Effects of Text Enhancement, Identical Prescription-Package Names, Visual Cues, and Verbal Provocation on Visual Searches of Look-Alike Drug Names: A Simulation and Eye-Tracking Study

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Objective: Simulation and eye tracking were used to examine the effects of text enhancement, identical prescription-package names, visual cues, and verbal provocation on visual searches of look-alike drug names.

Background: Look-alike drug names can cause confusion and medication errors, which jeopardize patient safety. The effectiveness of many strategies that may prevent these problems requires evaluation.

Method: We conducted two experiments that were based on a four-way, repeated-measures design. The within-subject factors were text enhancement, identical prescription-package names, visual cues, and verbal provocation. In Experiment 1, 40 nurses searched for and selected a target drug from an array of drug packages on a pharmacy shelf mock-up. In Experiment 2, the eye movements of another 40 nurses were tracked while they performed a computer-based drug search task.

Results: Text enhancement had no significant effect on the drug search. Nurses selected the target drugs more quickly and easily when the prescriptions and drug packages shared identical drug name formats. The use of a visual cue to direct nurses' attention facilitated their visual searches and improved their eye gaze behaviors. The nurses reported greater mental effort if they were provoked verbally during the drug search.

Conclusion: Efficient and practical strategies should be adopted for designs that facilitate accurate drug search. Among these strategies are using identical name appearances on drug prescriptions and packages, using a visual cue to direct nurses' attention, and avoiding rushing nurses while they are concentrating.

Application: The findings aim to inspire recommendations for work system designs that will improve the visual search of look-alike drug names.

Keywords: medication management and safety, visual search, decision making, simulation, eye movements

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INTRODUCTION

Confusion between look-alike drug names (e.g., lamivudine and lamotrigine) is an important patient safety issue because it can lead to medication errors (Davis, 1997; Hampton, 2004; Hoffman & Proulx, 2003; Lambert, Chang, & Lin, 2001). Accordingly, practitioners attempted to use various methods to reduce drug name confusions, such as redesigning medicine labels (DeHenau, Becker, Bello, Liu, & Bix, 2016; Filik, Purdy, Gale, & Gerrett, 2006; Hellier, Edworthy, Derbyshire, & Costello, 2006; Irwin, Mearns, Watson, & Urquhart, 2013; Schell, 2009), providing warnings and aids, and putting drugs with names that are potentially confusing in separate areas.

Using text enhancement to alter the font attributes of differing letters in look-alike drug names to emphasize their differences is one method for the problem (Cohen, 1999; U.S. Food and Drug Administration [FDA], 2001). Among various text enhancement techniques, Tall Man lettering (i.e., the use of capital letters to highlight the differing parts of confusing drug name pairs) has been recommended by the Institute for Safe Medication Practices (ISMP; 2016) and the FDA (2001). Despite these recommendations, however, studies of the effectiveness of Tall Man lettering have yielded conflicting results, indicating the need for further study (Lambert, Schroeder, & Galanter, 2016). Furthermore, basic visual search and detection studies have identified other font attributes that can provide visual emphasis, such as colored text, increased letter stroke width, and contrast (i.e., white characteristics on a black rectangle background; Sheedy, Subbaram, Zimmerman, & Hayes, 2005). However, these attributes have rarely been studied (Larmené-Beld, Alting, & Taxis, 2018). Based on those findings, we proposed and examined three other text enhancement methods in this study. The first method, *reverse Tall Man lettering*, uses lowercase for differing letters and uppercase for letters shared by look-alike drug names. Reverse Tall Man lettering may better facilitate drug searches because lowercase text is read more rapidly than uppercase text (Rudnicky & Kolers, 1984). We additionally proposed the use of text *boldface plus red* and *boldface plus contrast* to reduce name confusion, as boldface, red, and contrast lettering have each been shown to facilitate name differentiation (Gabriele, 2006; Or & Wang, 2014).

Various error-producing conditions compound the issue of drug similarity (Reason, 2001). Researchers have suggested that future studies should examine the effectiveness of text enhancement while considering other factors contributing to error (Filik et al., 2006; Irwin et al., 2013). Therefore, we examined the effects of text enhancement in combination with three other factors, namely identical prescription-package names, visual cues, and verbal provocation, on a visual search of look-alike drug names. The following sections introduce these three factors.

Identical Prescription-Package Names

Text enhancement can be used to highlight drug information on prescriptions (Mullen et al., 2018) and improve the readability of drug package labels (Hellier et al., 2006; Hellier, Tucker, Kenny, Rowntree, & Edworthy, 2010). However, very few studies have considered the simultaneous use of the same form of text enhancement to present drug names on prescriptions and drug packages. A drug search often requires clinicians to read a prescription, memorize the prescribed drug name, visually scan an array of drug packages, recall the drug name, and compare it with the names on drug package labels until the memory-matched name is found. The use of identical name formats on both drug packages and prescriptions may facilitate drug searches by reducing the effort required for name comparison. Empirical studies were needed to evaluate this possibility.

Visual Cues

Typically, a visual search for a target begins by decoding simple item features (e.g., colors) over a specific visual field (Beck, Hollingworth, & Luck, 2012; Vickery, King, & Jiang, 2005), followed by a serial process that focuses attention on observed items with high levels of target probability (Liversedge & Findlay, 2000; Najemnik & Geisler, 2005; Shomstein & Yantis, 2002; Treisman, 1982; Treisman & Gelade, 1980). The use of a spatial cue to direct attention to a potential target location would enable the searcher to detect and recognize the target more rapidly and accurately (Muller & Rabbitt, 1989; Posner, 1980). Accordingly, we believed that a spatial cue (e.g., a red flashing visual signal) could facilitate accurate searches for drug names. However, this factor has rarely been examined in empirical studies.

