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Tallman lettering as a strategy for differentiation in look-alike, sound-alike drug names: The role of familiarity in differentiating drug doppelgangers

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ABSTRACT

Tallman lettering, capitalizing the dissimilar portions of easily confused drug names, is one strategy for reducing medication errors. We assessed the efficacy of Tallman lettering in a visually complex environment using a change detection method with healthcare providers and laypeople. In addition, the effect of familiarity with the drug name was assessed using a subset of responses collected from healthcare providers.

Both healthcare providers and laypeople detected changes in confusable pairs of drug names more often ($P < 0.0001$) and more quickly ($P < 0.05$) when changes were presented in Tallman lettering, though the benefits were more pronounced for healthcare providers ($p < 0.05$). Familiarity with both drug names in a confusable pair mitigated the benefit of Tallman lettering. Results are discussed in terms of bottom-up and top-down attentional systems for processing of information in the context of the varied healthcare environments.

1. Introduction

According to The Institute of Medicine (IoM), medical errors are the 8th leading cause of death in the US, resulting in anywhere from 44,000 to 98,000 each year (Aspden et al., 2006; Kohn et al., 2000); data from other countries suggests that this problem is also common elsewhere. (Vincent et al., 2001; Department of Health (2007); Davis et al., 2001; Anderson, 2007). The most common type of medical error is a medication error, and the IoM has attributed several thousand deaths each year to these types of events (Aspden et al., 2006). As such, approaches that reduce medication errors have the potential to substantially impact the well-being of society.

Medication errors can occur in virtually all care settings and during almost every stage of care, including: prescribing, transcribing, dispensing, administering, complying and monitoring (Franklin, 2014). In addition, medication errors can be committed by varied actors involved in patient care, including: pharmacists, physicians, nurses, supportive personnel, students, clerical staff, administrators and pharmaceutical manufacturers as well as patients and their caregivers (American Society of Health-System Pharmacists (1993)). Finally, numerous factors contribute to medication errors, such as illegible handwriting, incomplete knowledge of drug names, newly available products and similar packaging and labeling (The Joint Commission et al., 2007). While each of these sources influences the potential for error, one major contributing factor is confusion created by look-alike, sound-alike drug names. In fact, Lambert estimates that 25% of error reports (Lambert et al., 1999) to the Medication Error Reporting Program involve look-alike, sound-alike drug names, names which are easily confused. Members of the research community (Lambert et al., 1999) and official agencies (American Society of Health-System Pharmacists (1993); The Joint Commission et al., 2007) have concluded confusable drug names to be one of the most common causes of medication error, and an issue of significant global concern.

In response, a number of design techniques have been explored for the purpose of differentiating look-alike, sound-alike drug

Abbreviations: US Food and Drug Administration, FDA; Institute of Medicine, IoM; Institute for Safe Medication Practices, ISMP; National Center for Patient Safety, NCPS.

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names. Many of these techniques include format manipulations of drug names on labels employing the use of: italics, bold type, underlining differing fonts and styles of typography (Darker et al., 2011; Gabriele, 2006). Tallman lettering constitutes one such approach. When presented in a Tallman format, the unique portions of confusable names are capitalized with the intention of increasing their discriminability (Institute for Safe Medication Practices, 2008). For example, Tallman lettering would style the look-alike drug name pair chlorpromazine and chlorpropamide as chlorproMAZINE and chlorproPAMIDE.

This approach has been endorsed by many recognized organizations. The World Health Organization (WHO) and The (US) Joint Commission have recommended the use of Tallman lettering to differentiate look-alike, sound-alike drug names (The Joint Commission et al., 2007), and, as part of its Name Differentiation Project, the US FDA requested that manufacturers revise the labeling of 16 pairs of potentially confused drugs to include Tallman lettering (US Department of Health and Human ServicesUS Food and Drug Administration, 2013). Despite these endorsements, and its growing use, the effect of Tallman lettering on attention and the ability to differentiate look-alike drug names is not completely understood.

1.1. Research regarding the use of Tallman lettering

A number of studies have used sensitive measures with simple displays for the purpose of studying the effect of Tallman lettering on the recognition of drug names (Darker et al., 2011; Schell, 2009; Filik et al., 2010). For instance, Darker et al. (Darker et al., 2011) presented a single drug name at very low visual contrast. Participants selected the name in a two-alternative, forced-choice task that included both the original and the confusable names. Discriminatory accuracy was higher when the unique portion of the name was presented in a Tallman format, suggesting that this type of threshold discrimination task is sensitive. However, there was a similar discrimination benefit when the entire name was presented in capital letters. Thus, their results suggest that capital letters are easier to visually resolve at low contrast, but the finding did not support the theory that Tallman lettering draws attention to the critical portion of the drug name (Darker et al., 2011).

