrupting workflow using an order verification screen by itself as compared with one including a patient picture. In our study, the photo was placed in each screen and not in a pop up verification screen as a single instance. This might help increase recognition of wrong-patient errors which are induced by interruptions and toggling between patients in CPOE systems, in addition to those which stem from juxtaposition errors. In contrast to highlighted selection, the use of a patient’s photo does not impose a forced break and therefore is less intrusive. Legitimate concerns for including photos include: patient resistance due to privacy or religious beliefs, staff resistance to the additional recording step, and the cost of cameras or scanners. There is also the challenge of having a photo that accurately represents what the patients look while they are ill or potentially disfigured. Nevertheless, taking the time to capture and place the photos in the medical records seems worthwhile when considering the benefits for patient safety.
4.3. Study Limitations

The main limitation of this study was the use of non-medical participants. This was partially compensated for by using simplified medical scenarios and participant directions in order to isolate the effects of the interface design. In our experiment, users interacted with a simple ordering system, according to Liu’s criterions (Liu 2009): it was easy to manipulate; had low hierarchy of tasks both in broadness and depth; contained a small amount of information; exhibited limited items in menus and pop up-windows; and required low cognitive and physical resources for operation. Yet, the simulated CPOE was representative of actual CPOE systems used in hospitals. Therefore, according to Liu’s model, it is reasonable to conclude that the results would be similar with medical experts. Our confidence is strengthened by the robust significant differences that we found among the experimental groups. The testing of more complex medical systems, such as clinical decision support systems, are more likely to yield significant differences in performance between medical experts, who have a better mental model of the patients, and non-medical users.

Aside from CPOE systems and the medical profession, there are many audiences and systems that can benefit from these interface design manipulations. The fact that we chose the medical domain demonstrates that the research on the effectiveness of interface manipulation on error recognition has important life-critical implications. The medical scenarios might have encouraged the participants to think that choosing the correct record was important. As we elaborated in the introduction, the evaluation of wrong-patient errors is very challenging and scarce. The fact that the results of this study are congruent with other studies, which were
conducted with physicians, is encouraging and further supports the important implications which stem from these results. This study sheds light on the positive effect of interface design, particularly animation and photos, on increasing error recognition. Future research with physicians will be necessary to support these findings.

In this study, the error was artificially induced. It is reasonable to assume that when people make slips in user interface actions they are often subconsciously aware and tend, at that point to glance up to check if everything went well during the interaction. However, since each participant was exposed to the inserted error once, it could not have caused the participants to mistrust that signal, in a way that led them to be extra vigilant.

An additional limitation was the potential un-blinding of participants to the purpose of the study. A large pool of participants was used to reduce the chances of communication, and the participants were randomized. If communication did occur, it would bias all groups towards higher recognition rates and non-significant differences between the groups.

This study was modeled after the Emergency Department where physicians may have multiple patients transferred under their care at the start of a shift from another physician all at once. It is also common for physicians to have to write orders for patients soon after receiving them on their service. In addition, there are certainly limitations in using this simulated model that may change in a live clinical environment where the physician is more familiar with the patients. However, we believe that only handling one patient at a time and having physical interaction with a live person, sitting in front of them, would likely improve the participants’ ability to distinguish one patient from another and make a wrong-patient error less likely. As
such, the effectiveness of the intervention in a variety of live clinical environments will need further testing.

Another limitation is that, for the purposes of this study, the forced error used easily recognizable photos of people with different appearances. In general, studies support the use of photos for improving recognition. Memory for pictures in general and faces in particular is usually considered to be exceptional (Bruce & Young, 1986; Oates & Reder, 2010). Another study reported that face-based recognition appears to be feasible even with unfamiliar faces (Huestegge & Pimenidis, 2014). However, it was demonstrated that it is easier to associate context to faces that have a preexisting long-term memory representation than to faces that do not (Reder at al., 2013). It has also been noted that people have better recognition performance with faces belonging to their own race (Levin, 2000). Further study is warranted to reduce the chances of unintended consequences of using patient photos for identification purposes in the clinical setting, including issues of photo size, quality, location and representativeness of the patient.

Optimization of the time interval used for the patient highlighting feature is also required in order to balance the need for directing user attention with the efficiency of the ordering process. The study did not find significant differences in total time-on-task among the four groups, meaning that the two seconds highlight did not slow performance. The biggest (however, insignificant) test ordering time difference between the three experimental groups and the control group was for the highlighted selection group, which did not include photos. The ordering time differences between the control group and the photo and the combined groups were negligible. A
possible explanation is that the photo in the patient list screen helped the participants to select the patient from the list more quickly. This was also noted by the experimenters.