Verbal Provocation

Verbal provocation (e.g., statements such as “hurry up” or “what’s taking you so long?”) occurs when clinicians are urged verbally to hasten their drug searches. In contrast to time pressure, which requires individuals to complete a task within a specific time constraint (de Pontbriand, Allender, & Doyle, 2008), verbal provocation does not specify a time limit. However, both time pressure and verbal provocation have common effects, such as increased physiological and psychological stress (Wahlström, Hagberg, Johnson, Svensson, & Rempel, 2002). These types of stress can affect the efficiency of information processing (Rendon-Velez et al., 2016) and further impair decision making (Starcke, Wolf, Markowitsch, & Brand, 2008). In the context of name confusion, a previous study demonstrated the adverse effect of time pressure on perceptions of look-alike drug names (Irwin et al., 2013). Given the aforementioned common effects of time pressure and verbal provocation, we believed that the latter would have a similarly adverse effect on drug name perception. For example, verbal provocation may alter a clinician’s attitude toward risk, leading them to ignore important information and increase the speed of a drug search. These changes could increase the risk of medication error. Empirical studies were required to evaluate the effect of verbal provocation.

Simulation

Most text enhancement studies have used computer-based tasks (e.g., DeHenau et al., 2016; Filik, Purdy, Gale, & Gerrett, 2004; Filik et al., 2006; Irwin et al., 2013), whereas very few have used simulations. A simulation intended to recreate the physical and task-oriented context of a drug search would require the individual to perform tasks in a physical setting that closely resembles a real-life situation (Estock et al., 2018). Moreover, a simulation would not involve actual patients, and therefore any errors would not cause harm to patients (Dieckmann, Clemmensen, Sorensen, Kunstek, & Hellebek, 2016). Accordingly, this study designed and used a simulation to examine the main and interacting effects of text enhancement, identical prescription-package names, visual cues, and verbal provocation on drug searches.

Eye Tracking and Visual Attention

Many tasks critical to safety, such as medication dispensing, require an effective visual search and detection procedure. Accordingly, researchers have aimed to understand how individuals pay visual attention to task-related objects by examining the effectiveness of their search and detection practices, with the intent to improve human-task interfaces and task performance safety (e.g., Schulz et al., 2011). For instance, in one health care study, eye movement data (e.g., durations of eye fixations and saccadic amplitudes) were collected from 15 anesthetists using a head-mounted eye tracker and used as indicators of the workloads under different task conditions (Schulz et al., 2011). That study demonstrated the feasibility of using an eye tracker to capture eye gaze behavior and elucidate visual attention. Studies of look-alike drug names should therefore adopt eye-tracking technology to examine individuals' visual attention and eye gaze patterns when searching for drugs. However, this technology was used in only one previous study by Filik et al. (2004). Therein, the participants' eye movements were tracked and recorded during tests in which the participants were asked to search for a target drug name in an array of similar drug names. In some tests, the differing letters were highlighted using Tall Man lettering. The participants' eye-tracking data revealed that their search performance improved when Tall Man lettering was used. However, the study did not examine other types of text enhancement. Moreover, as that study was based on an arbitrarily small sample size (20 participants) of individuals with no professional background in health care or medication knowledge (i.e., students and office staff), the results may not be generalizable to people who work primarily with confusingly named drugs in clinical practice (e.g., frontline nurses) (Filik et al., 2004). To address these research gaps, this study tested nurses and used eye-tracking technology to track their eye gaze behaviors while they searched for look-alike drug names.

EXPERIMENT 1

Method

Design. Experiment 1 was based on a four-way, repeated-measures design. Four independent variables were examined: text enhancement, identical prescription-package names (identical or not identical), visual cues (present or absent), and verbal provocation (present or absent). Specifically, the five text enhancement methods included lowercase (i.e., no text enhancement; for example, lamivudine vs. lamotrigine), Tall Man (e.g., lamiVUDine vs. lamoTRIgine), reverse Tall Man (e.g., LAMIvudINE vs. LAMOtriGINE), boldface plus red (e.g., lami[**vud**]ine vs. lamo[**tri**]gine; the letters in brackets are presented in red boldface), and boldface plus contrast (e.g., lami**vud**ine vs. lamo**tri**gine). Identical prescription-package names indicated that the appearance of the drug name in a prescription was identical to the name printed on the drug package. The visual cue was a red flashing light-emitting diode (LED) that indicated the row of a pharmacy shelf where the target drug was placed. The verbal provocation was a prerecorded, simulated voice saying "hurry up, work faster," which was played once every 3 s.

Each participant was asked to read a drug name in an e-prescription, memorize the name, and search/locate the needed drug from an array placed on a pharmacy shelf mock-up.

Recognition error and response time were used as measures of drug search performance. Recognition error was defined as the percentage of wrong searches. A wrong search was recorded if the participant located a drug that was believed to be the needed drug, but was, in fact, a wrong drug. The response time in milliseconds was defined as the time difference between two time-points: (1) when the participant clicked the “start” button on a computer application (see the “Apparatus” section) because they believed they had memorized the drug name in an e-prescription and (2) when the participant scanned the barcode on the package that they assumed contained the needed drug. We also measured the participants’ mental effort and perceived likelihood of error during the drug searches, using a questionnaire method based on a previous study (Holden et al., 2010). The questionnaire was delivered in an electronic format and comprised two items to measure mental effort (“how much mental effort is required for this search task?” and “to what extent does this search task require concentration?”) and a single item to measure the error likelihood (“how likely is it that you made a wrong decision in this search task?”). All participants’ responses were scored on a 7-point Likert-type scale (range: 1 = “not at all” to 7 = “a great deal”).

Participants. Forty nurses (32 females and eight males; mean age = 21.9 years, *SD* = 1.5 years) were recruited through flyers and emails to participate in Experiment 1. All participants provided informed consent before the experiment. All participants reported at least 2 years of experience in nursing, normal or corrected-to-normal vision, and normal color vision. Each participant received an incentive of HK$300 (approximately US$40) for participating.