Schell (Schell, 2009) and Filik et al. (Filik et al., 2010) both used a single-shot change detection method to evaluate how Tallman lettering influenced the ability to discriminate between confusable drug names. In these studies, a drug name was briefly presented, followed by a delay, and then a second drug name was presented that either matched or was commonly confused with the original. Participants indicated whether the drug name changed or not. In Schell's experiment, the first name could be present either in traditional or Tallman font, and the second name was always presented in traditional font. Tallman increased “false alarms” (i.e. participants reported a change in the drug name when it was the same), leading the researchers to conclude that Tallman lettering failed to reduce drug name confusion (Schell, 2009). However, the change in font type that existed in Tallman trials may have been confused with name changes, producing an inflation of false alarms and masking the true advantage of Tallman. Indeed, Filik et al. (Filik et al., 2010) used a similar method, except that both names were presented in either traditional or Tallman font during a given trial, and found that Tallman lettering enhanced discriminatory performance.

While these results provide some evidence for the effectiveness of Tallman, all the above studies' displays consisted of a single drug name presented in isolation. Thus, there was little competition for attention. This design, while appropriate for investigating the visual resolution of Tallman lettering, may not capture the full benefit of the Tallman letter scheme. The Tallman technique capitalizes only the unique portion of a drug name rather than the whole name. The logic behind this is that attention will be drawn to the critical information, thereby decreasing drug name confusion. Directing attention to the critical portion of the name, however, is likely to be most beneficial when displays tax attentional resources. That is, under taxing conditions, such as crowded labels and displays, a technique that attracts attention to critical information would be expected to be most advantageous.

Key strengths of the above experiments include sensitive measurement methods (i.e. change detection, and threshold discrimination), excellent experimental control, and the ability to address the impact that Tallman lettering has on the visual resolution of drug names. However, previous studies used simple testing displays in which there was little competition for attention, such that these experiments were unable to investigate the full extent to which Tallman lettering effectively attracts attention to critical information. In addition, such simplified displays do not capture the complexity of more realistic scenarios where many drug labels compete for selection and present a great deal of information in addition to the drug name (e.g., dosage information, route of administration, expiration dates, competing products, etc.).

An experiment by Gerrett et al. (Gerrett et al.,) used extremely realistic and ecologically valid displays. In that experiment, heath care providers filled prescriptions using an e-prescribing software (Gerrett et al.,). An audio file presented a drug name, dosage, and formulation for a prescription. Participants then began typing the drug name into the prescription program, which populated a list of possible medications. Participants were to select the one with the correct drug name, dosage and formulation. Drug names were presented in traditional fonts or four variations of Tallman lettering schemes. Unlike earlier experiments, this experiment had complex displays expected to tax cognitive resources, and included realistic information that would compete with drug names during a prescribing scenario. Thus, the stimuli were ideal to detect the benefit of Tallman lettering. However, their dependent measure was the number of prescribing errors, and across all 28,602 trials there were only 81 name errors. These were distributed across the five font conditions, yielding too few errors to grant sound inference. While all four Tallman treatments produced fewer name errors than the traditional format, differences between treatments were not statistically significant. Results are promising, but inconclusive.

Taken as a whole, prior research suggests that what is missing from the topic of Tallman's efficacy is a method that uses complex stimuli where extraneous information competes for viewer attention (like those of (Gerrett et al.,)), but employs a highly sensitive measurement method capable of detecting whether Tallman lettering produces significant benefits (like those of (Darker et al., 2011) and (Filik et al., 2010)).

A study by Filik et al. (Filik et al., 2004) attempted to fill this gap within a population of laypeople. The researchers tracked participants' eye movements during a search of an array of 16 complex drug labels, and found fewer false positives (i.e. a look alike, sound alike doppleganger matched the target drug name) when the doppleganger appeared in Tallman lettering. However, it is not clear from the publication how the search target name was presented. If always presented in traditional fonts, the reported reduction in false positives may have been caused by a bias to believe that two drug names are different when the fonts in which they are displayed were different. This type of criterion shift due to differences in font between a sample and test has been reported in past investigations of Tallman lettering (Schell, 2009). To eliminate this possibility, the publication could have demonstrated that there was not a similar bias to say names were different in target present trials (more false negatives) with Tallman lettering. However, no target

present data was reported. In short, there still appears to be a need for a study that has complex stimuli and sensitive measures.

Here we aim to fill that gap, thereby providing a test of the effectiveness of Tallman lettering as a tool for enhancing the discriminability of look-alike drug names, in conditions where multiple stimuli compete for attention.

To do so, we use a "flicker" change detection methodology based on the work of Rensink (Rensink et al., 1997), as described in Fig. 1. During flicker testing, an image appears on a computer screen for a period of 240 ms (ms); this is followed by the same image containing a slight alteration. In our case, a single drug name (in a field comprised of sixteen different drug packages) changed to its doppelganger in the same text format, either Tallman or traditional. The images, which are identical with the exception of the single change in drug name, iterate with interleaving gray screens (80 ms), producing a "flickering appearance" where the change occurs. Participants are instructed to press the space bar as soon as they spot the change. The resulting outcome variable is continuous in nature (i.e. time to detection of the change), thus allowing for more powerful inference than the binary results collected in previous studies. Further, we use a display where other information competes for the attention of the viewer, not just a single drug name in isolation.

