Recognition Performance for Damaged Safety Signs with Different Levels of Color Deterioration

Annie W. Y. Ng and Alan H. S. Chan

***Abstract*—When safety signs are in service they can be damaged beyond the point of being useful by sudden damage or due to gradual natural conditions, causing physical marks, defects, fading, discolouration or blurring of the sign. The damaged signs may consequently be much less effective in providing timely information about safety threats or risks. There has been limited research on the effects of damaged safety signs on user performance. To partially fill this gap, this study investigated recognition performance for damaged safety signs with different levels of color deterioration. Fifteen safety signs were chosen for study and damage was simulated, with different levels of color deterioration by using bandpass filters (Photoshop CS® software) to create 15 different levels for the ratio of white pixels to total pixels. Fifty Hong Kong Chinese males (21 – 45 years old) familiarized themselves with all the test sign referents first, and then the signs were presented in random order with each sign shown progressively from the most filtered to the complete version. Participants consistently waited to accumulate sufficient perceptual evidence before making an affirmative decision about the sign meaning. Accurate identification decisions mainly occurred around and between the seventh level pixel ratio (77.14%) and the ninth level (82.86%). The grand mean image level at which safety signs were correctly identified was 8.23 with an identification threshold (pixel ratio) of 80.68%. This implied that at a pixel ratio lower than this identification threshold, a sign may not be identified correctly and should be restored or replaced as soon as possible. The lifespan of a safety sign in future might also be determined through consideration of the estimated prescribed level of identification threshold for damaged signs. Overall, the findings of this study should help further develop and assist implementation of safety sign maintenance programmes and management systems from the perspective of human factors and ergonomics.**

***Index Terms*—color deterioration, damaged sign, human factors, safety sign, sign recognition**

I. Introduction

PROVISION of safety signs is one of the safety precaution measures that can be implemented quickly to attempt to reduce the occurrence of accidents, injuries and fatalities in workplaces and public areas. Safety signs are visual interfaces with particular meanings intended to deliver prohibition, mandatory, warning and guidance messages to people to promote appropriate and responsible behavior within a context. They may represent a hazard, a hazardous situation, and a result of not avoiding a hazard. They also may describe safety precautions, advise users of the evasive actions to take, or provide other directions to eliminate or reduce hazards.

However, in-service signs can be damaged beyond usefulness based on sudden or gradual natural causes such as age, weather, vehicle scrapes and accumulation of tree sap, or as a result of human actions such as vandalism, paintball marks, gun shots and graffiti [1–4]. These natural or man-made causes lead to physical marks or defects such as dimples, scratches and nicks on the sign face [5] and cause some sign areas to fade and blur [6]. Some examples are shown in Figure 1.

Immaneni et al. [3] found that signs colored yellow were more prone to man-made vandalism. It has also been reported that, due to being damaged, signs might be less visible and less legible, and in some cases it may be impossible to distinguish the legend of the signs [5], such that there is poor or non-existent communication of the intended message to users. Obviously a sign that fails to convey warning information effectively will pose a safety threat and may lead to injury or death. There is a critical need to periodically check for and rectify damaged signs. Both manual and computer-aided sign inspections are currently used in field audits. Harris et al. [2] stated that human visual based inspection can be prone to false alarm and miss errors, such that some signs above particular threshold(s), that should be accepted, would be rejected while some signs below the thresholds, that should be rejected, would be retained. Unfortunately, computer-assisted automatic sign detection and inspection still has plenty of room for improvement [4, 7] so human eyes are still needed. Generally, it would be good practice to replace signs that are significantly damaged [8].

Studies have been reported on various aspects of safety signs, for example, noticeability [9], font size and message layout [10], training [11–13], comprehensibility and usability [14–18], legibility [19, 20], cultural differences [14, 21, 22], and the role of pictorials in signs [23]. A review of the literature shows that to date there has not been much ergonomics research on damaged safety signs and other graphic signs. The study reported here focused on investigating recognition performance for damaged safety signs with different levels of color deterioration. The findings

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should prove useful in estimation the average identification threshold at the damage level (in terms of color deterioration) at which the safety signs can be correctly identified. Safety signs could then be restored or replaced when they have deteriorated beyond an estimated prescribed level of identification threshold. The service life of a sign in future might also be determined by considering user recognition performance for damaged signs. These actions should help to develop and implement better safety sign maintenance programs and management systems.