Apparatus. A pharmacy shelf mock-up was built and set up in a sound-attenuated and temperature- and light-controlled experimental room. Each participant was given a wireless portable scanning gun and instructed to scan the barcode of a drug package they located on the shelf. An application developed using Visual Basic 6.0 was run on a desktop computer with a 23-in. LCD monitor (resolution: 1280 × 1024 pixels). This application was used to present the e-prescriptions and record the participants’ responses to drug searches (i.e., recognition error, response time, perceived mental effort, and perceived error likelihood).

Stimuli. The drug name stimuli were based on the lists of 174 look-alike drug name pairs published by the FDA and ISMP (2016). We used Kondrak and Dorr’s (2006) BI-SIM measure to calculate the level of similarity between the two names in each of the 174 pairs. The BI-SIM algorithm was detailedly explained in the paper by Kondrak and Dorr (2006). The median BI-SIM value herein was 0.6, which we used to define low (BI-SIM ≤0.6) and high similarity (BI-SIM >0.6 to <1). Because word length may be used as a search cue, we removed name pairs in which the lengths of the two names differed by more than one letter. Also, as a longer name length could increase the likelihood of a name differentiation error (Emmerton & Rizk, 2012; Filik et al., 2004), we only included pairs in which the drug names comprised seven to 13 letters. Short and long name lengths were then defined as seven to nine and 10 to 13 letters, respectively. After these exclusions, 110 drug name pairs were retained. Of these, 41 pairs had a short length and 69 had a long length. Also, 52 pairs corresponded to low similarity and 58 to high similarity. We randomly selected 60 drug name pairs as our experimental stimuli: 11 pairs with a short length and low similarity, 11 pairs with a short length and high similarity, 19 pairs with a long length and low similarity, and 19 pairs with a long length and high similarity. Mock drug packages were then created to present the drug name stimuli in 16-point Arial font. These mock drug packages were alphabetically placed on the pharmacy shelf mock-up.

Procedure. A trained research assistant (RA) began the experiment by introducing the background of the study to the participants. The participants’ demographic information was subsequently collected using a questionnaire. The experiment comprised two phases: a 15-trial practice phase and a 160-trial test phase. To familiarize the participants with the study procedure, the 15 practice trials followed the same format as the test trials but used words unrelated to drug names (e.g., “familiar” and “family”). After the practice trials, the participants were given a 3-min break before commencing the 160

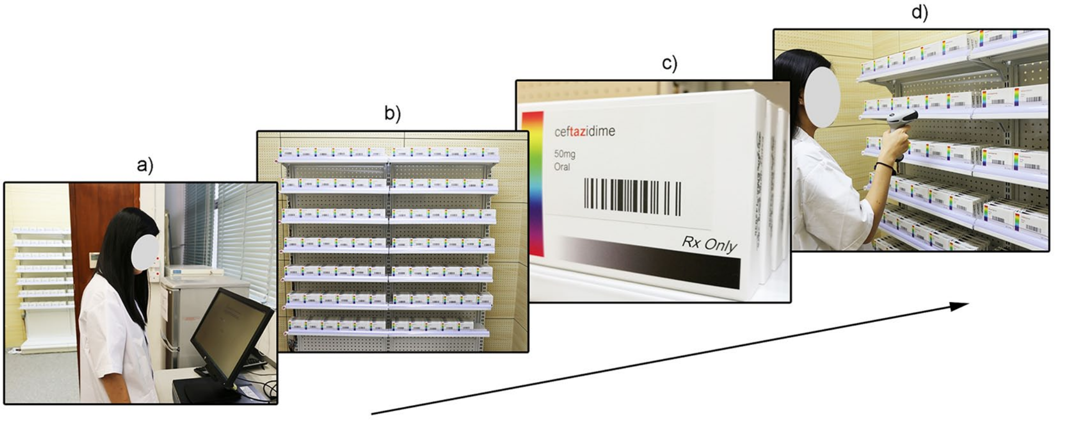

Figure 1. The drug search procedure used in Experiment 1: (a) Read and memorize a drug name presented in an e-prescription, (b) enter the experimental room containing the pharmacy shelf mock-up, (c) visually search/locate the needed drug, and (d) scan the barcode on the drug package label.

test trials of drug name stimuli. Four trials (four drug name pairs randomly selected from the Four Length × Similarity Combinations) were conducted per combination of the independent variables (Five Text Enhancement Conditions × Two Identical Prescription-Package Names Conditions × Two Visual Cues Conditions × Two Verbal Provocation Conditions). Only the test trial data were used in data analyses.

Figure 1 depicts the drug search procedure used in Experiment 1. In each drug search, the participant was asked to read and memorize a drug name presented in an e-prescription, with no time constraint. Once the participant thought they had memorized the drug name, they were asked to click the "start" button on the computer application. Next, the participant entered the experimental room with a scanning gun in hand, where they were required to find the drug with the memorized name on the pharmacy shelf mock-up as quickly and accurately as possible. Once they located the needed drug, they were asked to use the scanning gun to scan the barcode on the drug package. The search ended when the participants finished scanning the barcode. Upon completing each search, the participant rated their perceived mental effort and error likelihood using the aforementioned electronic questionnaire.

Based on the text enhancement variable (five levels), we divided the 160 test trials into five blocks and counterbalanced the testing sequence using a Latin Square (MacKenzie, 2013). Within each block, the 32 trials were also randomized to reduce order effects. After each block, the participant rested for 3 min. The entire experiment lasted approximately 100 to 120 min.

Data analysis. A repeated-measures analysis of variance (ANOVA) was used to examine the main effects of the independent variables and their interactions. Bonferroni post hoc tests were performed for pairwise comparisons. A partial eta squared (η_p^2) was used for the effect size measurement, with values of 0.01, 0.06, and 0.14 indicating small, medium, and large effects, respectively.

Results and Discussion

Table 1 presents the mean values (*SD*s) of the recognition error, response time, perceived mental effort, and perceived error likelihood according to each independent variable.