A second gap that exists in prior work on Tallman lettering is a failure to directly compare its effectiveness across laypeople and health care providers. Filling this gap has important implications for understanding the mechanisms by which Tallman lettering may work. The use of capital letters for the unique portion of the name is likely to increase the visual distinctiveness of that portion of text, thereby increasing the bottom-up saliency of the critical portion of the text. This increased saliency may drive the bottom-up attentional system, a system which operates on the basis of visual salience. A considerable amount of data suggests that salient visual stimuli capture attention in a fast and automatic manner (Itti and Koch, 2001; Theeuwes, 1992). In theory, this automatic system should work regardless of a person's knowledge of the purpose of Tallman lettering (Parkhurst et al., 2002) and, thus, should confer a benefit for participants who are naïve (laypeople) as well as those who are healthcare providers. However, there is also a top-down attentional system that guides attention to aspects of the scene based on goals and prior knowledge of the information that is likely to be important in a scene (Torralba et al., 2006; Olivia et al., 2003). This volitional, top-down system should require knowledge of the Tallman lettering scheme and, therefore, should be of primary benefit to those who are most familiar with the purpose of Tallman lettering. Based on this logic, if Tallman derives a benefit solely because it stimulates the bottom up attentional system, the effects should be equivalent across naïve and knowledgeable participants. By contrast, if Tallman also can engage the top-down attentional system, it should be of more benefit among those with knowledge of the system. By directly comparing the influence of Tallman lettering on laypeople and healthcare providers, we hope to gain knowledge about the attentional mechanism/s that are stimulated by Tallman lettering.

1.2. Our contribution

In this study we address these gaps in our knowledge by having laypeople and healthcare providers perform a sensitive change detection task with complex displays of drug names where multiple labels compete for attention (see Section 2.2). Further, we present pilot work that begins to directly investigate how healthcare providers' familiarity with drug names influences the efficacy of Tallman lettering.

2. Materials and methods

All methods were conducted in accordance with procedures approved under Michigan State University's Social Science/Behavioral/Education Institutional Review Board, one of the groups tasked with oversight of research involving human subjects, at MSU (IRB #09–623).

2.1. Study participants

Eighty participants were recruited from two populations using email communication: healthcare providers (n = 40; 16 nurses, 24 were healthcare providers outside of nursing), and laypeople (n = 40). Because medication errors are documented to occur at varied steps within therapeutic treatment, we attempted to recruit people with varied roles likely to interface with medications (e.g. pharmacy techs, surgical technologists, respiratory technologists,

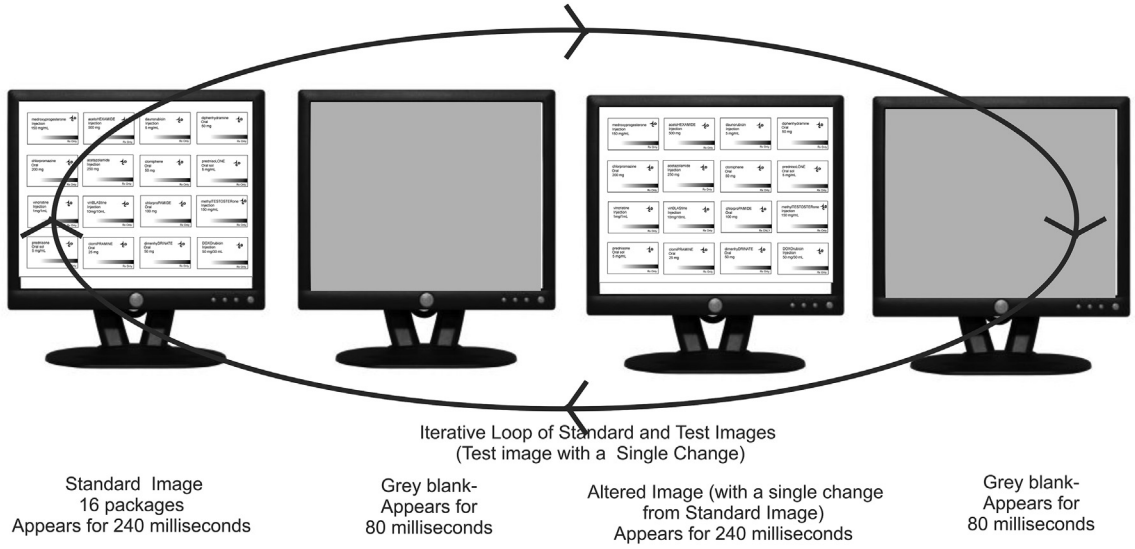

Fig. 1. Change detection methods and timing, based on the work of Rensink et al. (Theeuwes, 1992).

as well as nurses). Of the tested providers, 14/16 nurses (87.5%) reported having been involved in a medication error, while 6 of the 24 (25%) from the "other" group reported this experience. Thus, for the purpose of analyses, healthcare provider participants were categorized into two test groups, those in the nursing profession and "other healthcare providers." Healthcare providers were drawn from three locations: (Aspden et al., 2006) Westlake, OH, with the assistance of Westlake Village (Kohn et al., 2000) Ann Arbor, MI, with the assistance of the National Center for Patient Safety (NCPS) and (Vincent et al., 2001) East Lansing, MI, with the assistance of the College of Nursing.