Fig.1. Examples of safety signs with different types of damage.
(a) Safety sign with color fade
(b) Safety sign with a sticker on its graphic element
(c) Safety sign with dirt
(d) Sign bent and creased

II. Method

A. Participants

Fifty Hong Kong Chinese males, aged between 21 and 45 years old, participated in the study. All participants had normal or corrected-to-normal vision.

B. Safety Signs

Fifteen common safety signs (267 X 267 pixels) were selected for testing in this study. To simulate damaged safety signs with different color deterioration levels, each sign was bandpass filtered (using Photoshop CS® software) according to the ratio of number of white pixels to total number of pixels (Table 1). This procedure was performed at 15 different levels of filtering for each sign (see Appendix). A computer program prepared with Visual Studio 2005® and C# language was used to present the different image levels for the signs and to capture the participant recognition responses during the tests.

C. Procedure

Participants were briefed on the objectives of the study and given verbal instructions at the beginning of the study. The procedure used was to the progressive stimulus revelation paradigm [24, 25] which consisted of a study phase and an identification phase. The study phase was to familiarize all participants with the 15 intact/unfiltered sign referents before the identification task.

In the study phase, participants read each of the 15 sign referents (2s for each) on the computer screen. The sequence of referent presentation was in random order.

During the Identification phase, for each trial, the first (most blurred) image level of a given sign was presented for 3s. Next, the second (next most blurred) image level of the same sign (containing higher ratio of number of white pixels to total number of pixels) was immediately presented for 3 s, and this same procedure was repeated with successively less blurred images until the presentation of the 15^{th} image level (intact/unfiltered sign) or until the sign was recognized. Hence, this procedure resulted in progressive and predictable revelation of the image quality by increasing in a stepwise fashion the pixel ratio from an initial most blurred sign. Participants were asked to click a "Bingo" button on the screen (Figure 2) when they felt that they could identify the sign at a particular image level. The corresponding sign referent was then shown. Participants were asked to click a "yes" button if they were certain that the given sign referent was the intended message of that image. Otherwise, they clicked a "no" button. To minimize order effect, the sequence of sign presentation was different in the study and identification phases.

TABLE 1
THE 15 PIXEL RATIOS USED TO FILTER THE SAFETY SIGNS

Image level	Ratio of number of white pixels to total number of pixels in the sign (%)
1	60.00
2	62.86
3	65.71
4	68.57
5	71.43
6	74.29
7	77.14
8	80.00
9	82.86
10	85.71
11	88.57
12	91.43
13	94.29
14	97.14
15	100 (i.e. intact/unfiltered sign)

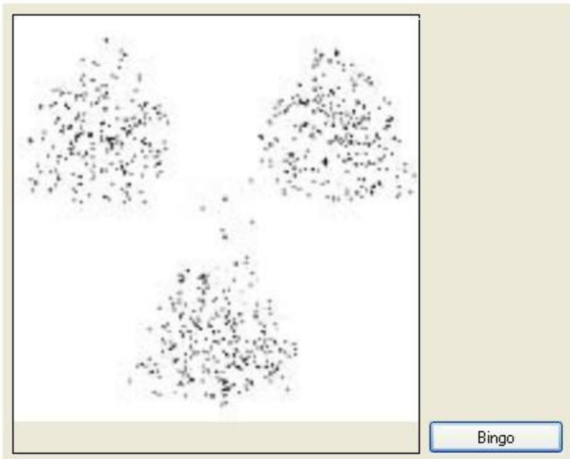

Fig. 2. S9 – 'Radiation' at image level 2 on the computer screen during the identification phase.