Recognition error. Text enhancement, identical prescription-package names, visual cues, and verbal provocation had no significant main effects on the recognition error (all p values > .05).

Response time. Visual cues had a significant main effect on the response time, $F(1, 39) = 74.597$, $p < .0005$, $\eta_p^2 = 0.657$. When a visual cue was used, the participants' response time decreased significantly from 7,682.2 ms (*SD* = 1,913.4 ms) to 5,777.2 ms (*SD* = 933.3 ms).

TABLE 1: Mean Values (*SD*s) of the Recognition Error, Response Time, Perceived Mental Effort, and Perceived Error Likelihood According to the Independent Variable Level

Independent Variables	Levels	Recognition Error (%)	Response Time (ms)	Perceived Mental Effort (Scale: 1 to 7)	Perceived Error Likelihood (Scale: 1 to 7)
Text enhancement	Lowercase	2.2 (0.024)	6,441.9 (1,596.4)	1.90 (0.58)	1.32 (0.38)
	Tall Man	2.7 (0.043)	6,888.0 (2,007.7)	2.00 (0.65)	1.36 (0.47)
	Reverse Tall Man	2.0 (0.030)	7,004.0 (1,670.7)	2.05 (0.66)	1.41 (0.45)
	Boldface plus red	1.9 (0.034)	6,565.1 (1,687.3)	1.94 (0.66)	1.30 (0.39)
	Boldface plus contrast	1.4 (0.028)	6,749.6 (1,323.7)	1.94 (0.60)	1.31 (0.40)
Identical prescription-package names	Identical	1.9 (0.023)	6,605.9 (1,219.0)	1.97 (0.58)	1.33 (0.37)
	Not identical	2.1 (0.023)	6,853.5 (1,540.2)	1.96 (0.60)	1.35 (0.39)
Visual cues	Absent	2.3 (0.026)	7,682.2[a] (1,913.4)	2.06[b] (0.65)	1.38[c] (0.41)
	Present	1.8 (0.023)	5,777.2[a] (933.3)	1.87[b] (0.57)	1.30[c] (0.36)
Verbal provocation	Absent	2.0 (0.025)	6,783.3 (1,403.2)	1.91[d] (0.58)	1.32 (0.36)
	Present	2.0 (0.022)	6,676.1 (1,351.8)	2.02[d] (0.61)	1.36 (0.40)

Note. Values labeled with superscript letters a, b, c, or d differ significantly at a level of .01.

Perceived mental effort. Visual cues and verbal provocation had significant main effects on the perceived mental effort, $F(1, 39) = 12.858$, $p = .001$, $\eta_p^2 = 0.248$; $F(1, 39) = 17.393$, $p < .0005$, $\eta_p^2 = 0.308$, respectively. The use of a visual cue significantly reduced the participants' perceived mental effort from 2.06 ($SD = 0.65$) to 1.87 ($SD = 0.57$). In addition, the participants perceived significantly more mental effort when they were verbally provoked during the drug search ($M = 2.02$, $SD = 0.61$), compared with the unprovoked condition ($M = 1.91$, $SD = 0.58$).

Perceived error likelihood. Visual cues had a significant main effect on the perceived error likelihood, $F(1, 39) = 8.851$, $p = .005$, $\eta_p^2 = 0.185$. The error likelihood decreased significantly from 1.38 ($SD = 0.41$) to 1.30 ($SD = 0.36$) when the visual cue was applied.

Interactions. No significant interactions were observed among the independent variables (all p values > .05). Figure 2 depicts the associations of text enhancement with visual cues and verbal provocation, as the latter two variables had significant main effects on the response time, perceived mental effort, and perceived error likelihood. Similar text enhancement effect patterns were observed between the two visual cue levels and between the two verbal provocation levels.

EXPERIMENT 2

Method

Design. Experiment 2 was based on a four-way, repeated-measures design. The independent variables were identical to those tested in Experiment 1 except for one operational difference in the visual cue. In Experiment 2, we modified the visual cue by presenting a red flashing dot on a computer application designed for data collection (see "Apparatus" section). We used a computer-based drug search task to evaluate the independent variables. The participant was required to read and memorize a drug name (i.e., "target") in an e-prescription and then locate the target from an array of computer images of mock drug packages. The participant's eye movements were tracked and recorded during this search.

The dependent variables in Experiment 2 were the fixation count, fixation duration, and pupil diameter, which were used to reflect the