To participate, subjects had to be at least 18 years old, have no history of seizure and not legally blind. Laypeople were a convenience sample consisting primarily of students and University employees.

Table 1 provides information regarding the gender and test group status of the participants. Participant age was reported when they circled a range that was preset by the research team (see limitations). Table 2 provides frequency of the reported age ranges by test group (lay person, other healthcare provider and nurse).

2.2. Change detection testing

During a trial (Fig. 1), a standard image and a test image (i.e. the standard image with a slight alteration) alternated cyclically, separated by a brief gray screen (Rensink et al., 1997). The cycle looped giving a "flickering" appearance to the image; participants were asked to find the changing aspect of the image. This type of change detection requires focal attention to the change in the image (Rensink et al., 1997) and, thus, time to detect a change can be used as a proxy for the time when attention was first deployed to the changing stimulus (Bix et al., 2010; Tse, 2004). Participants were instructed to press the space bar as quickly as they identified the change, and subsequently they were asked to identify the change location using a mouse. Correctly identifying the change commenced a new trial; if the subject failed to do so, the image pair was repeated until the participant successfully detected the change (with the trials summed) or timed out at two minutes, whichever came first.

2.2.1. Treatments

Test and altered images consisted of a 4 × 4 grid of 16 drug labels that were adapted from those used by Filik et al. (Filik et al., 2004) (See Fig. 2). Each label had five elements, namely, brand name, brand symbol, Rx status, route of administration and concentration. The sixteen drug names tested, comprising eight confusable pairs, were selected from those that the US Food and Drug Administration requested (as part of the Name Differentiation Project) be revised to incorporate Tallman lettering because of the potential for error and confusion (US Department of Health and Human Services, 2013) (see Table 3). The specific letter formatting that was used was that recommended to manufacturers by the Agency.

Participants completed 16 critical trials in which the change involved a drug name changing to its confusable alternative in a single label of the 4 × 4 display of labels (see Fig. 2). In half of these trials, both members of the pair were presented in Tallman lettering, and in the other half both members of the pair were presented in traditional font. In other words, a *single drug name* within the field of sixteen labels changed to its doppelganger, with both being presented in either a Tallman or traditional format. Critical trials were interspersed among 16 non-critical trials in which the change did not involve the drug name. These non-critical trials were used to keep participants from focusing exclusively on the drug names. The 32 total trials were presented in four blocks of eight trials with brief visual breaks between blocks. Each block had four critical and four filler trials. Careful randomization schemes were designed to mitigate potential effects of order of appearance of trials and position of change on the screen (DeHenau, 2010).

Table 1
Participant frequency by gender and professional status.

	Lay people	Other healthcare provider	Nurses	Totals
Male	23	2	2	27
Female	17	22	14	53
Total	40	24	16	80

Table 2
Participant frequency by reported age group and professional status.

Age range	Lay people	Other healthcare provider	Nurses	Totals
18–24	22	4	0	26
25–34	10	6	4	20
35–49	2	7	4	13
50+	6	7	8	21
Totals	40	24	16	80

2.3. Survey

The forty healthcare providers were asked to complete a brief survey on demographics and work experience, including: years, settings, shift type and experience with errors. At the conclusion of the survey, participants were presented with a list of the 16 confusable drug names tested (See Table 3- traditional formats) and asked to circle those that they were familiar with prior to this study. Familiarity was coded a "0" (none from a pair circled), a "1" (one of the pair circled) or a "2" (both names of the pair circled) (Fig. 6).

2.4. Statistical analysis

2.4.1. Statistical treatment of the complete data set (both non healthcare provider and healthcare providers included)

We recorded two dependent variables: (1) The number of successful change detection trials made within the allotted two minute period and (2) the time that it took to detect changes. The probability of successful change detection within the allotted 2-min period was modeled using a generalized linear mixed model that assumed a binomial distribution. In turn, time to detected change was modeled using a general linear mixed model following log transformation of the response to meet model assumptions. For both statistical models, the linear predictor included the fixed effects of test group (laypeople, nurses and other healthcare providers), graphic presentation (Tallman and traditional) and their two-way interaction, as well as effects of block and position of the change within the screen. Random effects were specified to properly recognize as the appropriate experimental unit for each factor and to account for technical replication."