4.4. Summary and Implications

Inadvertently slipping off a menu item, while trying to select it, is a common problem. While many methods focus on making item selection easier in order to mitigate the problem, this study chose to provide a more salient visual feedback on actual selection using two interface manipulations. The results indicated that: (1) visual feedback about the selected item (highlight on departure) helps steer user attention to verify the users’ choice; (2) visual feedback of related information, i.e., the photo, provides additional opportunities to validate the choice or to detect errors. Implementing the suggested techniques could have payoffs for many applications, such as: 1) systems used by teachers and lecturers to grade students’ work, which can help avoiding entering the wrong grade to the wrong student; 2) choosing a person from a contact list and sending him/her a message, or an email; and 3) bank clerks who make transactions for a specific customer, or account.

In the medical domain, careful interface design could be life-saving. The widespread adoption of CPOE systems makes patient selection using a computer screen a frequent task for clinicians. Previous research described the safety problems associated with patient selection and recommended to apply human computer interaction design techniques to alleviate the problem. However, scientific evaluation of those techniques is challenging due to the clinical environment and infrequent occurrence. This study of a simulated CPOE system found significant
improvement in wrong-patient error recovery by using patient photos and highlighted selection in a forced wrong-patient error scenario.

We demonstrated that improved user interface design can help mitigate the problem of wrong-patient errors by helping physicians to recall their patients’ identities, accurately select their names, and spot errors before orders are finalized. The suggested interface design manipulations can increase recovery from both types of errors. Slips can be recovered by providing feedback—highlighting the selected row. Mistakes can be recovered by providing memory aids—providing photos of the patient on all of the screens to remind the clinician of the patient identity. This might be especially beneficial when there are interruptions or distractions between the intent formation and task performance. Further study in the clinical environment is needed to evaluate the optimal timing, location and use of patient photos and highlighting in CPOE systems to reduce the occurrence of wrong-patient errors. Long-term in-situ evaluations will require accurate error detection, safety monitoring and active participation of vendors that will integrate novel techniques in their user interfaces.

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References


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Authors’ Biographies:

**Dr. Meirav Taleb-Maimon** is a senior faculty member at the department of Software and Information Systems Engineering at Ben-Gurion University of the Negev, Israel. She specializes in Human Factors, Human-Computer Interaction, Information Visualization, Design and Analysis of Experiments and Evaluation of Information Systems, Interfaces and Visual Analytics Systems.

**Dr. Catherine Plaisant** ([www.cs.umd.edu/hcil/members/cplaisant](http://www.cs.umd.edu/hcil/members/cplaisant)) is a Senior Research Scientist at the University of Maryland Institute for Advanced Computer Studies and Associate Director of Research of the Human-Computer Interaction Lab. She was elected to the ACM SIGCHI Academy in 2015 for her contributions to the field of human-computer interaction, medical informatics and information visualization.

**Dr. Aaron Zachary Hettinger** is an Assistant Professor of Emergency Medicine at the Georgetown University of School of Medicine and both Medical Director and Director of Cognitive Informatics at MedStar Health’s National Center for Human Factors in Healthcare. He is board certified in both emergency medicine and clinical informatics. He focuses on patient safety research and health IT systems.

**Prof. Ben Shneiderman** ([http://www.cs.umd.edu/~ben](http://www.cs.umd.edu/~ben)) is a Distinguished University Professor in the Department of Computer Science, Founding Director (1983-2000) of the Human-Computer Interaction Laboratory ([http://www.cs.umd.edu/hcil/](http://www.cs.umd.edu/hcil/)), and a Member of the UM Institute for Advanced Computer Studies (UMIACS) at the University of Maryland. His latest
Figure 1 Example for the five screens included in the control version of the simulated CPOE.  
1a- List of patients (screen 1). 1b- Patient medical data summary (screen 2). 1c- Test selection (screen 3). 1d- Data entry of patient information (screen 4). 1e- Order confirmation (screen 5).
Figure 2 The highlighted selection phase of the highlighted selection version.
Figure 3 Examples of the first and fourth screens of the photo version. 3a- List of patient screen of the photo version. 3b- Data entry screen of the photo version.
Figure 4 The highlighted selection phase of the combined version.
Figure 5 Error recognition rates for each group.
Table 1: Medical scenarios and chief complaints of the 12 patients and the tests the participants ordered for the five patients