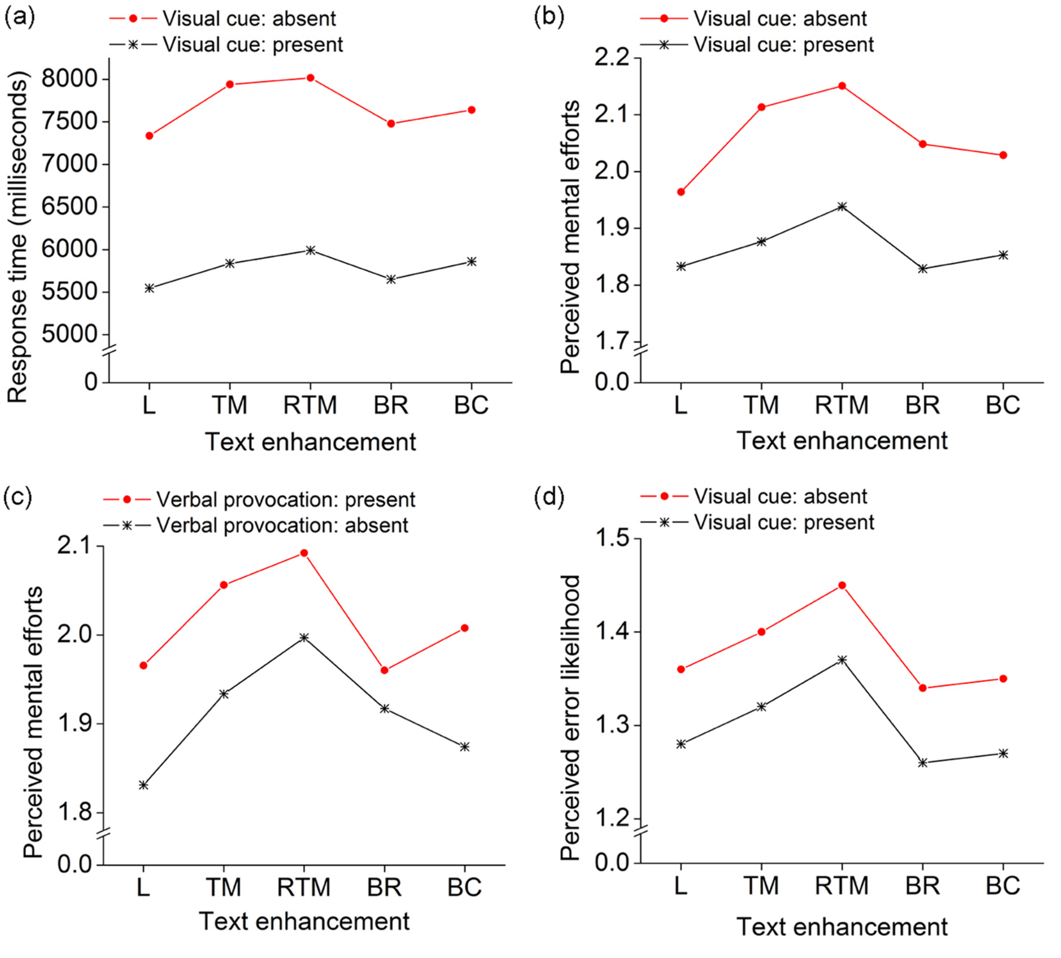

Figure 2. Associations of text enhancement with visual cues on (a) response time, (b) perceived mental effort, and (d) perceived error likelihood; and with verbal provocation on (c) perceived mental effort. L = lowercase; TM = Tall Man; RTM = reversed Tall Man; BR = boldface plus red; BC = boldface plus contrast.

participants' eye gaze behaviors when they performed drug searches. The fixation count was measured as the total number of times the participant's visual attention was fixated on the package label of the target drug, which we defined as the area of interest (AOI). The total time spent fixating on an AOI in milliseconds was recorded as the fixation duration. The mean value of the pupils in both eyes during the fixation of visual attention on an AOI was recorded as the pupil diameter in millimeters.

Participants. Forty nurses (34 females and six males; mean age = 26.3 years, *SD* = 1.5 years) who did not participate in Experiment 1 were recruited for this experiment through flyers and emails. The participants reported at least 2 years of experience in nursing, normal or corrected-to-normal vision, and normal color vision. Each participant received an incentive of HK$200 (approximately US$26) for participating. All participants provided written informed consent prior to the experiment.

Apparatus. An application developed using Visual Basic 6.0 was run on a desktop computer with a 19-in. flat-screen color monitor (resolution: 1,280 × 1,024 pixels). The application was used to present drug name stimuli. The fixation count, fixation duration, and pupil diameter

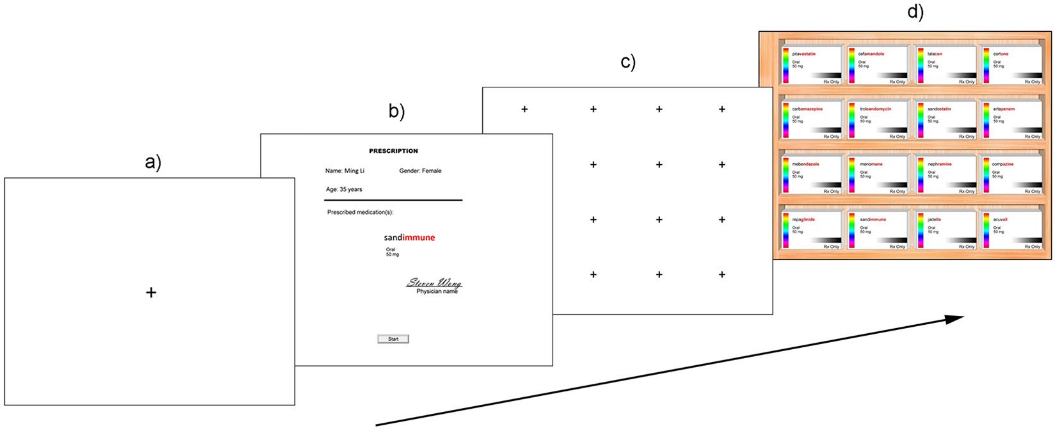

Figure 3. The drug search procedure used in Experiment 2: (a) Focus on the plus sign for 1 s, (b) read and memorize a drug name presented in an e-prescription, (c) observe 16 plus signs for 1 s, and (d) visually locate the target drug and click the corresponding package label.

data were measured and recorded using an SMI RED250 mobile eye tracker (SMI, Germany) designed to capture and analyze gaze behaviors in real-time. The data were processed using BeGaze SMI software (version 3.6), which was supplied with the eye tracker.

Stimuli. The 60 look-alike drug name pairs tested in Experiment 2 were the same as those used in Experiment 1. In each drug search trial, we presented the participants with one look-alike name pair and 14 distracting drug names. The latter were randomly selected from a list of common drug names published by the U.S. National Institutes of Health (2016). The drug names were presented in 16-point Arial font on computer images of the mock drug packages.