2.4.2. Statistical treatment of the survey data (healthcare providers only)

We conducted a second analysis using survey data from the healthcare professionals. Time to successful change detection, recorded in seconds, was square-root transformed to meet model assumptions and used to fit a general linear mixed model. The linear predictor of the statistical model included the fixed effects of graphic presentation, familiarity (expressed in three levels: 0,1,2, as described in the previous section), as well as their interaction, along

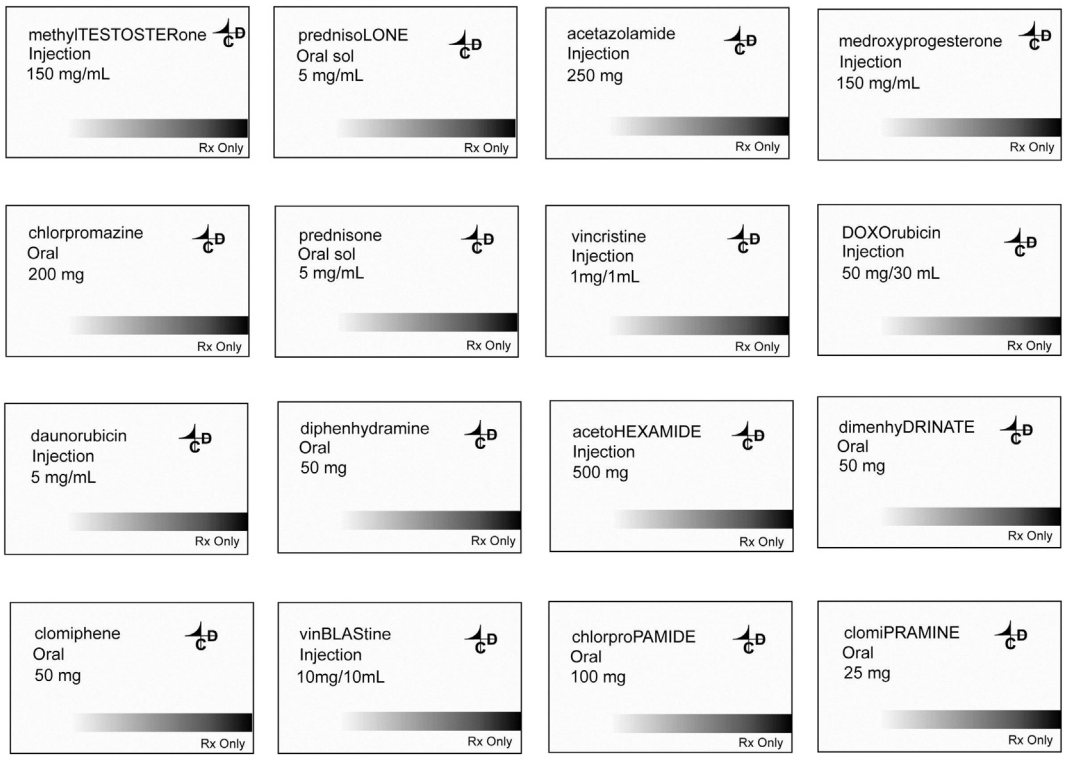

Fig. 2. An example of a standard image; labels were adapted from Filik et al. (2004) (Parkhurst et al., 2002).- During testing, this image would be paired with a test image that included a single change to one of the 16 labels. For complete details regarding positional randomization, randomization and order of presentation, etc. please see DeHenau.

with, block and position. Random effects were specified to properly recognize as the appropriate experimental unit for each factor and to account for technical replication." Overall, general and generalized linear mixed models were fitted using the GLIMMIX and MIXED procedures of SAS software (SAS Version 9.2, Cary, NC), respectively. Degrees of freedom were estimated using Kenward-Roger's approach. Tukey-kramer or Bonferroni adjustments were used to prevent inflation of Type I error due to multiple comparisons.

3. Results

3.1. Successful detections

We found evidence for a significant main effect of graphic presentation on the probability of successful change detection ($P < 0.0001$). In particular, confusable pairs presented in Tallman were more likely to be detected than those presented in traditional formats (95.1 ± 1.4% and 85.9 ± 3.3%, respectively) and this was apparent in both healthcare professionals and laypeople. This suggests that Tallman lettering enhanced change detection performance relative to traditional format regardless of the test group of the participant.

Irrespective of the graphic presentation, the probability of successful change detection differed by test group ($P = 0.0013$), whereby laypeople were more likely to detect changes than either nurses or other healthcare professionals (95.8 ± 1.2, 87.2 ± 4.0% and 89.2 ± 3.2, respectively). Consistent with prior findings (Filik et al., 2010), this could potentially be explained by age effects, which were partially confounded with professional occupation in this study, with the younger participants (i.e. laypeople) performing better than their older counterparts employed in the healthcare industry (see Table 1). No evidence for differences was apparent when the probability of change detection was compared between nurses and other healthcare professionals (see Fig. 3). Further, no evidence of interaction between graphical presentation and test group on the probability of successful change detection was apparent.