<table>
<thead>
<tr>
<th>#</th>
<th>Patient’s Name</th>
<th>Medical scenario and chief complaint</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nancy Walsh</td>
<td>Patient fell in her house and has severe pain in her left hip. There is suspicion for fracture in her hip.</td>
<td></td>
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<tr>
<td>2</td>
<td>Fred Gomez</td>
<td>Patient has severe abdominal pain in the lower right side of abdomen, and has high fever. There is severe tenderness in the right lower abdomen when pushing on it. There is a suspicion for appendicitis.</td>
<td>Abdominal CT scan (Computerized Tomography).</td>
</tr>
<tr>
<td>3</td>
<td>Emily Zeltser</td>
<td>Patient complains of small amounts of blood in her stool for two days. There is a concern for gastrointestinal bleeding.</td>
<td>Complete blood count (CBC).</td>
</tr>
<tr>
<td></td>
<td>Name</td>
<td>Description</td>
<td>Additional Info</td>
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<td>---</td>
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<td>---------------------</td>
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<tr>
<td>4</td>
<td>William Altman</td>
<td>Patient is alert, disoriented for three months. His medical work up has been negative so far. Suspicious for Alzheimer.</td>
<td>Neurology consult</td>
</tr>
<tr>
<td>5</td>
<td>Josh Dimassio</td>
<td>Patient status post motor vehicle accident. Patient presents with sharp, stabbing chest pain that worsens with breathing, non-productive cough, shortness of breath and diminished lung sounds on the right side of the chest. There is a suspicion for lung puncture, as a result of broken rib(s).</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Rachel Evans</td>
<td>Patient is having intermittent severe left flank (side) pain for five hours with blood in urine. This is concerning for a kidney stone.</td>
<td></td>
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<tr>
<td>7</td>
<td>Aboud Fateesh</td>
<td>Patient status post motor vehicle accident. Patient complains of pain in neck. There is a</td>
<td>X-ray of neck (cervical spine).</td>
</tr>
<tr>
<td></td>
<td>Patient</td>
<td>Symptoms and Suspicion</td>
<td>Tests Performed</td>
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<tr>
<td>8</td>
<td>Charlie Willson</td>
<td>Patient with pain and pressure in the chest radiating to left arm. There is a suspicion for a heart attack (MI-Myocardial Infarction).</td>
<td>EKG (Electrocardiogram).</td>
</tr>
<tr>
<td>9</td>
<td>Georges Driscoll</td>
<td>Patient presents with blurry vision, slurred speech, facial droop and has left sided weakness and numbness with unsteady gait. Suspicious for a stroke (CVA-Cerebral vascular accident).</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Emma Johnson</td>
<td>Patient presents with severe headache, vomiting and blurry vision. Concerning for a brain tumor.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Name</td>
<td>Symptoms</td>
<td>Testing</td>
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<td>--------------------------------------------------------------------------</td>
<td>---------------</td>
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<tr>
<td>11</td>
<td>Samantha Poulson</td>
<td>Patient presents with blood in urine, frequent urination and burning while urinating.</td>
<td>Urine Analysis.</td>
</tr>
<tr>
<td>12</td>
<td>Danny Holmes</td>
<td>Patient tripped over a curb while walking and fell onto outstretched arm. Patient complaints of severe pain and presents with swelling and bruising of right forearm. There is a suspicion for forearm fracture.</td>
<td></td>
</tr>
</tbody>
</table>
**Table 2:** The results of the paired comparisons between the error recognition rates of the different groups

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Chi-square statistic</th>
<th>P&lt;sub&gt;value&lt;/sub&gt;</th>
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<td>P&lt;sub&gt;Control&lt;/sub&gt;</td>
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<tr>
<td></td>
<td>P&lt;sub&gt;Photo&lt;/sub&gt; -</td>
<td>P&lt;sub&gt;Control&lt;/sub&gt;</td>
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<tr>
<td></td>
<td>P&lt;sub&gt;Combined&lt;/sub&gt; -</td>
<td>P&lt;sub&gt;Control&lt;/sub&gt;</td>
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<tr>
<td></td>
<td>P&lt;sub&gt;Photo&lt;/sub&gt; -</td>
<td>P&lt;sub&gt;Highlighted Selection&lt;/sub&gt;</td>
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<td>P&lt;sub&gt;Combined&lt;/sub&gt; -</td>
<td>P&lt;sub&gt;Highlighted Selection&lt;/sub&gt;</td>
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<tr>
<td></td>
<td>P&lt;sub&gt;Combined&lt;/sub&gt; -</td>
<td>P&lt;sub&gt;Photo&lt;/sub&gt;</td>
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