Procedure. The procedure for Experiment 2 was the same as that used for Experiment 1, except that the drug search task was computer-based. Figure 3 shows the steps used in Experiment 2. During each drug search task, the participant was first presented with a plus sign (+) on the computer screen to indicate where a drug name would appear. After 1 s, the plus sign was replaced by an e-prescription with a drug name (i.e., "target"). The participant was asked to read and memorize the drug name, with no time constraints. When they believed that they had memorized the drug name, they were asked to click a "start" button on the computer application. Subsequently, the participant was presented with a mask of 16 plus signs to indicate where drug names would appear on the screen. One second later, the 16 plus signs were replaced by one drug name pair and 14 distracting drug names. The participant was then required to find the target and click the corresponding drug package label as quickly and accurately as possible. The trial ended when the participant finished clicking the package of a drug that was believed to be the target drug. The participant rested for 1 min after finishing each of the five stimuli blocks (please see Experiment 1 for more details about the stimuli blocks). Before each block, the eye tracker was calibrated to ensure a correct setup. The experiment lasted approximately 60 min.

Data analysis. We applied the same data analysis methods used in Experiment 1 to analyze the main effects and interactions of the independent variables on fixation count, fixation duration, and pupil diameter.

Results and Discussion

Table 2 presents the mean values (*SD*s) of the fixation count, fixation duration, and pupil diameter according to the independent variables.

Fixation count. Identical prescription-package names and visual cues had significant main effects on the fixation count, $F(1, 39) = 6.262$, $p = .017$, $\eta_p^2 = 0.138$; $F(1, 39) = 120.516$, $p < .0005$, $\eta_p^2 = 0.756$, respectively. When the drug names were formatted identically on prescriptions and

TABLE 2: Mean Values (*SDs*) of the Fixation Count, Fixation Duration, and Pupil Diameter According to the Level of Each Independent Variable

Independent Variables	Levels	Fixation Count	Fixation Duration (ms)	Pupil Diameter (mm)
Text enhancement	Lowercase	1.74 (0.36)	856.8 (217.8)	3.46 (0.35)
	Tall Man	1.84 (0.45)	873.5 (268.6)	3.45 (0.36)
	Reverse Tall Man	1.86 (0.45)	931 (299.7)	3.47 (0.37)
	Boldface plus red	1.77 (0.33)	873.3 (227.9)	3.45 (0.38)
	Boldface plus contrast	1.78 (0.41)	914.9 (273)	3.50 (0.38)
Identical prescription-package names	Identical	1.77^{a} (0.36)	877.2^{b} (233.7)	3.47 (0.36)
	Not identical	1.82^{a} (0.36)	902.6^{b} (234.4)	3.46 (0.36)
Visual cues	Absent	2.02^{c} (0.41)	$1{,}013.6^{d}$ (249.9)	3.49^{e} (0.35)
	Present	1.58^{c} (0.33)	766.2^{d} (243.3)	3.44^{e} (0.36)
Verbal provocation	Absent	1.78 (0.35)	895.4 (233.8)	3.46 (0.36)
	Present	1.81 (0.37)	884.4 (234.1)	3.47 (0.36)

Note. Values labeled with a superscript a or b differ significantly at the .05 level. Values labeled with a superscript c, d, or e differ significantly at the .01 level.

drug packages, the fixation count decreased significantly from 1.82 (*SD* = 0.36) to 1.77 (*SD* = 0.36). When a visual cue was used, the fixation count also decreased significantly from 2.02 (*SD* = 0.41) to 1.58 (*SD* = 0.33).

Fixation duration. Identical prescription-package names and visual cues also had significant main effects on the fixation duration, $F(1, 39) = 6.550$, $p = .014$, $\eta_p^2 = 0.144$; $F(1, 39) = 87.427$, $p < .0005$, $\eta_p^2 = 0.692$, respectively. When the drug names were formatted identically on the prescription and drug package, the fixation duration decreased significantly from 902.6 ms (*SD* = 234.4 ms) to 877.2 ms (*SD* = 233.7 ms). When a visual cue was used, the fixation duration decreased significantly from 1,013.6 ms (*SD* = 249.9 ms) to 766.2 ms (*SD* = 243.3 ms).

Pupil diameter. Visual cues had a significant main effect on the pupil diameter, $F(1, 39) = 37.219$, $p < .0005$, $\eta_p^2 = 0.488$. The pupil diameter decreased significantly from 3.49 mm (*SD* = 0.35 mm) to 3.44 mm (*SD* = 0.36 mm) when a visual cue was used.

Interactions. Significant interactions between text enhancement and identical prescription-package names were observed for the fixation count, $F(4, 156) = 3.171$, $p = .015$, $\eta_p^2 = 0.075$, and fixation duration, $F(4, 156) = 4.809$, $p = .001$, $\eta_p^2 = 0.110$. No other significant two-way interactions were identified (all p values > .05). Figure 4 depicts the associations of text enhancement with identical prescription-package names and visual cues, as the latter variables had significant main effects on the fixation count, fixation duration, and pupil diameter.

GENERAL DISCUSSION

This study examined the effectiveness of text enhancement, identical prescription-package names, visual cues, and verbal provocation in look-alike drug name search and differentiation. The findings can inform the development of strategies and methods designed to reduce confusion between look-alike drug names.

Text Enhancement

The results of both experiments suggest that text enhancement does not improve the outcomes of nurses' visual searches of look-alike drug names. Here, we will discuss each text enhancement method in detail. Consistent with previous studies (Schell, 2009; Zhong, Feinstein, Patel, Dai, & Feudtner, 2016), we found that Tall Man lettering had a nonsignificant