We also found evidence for an effect of block ($p < 0.0001$; worse performance in the first block of trials than any other subsequent blocks), as well as marginal evidence for an effect of change position ($p = 0.0554$; with better performance for changes in the upper

Table 3
Look-alike, sound-alike drug names selected for study based on those approved for use by the US Food and Drug Administration (FDA).

Word pair	Tallman lettering		Traditional format	
1	acetoHEXAMIDE	acetaZOLAMIDE	Acetohexamide	Acetazolamide
2	chlorproMAZINE	chlorproPAMIDE	Chlorpromazine	Chlorpropamide
3	clomiPHENE	clomiPRAMINE	Clomiphene	Clomipramine
4	DAUNOrubicin	DOXOrubicin	Daunorubicin	Doxorubicin
5	dimenhyDRINATE	diphenhydrAMINE	Dimenhydrinate	Diphenhydramine
6	medroxyPROGESTERone	methylTESTOSTERone	Medroxyprogesterone	Methyltestosterone
7	predniSONE	prednisoLONE	Prednisone	Prednisolone
8	vinBLAStine	vinCRIStine	Vinblastine	Vincristine

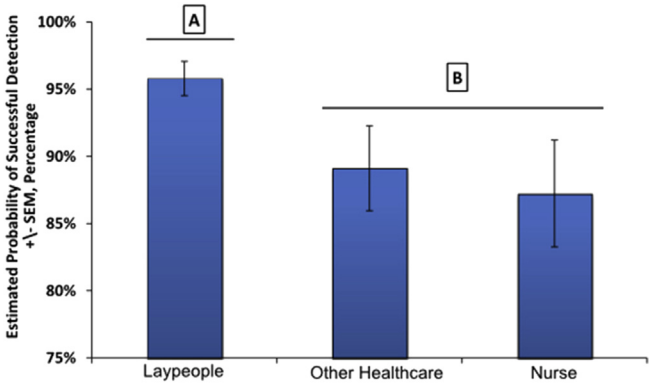

Fig. 3. Estimated probability of successful change detection by test group, averaged across graphical presentations. A, B indicated significant differences ($P < 0.05$) between laypeople and healthcare providers.

left quadrant of the screen). We report these results for completeness despite the fact that they do not bear directly on the assessment of the effectiveness of Tallman lettering. We emphasize that our randomization process prevented issues of confounding by ensuring comparable replication of treatments within blocks and change positions across subjects. Further, our modeling approach allowed us to account for block and change position effects when making inference on treatment effects of interest.

3.2. Time to change detection

For all three test groups, Tallman lettering resulted in faster change detection times than traditional formatting ($P = 0.015$, 0017 and <0.0001 for laypeople, other healthcare providers and nurses, respectively); however, the magnitude of the discriminatory advantage conferred by Tallman lettering was significantly larger for the nursing group than for other test groups ($P = 0.0243$, see Fig. 4).

One possible interpretation of this is that the effectiveness of Tallman lettering over traditional format differed based on the participant's professional experiences and their prior knowledge of Tallman lettering as an approach to name differentiation; this interpretation is supported by previous findings that suggest that Tallman is more efficacious to those who are aware of its purpose (Filik et al., 2006). This is also supported by our finding that the

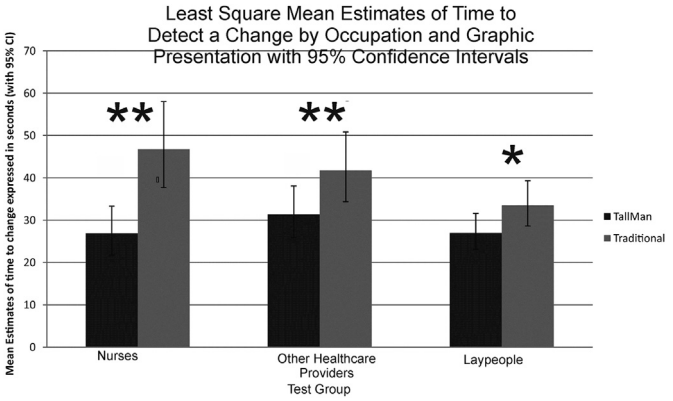

Fig. 4. Least square mean estimates of time to detect a change by test group and graphic presentation with 95% confidence intervals. * and ** indicate $P < 0.05$ and $P < 0.0001$, respectively, for comparisons between traditional and Tallman formatting within each test group.

interaction between test group and Tallman lettering was also apparent for the other healthcare providers, who had a more comparable age distribution to those of nurses. Thus, it is possible that our finding of a larger discriminatory advantage of Tallman lettering for nurses relative to other test groups suggests that prior knowledge and background experience could possibly impact the effectiveness of the Tallman lettering design.

However, the potential confounding effect of age difference between test groups, whereby young laypeople were compared to an older population of nurses, is another explanation for the difference.