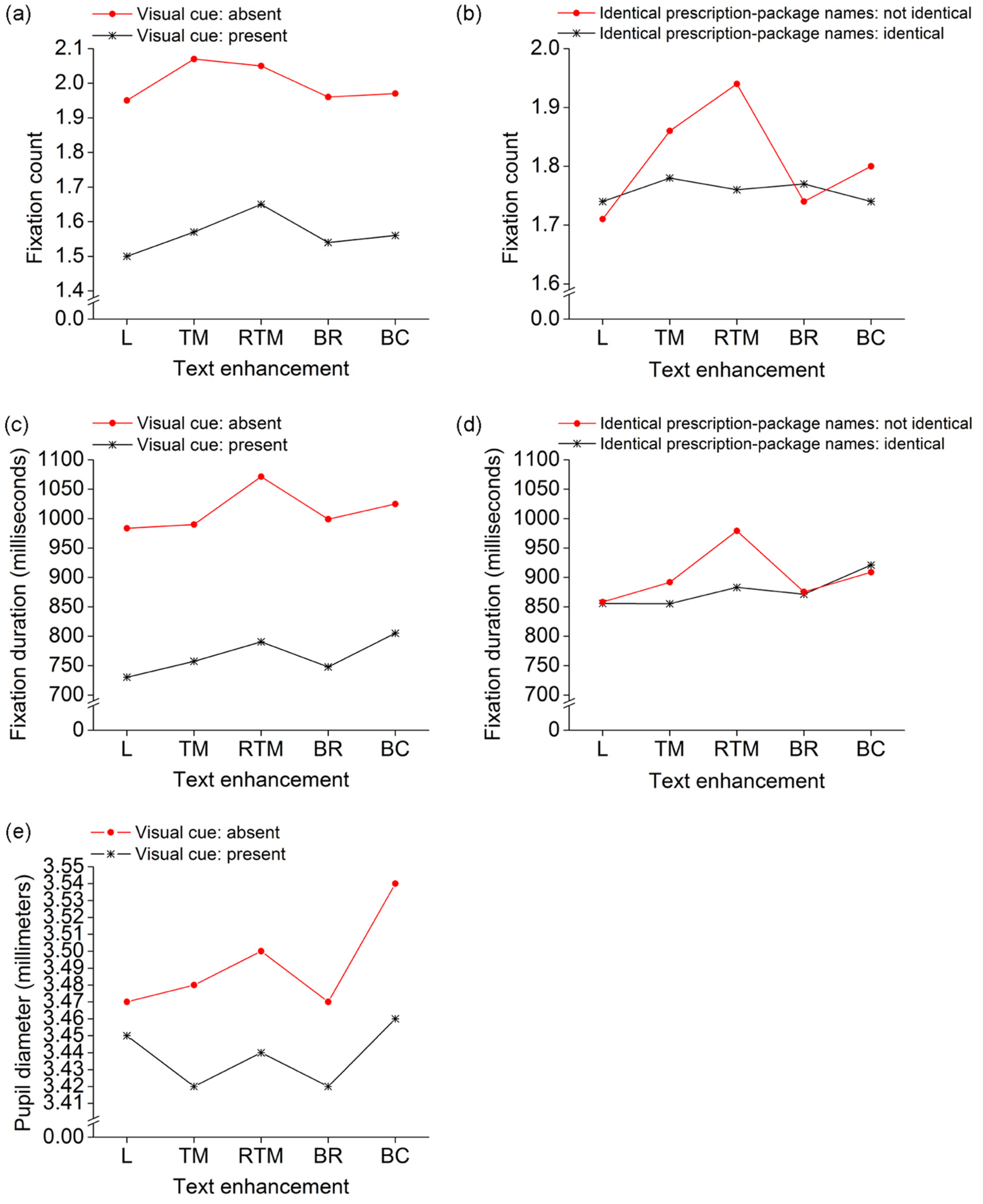

Figure 4. Associations of text enhancement with visual cues on (a) fixation count, (c) fixation duration, and (e) pupil diameter; and with identical prescription-package names on (b) fixation count and (d) fixation duration. L = lowercase; TM = Tall Man; RTM = reverse Tall Man; BR = boldface plus red; BC = boldface plus contrast.

effect on name perceptions. Eye movement data also indicated that the use of Tall Man lettering did not alter nurses' eye gaze behaviors, in contrast to Filik et al. (2004), who reported that this method reduced the fixation time and fixation count of non–health care professionals. We further found that reverse Tall Man lettering led to less satisfactory performances when compared with lowercase text alone (see Tables 1 and 2). This format may have disrupted word recognition and perception (Mayall, 2002; Mayall & Humphreys, 1996). Specifically, when a nurse views a name in reverse Tall Man lettering, he or she may gaze at the uppercase letters first, as these are more legible than lowercase text (Sheedy et al., 2005). To memorize the different letters presented in lowercase, the nurse must move their eye gaze from uppercase to lowercase letters, which would require extra time and effort. Furthermore, boldface, red, and contrast text have each been reported to perform better than lowercase in name differentiations (Gabriele, 2006; Or & Wang, 2014). However, in our present study, the combinations, that is, boldface plus red and boldface plus contrast we tested herein, did not improve drug searches when compared with lowercase text. In general, the nonsignificant effects of text enhancement may be attributable to each participant performing only 160 drug search trials. The wrong drug error rate, 0.13%, was relatively small and did not achieve statistical significance (Flynn, Baker, & Carnaham, 2003). The nonsignificant findings may also be attributable to the manner in which we defined the AOI when extracting eye movement data. According to a previous study (Filik et al., 2004), we treated the drug label, rather than the enhanced portion of the drug name, as the AOI, which may have led to an underestimation of the effect of text enhancement on eye gaze behaviors. Furthermore, the percentage improvements by text enhancement in recognition error should be noted, even these improvements were not statistically significant. For example, boldface plus contrast reduced recognition error by 0.8% as compared with lowercase. At first glance, the percentage improvement seems to be low. However, given that a large number of prescriptions are written annually (e.g., 3 billion in the U.S. alone; Lambert, Lin, & Tan, 2005), and with a wrong drug error rate of 0.13% (Flynn et al., 2003), a small percentage improvement would reduce a large number of wrong drug errors.

Identical Prescription-Package Names

The findings from Experiment 2 revealed that the use of identical prescription-package names significantly reduced the fixation count by 2.8% and the fixation duration by 2.9%. In other words, nurses could extract and process name information more efficiently when the names on prescriptions and packages had identical appearances. During a drug search, nurses must frequently retrieve name information from memory and compare it with information on drug packages until they find the target item. The use of identical name formats on prescriptions and drug packages would, thus, reduce the time and effort required to compare names before confirming a drug search. Therefore, we recommend that drug names should be printed in the same format on prescriptions and drug packages. This recommendation could be implemented through collaborations among the pharmaceutical companies that design and print drug packages, system software developers who redesign e-prescriptions, and health care organizations that reformat drug names on shelf labels and paper-based prescriptions.

Visual Cues

This study showed that a visual cue significantly reduced the nurses' response time by 24.8% (i.e., 1,905 ms). This finding further confirms the effects of cues during visual searches (Muller & Rabbitt, 1989; Posner, 1980). Moreover, the nurses perceived reductions in mental effort (decreased by 9.2%) and error likelihood (decreased by 5.8%) when a visual cue was presented. As the nurses were informed before the experiment that a visual cue would indicate the potential location of the target, they may have been more confident that they would identify the target on the highlighted shelf row. Furthermore, the improved eye gaze behaviors (fixation count reduction of 21.8%, fixation duration reduction of 24.4%) indicated that the nurses could search for drugs more easily with assistance from a visual cue. Given our findings and the high cost required to equip small- and medium-scale pharmacies with an automated pharmacy system (Le, 2008), an efficient and economic technique such as visual cues may aid health care providers during drug searches and enhance medication safety. Therefore, this method warrants further promotion.

Verbal Provocation

Verbal provocation may impose psychological pressure on an individual during a target search task. Such pressure can divert their attention, increase their mental effort, and induce them to search for the target objects hastily and erroneously (Cella, Dymond, Cooper, & Turnbull, 2007; DeDonno & Demaree, 2008). However, this study only revealed a significantly positive effect of verbal provocation on the perceived mental effort, which increased by 5.8% when nurses were verbally provoked during drug searches. No other significant effects of this factor were observed. Nurses may become accustomed to working under verbal provocation from colleagues, managers, or customers and thus develop the ability to withstand pressure. Therefore, their actual performance is not affected even though they perceive an increase in mental effort. Moreover, our findings may have been affected by the type of simulated verbal provocation (i.e., a recording). After several test trials, the nurses may have treated the verbal provocation as external noise and ignored it. This may have led to an underestimation of the adverse effects of verbal provocation. This factor should be examined further before drawing any conclusions.

Study Limitations

The mock drug packages used in these experiments contained less information than actual drug packages. However, we attempted to minimize this limitation by including information about the drug name, dosage, administration route, Rx status, colorful gradient and black strips, and a barcode (Figures 1 and 3). Our simulated packages provided more information than the packages used in previous studies of look-alike drug names (e.g., DeHenau et al., 2016; Filik et al., 2004; Irwin et al., 2013). Moreover, we designed our study to focus only on drug names and to investigate how the participants paid visual attention to the areas of specific interest. Another limitation involved the use of a nonexhaustive list of confusing look-alike drug names in our study. However, we used a systematic and random approach to select the drug names as experimental stimuli and thus avoid bias.

Implications

This study extends the current human factor-related literature on drug safety from the following perspectives. First, three new text enhancement methods (reversed Tall Man lettering, boldface plus red, and boldface plus contrast) were examined empirically for the first time. Although these methods had nonsignificant effects on visual searches of look-alike drug names, some encouraging points were found and discussed, such as the use of boldface plus red as a format with a potentially high ability to facilitate nurses' visual searches. Further investigations of combinations of different format types are needed. Second, regarding methodological design, this study provided examples of the use of eye-tracking and simulation techniques to address drug safety issues. We recommend the use of eye movement data in future human factor studies of visual searches, as such quantitative data can demonstrate how individuals pay visual attention to objects of interest. This study also presented an experimental design involving the use of a simulation in drug safety research. This design placed the participants (e.g., nurses) in a physical setting that closely resembled a real-world situation (e.g., pharmacy) to ensure that the outcomes would be more realistic when compared with nonsimulation designs. Third, regarding multiple factors, this study extended traditional text enhancement studies by incorporating different environmental factors (e.g., visual cues and verbal provocation). As no drug safety issue can be attributed to a single factor, we strongly recommend future human factor studies of drug safety following the trend of examining multiple factors simultaneously.

Regarding practical implications, our findings do not support the use of text enhancement for reducing errors caused by look-alike drug names. Text enhancement may only emphasize name confusion but cannot reduce memory-related confusion (Filik et al., 2006). Therefore, measures intended to reduce errors of name confusion should not be based primarily on the orthographic highlighting of differences in look-alike drug names. Our study differed from previous studies that used expensive error prevention approaches, including automated dispensing drawers (Cooper, Barron, Gallagher, & Sciarra, 2007), pharmacy robots (Franklin, O'Grady, Voncina, Popoola, & Jacklin, 2008), and barcode technology (Poon et al., 2006), and the results provide empirical evidence to support some economic strategies for reducing medication errors. For example, pharmaceutical companies, system software developers, and health care organizations should collaborate to present drug names identically on prescriptions and drug packages. In addition, pharmacies should be equipped with visual cue systems that facilitate drug searches by health care providers.

CONCLUSION

The two above-described experiments provide empirical evidence to support the redesign of systems and procedure management with the intent to reduce medication errors and promote the selection of proper drug packaging and labeling approaches. Notably, we did not find that typographically emphasizing the differing letters of look-alike drug names yielded any significant improvements. However, we propose several practical and efficient strategies for facilitating accurate drug searches, such as the use of identical name appearances on prescriptions and drug packages and of visual cues to direct visual attention, as well as avoiding the verbal provocation of nurses during their drug searches.

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KEY POINTS

- Highlighting the primary differences of look-alike drug names did not significantly improve nurses' drug searches.
- Identical name appearances on prescriptions and drug packages improved nurses' eye gaze behaviors during drug searches.
- A visual cue significantly improved nurses' search performances and eye gaze behaviors during drug searches.
- Nurses perceived more mental effort when they were verbally provoked to hasten their drug searches.

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