3.3. Survey data

To explore a potential relationship between familiarity and the performance of Tallman lettering on a pilot basis, we investigated the association between drug name familiarity (as reported by healthcare providers in the survey-see Fig. 5) and the discriminatory effectiveness of Tallman lettering, as recommended by Darker et al. (Darker et al., 2011).

We found a significant interaction between graphic presentation and familiarity on time to detected change ($P = 0.0259$). When healthcare providers were familiar with both drug names, there was no evidence to indicate that Tallman lettering sped change detection ($P = 0.999$). By contrast, when the healthcare provider was unfamiliar with one of the names in the pair, a significant Tallman benefit was evident ($P = 0.0001$); change was detected sooner in Tallman formats than traditional lettering. When both members of the confusable pair were unknown to the participant, marginal evidence for Tallman benefit was apparent ($p = 0.06$).

4. Discussion

Tallman lettering led to more effective and rapid change detections of confusable drug names regardless of test group. The magnitude of the Tallman advantage was most pronounced for the test group comprised of nurses, a population that is frequently and directly involved in administration of medication in hospital settings. Further, within all healthcare providers (both nurses and those in the “other” category), there was a discriminatory advantage of Tallman lettering relative to traditional formatting when the provider was familiar with one of the two confusable drug names.

One possible interpretation of the overall pattern of our results is enlightened by a discussion of attentional allocation, which is determined by the interplay of two distinct cognitive systems, a bottom-up system and a top-down mediated system (Corbetta and Shulman, 2002). The bottom-up system drives attention toward the most salient, or visually discrepant, aspects of the stimulus and operates in a feed-forward way via responses in early visual areas (Itti and Koch, 2001). By contrast the top-down system is under volitional control, driving attention toward goal-relevant aspects of a scene (Folk et al., 1992) and is mediated by a frontoparietal brain network (Corbetta et al., 2008).

Within this framework, presenting the unique portions of a drug name in a larger font may serve to increase the visual saliency of that portion of the text, thereby increasing the bottom-up signal driving attention to this critical text. This bottom-up effect is expected to work regardless of one's knowledge of the Tallman lettering scheme. Thus, this bottom up aspect may be responsible for the benefit seen in laypeople, who should have been naïve to the Tallman lettering approach. This suggests its use can increase attention to relevant aspects of a drug name in a relatively automatic manner.

We did, however, also find that the magnitude of the benefit conferred by Tallman lettering was *larger for nurses* than lay

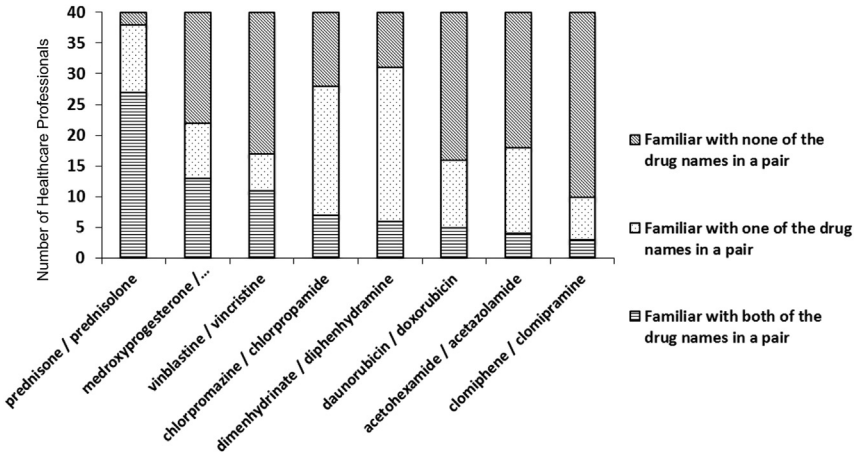

Fig. 5. Frequency counts for familiarity with none, one or both drug names of each pair for the 40 healthcare professional participants.

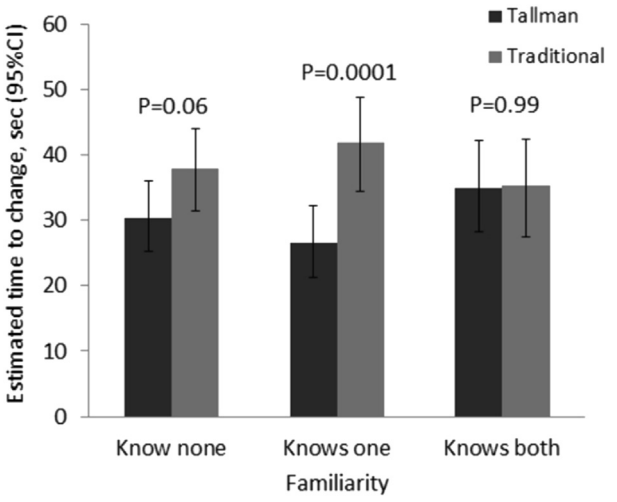

Fig. 6. Least square mean estimates of time to change detection, expressed in seconds (and 95% confidence intervals), when the healthcare provider was familiar with none, one or both words in a confusable pair presented either with Tallman lettering or traditional format.

participants. This difference in magnitude cannot be explained in terms of the bottom-up attentional system. Instead, this result suggests that Tallman lettering may also impact performance via the top-down attentional system. There is substantial evidence that people can guide attention in a top-down manner to items which have a particular visual feature (Maunsell and Treue, 2006). This type of feature-based attention may allow people who are familiar with the purpose of Tallman to set a volitional control signal, guiding attention to the capital letters. In short, the increased benefit of the Tallman system by nurses suggests that the approach can also increase attention to critical portions of the drug name through top-down attentional control.

Further evidence for top-down attentional control is provided by our data comparing Tallman vs. traditional formatting while accounting for drug name familiarity by healthcare professionals. Tallman lettering was particularly effective when a health care provider was unfamiliar with one of the drug names in the pair. This finding suggests that Tallman lettering can drive attention to the critical regions of drug names when one of the names is unknown. By contrast, when both drug names in the pair were known to the participant, there was no evidence for any benefit of Tallman lettering; probably because people were able to find the change quickly even when the names were presented in traditional font. This suggests that participants who know both names can use this knowledge to guide attention toward the critical portions of the words. With this knowledge driving attention to the critical location in this top-down manner, there seems to be little, if any, additional benefit conferred by Tallman lettering.

Finally, it is worth highlighting our finding that Tallman lettering can engage both top-down and bottom-up attentional mechanisms, as this may have clinical importance. The top-down system requires cognitive resources to engage, and thus is less effective under conditions of high stress or anxiety (Moser et al., 2012; Sänger et al., 2014). Therefore, the top-down benefit may help to lower medication errors in non-stressful situations. By contrast, in high stress, sufficient cognitive resources to engage top-down attentional guidance may not be available. Even so, the automatic bottom-up system may enhance the ability of Tallman lettering to reduce look-alike, sound-alike medication errors.

5. Limitations

As with any study, there are some limitations that the authors wish to acknowledge.

Drug familiarity was assessed (and the effect tested) only amongst healthcare providers. To assess familiarity, subjects participated in a survey after the change detection study where they were asked to circle the names of the drugs that they were familiar with *prior to the study*. Since the survey was conducted after change detection testing, we cannot rule out the possibility that some reports of familiarity were based on perceiving the name during the change detection task rather than prior experience. However, had the survey been conducted prior to the change detection task, it is unclear how, if at all, exposure to drug names during the survey may have affected the outcome of the change detection task. We strongly recommend further work investigation of the effect of drug name familiarity on Tallman's efficacy as our results indicated only marginal evidence ($P = 0.06$) that Tallman lettering was beneficial when participants were unfamiliar with both names of a drug pair.

Age is an important and noted factor in studies of attention (Brink and McDowd, 1999; Madden, 2007). In our study, we tested two different groups of subjects: laypeople, comprised primarily of University students and employees, and healthcare providers. In recruiting subjects this way, test group (laypeople vs healthcare provider) was partially confounded with age, as shown in Table 1.

This was further complicated by the fact that participant age was collected categorically in age groups, as opposed to actual years of age. As such, we know that the group comprised of laypeople was generally younger than that of healthcare providers, but our assessment of more specific age effects is limited. That said, the benefit of the Tallman lettering was evident across test groups. Further, the benefit that was derived from the presence of the Tallman lettering was larger for the nurses than for the group of other healthcare providers (see Fig. 4), even of comparable age. This is relevant, given current aging trends in the nursing profession as it suggests that the use of Tallman is beneficial even with older populations.

6. Conclusions

We used a sensitive change detection method to investigate how Tallman lettering impacts discrimination of confusable drug-name pairs in realistic medication labels and in a complex visual environment. Our results provide evidence that Tallman lettering can be an effective technique for driving attention towards the critical portion of look-alike, sound-alike drug names, presenting an efficacious strategy, potentially mitigating medication errors. It appears that Tallman lettering derives some benefit via an automatic bottom-up attentional mechanism. Further, it has been proposed that knowledge of the purpose of Tallman lettering yields benefit (Filik et al., 2006), suggesting additional advantage could be derived via a top-down attentional mechanism.

In short, our lab-based testing provides evidence that Tallman lettering may be effective at reducing drug errors. We believe that this evidence supports the adoption of the Tallman lettering system as a strategy to mitigate medication errors.

Disclosures

Carly DeHenau, Mark Becker, Nora Bello and Sichang Liu report no financial disclosure related to this work. Laura Bix has served as an expert witness (plaintiff) in cases involving drug labels. None of these cases have involved the use (or absence) of Tallman lettering.

Right Med Label, provided a space for testing, assisted in recruitment and a number of subject incentives. Their technology, a labeling system for parenteral drugs used in the OR, is not impacted by whether or not a Tallman strategy is employed. Right Med Label had no role in the study design, data collection and analysis, decision to publish or preparation of the manuscript submitted.

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