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III. RESULTS

Figure 3 shows the average identifiable image level for each test sign. With the exception of the 'falling rocks' sign (S12), the average identifiable image level of each safety sign was between 7 and 9. In general, the first most frequent identifiable image level for a safety sign was 7, while the second most frequent identifiable image levels were 8 and 9. The sign S12 was identified at the exceptionally higher image level of 13.1, while 'radiation' (S9) was the sign recognized at 6.9, the lowest image level. The grand mean identification level at which the safety signs were correctly identified (identification threshold) was 8.23 (shown by a dotted line in Figure 3), with a standard deviation of 1.48.

Based on the ratio of number of white pixels to total number of pixels of different image levels in Table 1, a linear equation was generated: Pixel ratio at a particular image level = 2.86 image level + 57.14. This equation can be used to determine the exact pixel ratio for a particular identifiable image level in this study. By substituting the grand mean identification threshold (i.e. 8.23) into the equation, the corresponding ratio of number of white pixels to total number of pixels was found to be 80.68%. That is, when a safety sign had a pixel ratio lower than 80.68%, in general, the sign could not be identified with certainty.

Participants were generally accurate in the identification task with a grand mean error rate of 14.13% (standard deviation = 5.26%). The error rate here referred to the ratio of participants that could not recognize a sign correctly to total participants. Figure 4 illustrates the average error rate for each test sign. The sign 'pull plug before opening' (S15) had the lowest error rate (0.06), and the sign 'falling rocks' (S12) had the highest (0.3). Both the error rate and identifiable image level were not normally distributed. Spearman correlation showed no significant relationship between error rate and identifiable image level ($p < 0.05$).

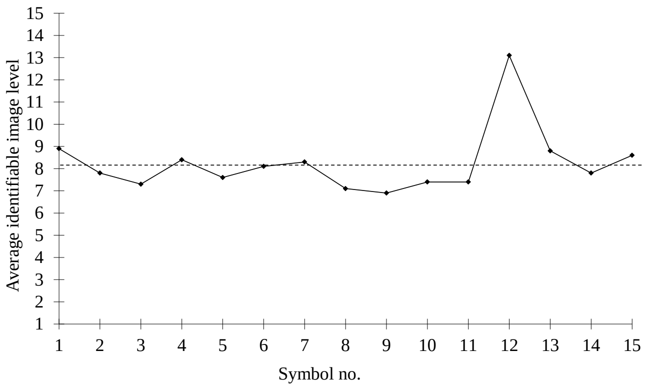

Fig. 3. The average identifiable image level for each test sign. The dotted line represents the grand mean identification threshold

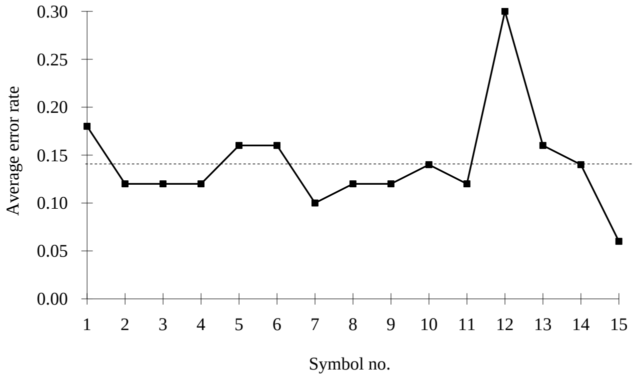

Fig. 4. The average error rate for each test sign. The dotted line represents the grand mean error rate.

IV. DISCUSSION

This study focused on the investigation of human recognition performance for damaged safety signs with different levels of color deterioration. Participants here did not respond randomly across trials and did not simply guess the intended meaning of the safety signs. Rather they waited to accumulate sufficient perceptual evidence before making an affirmative decision about the sign meaning. Decisions generally occurred at or about the presentation of the seventh (pixel ratio: 77.14%), eighth (pixel ratio: 80%) or ninth (pixel ratio: 82.86%) image level. However, amongst all the test signs, the 'falling rocks' sign (S12) was identified at an exceptional high image level of 13.1 (out of 15). Such a high identifiable image level may have been due to the fact that in the pictorials, 'rocks', in the sign only became clear and obvious at that image level. The results of this type of study can provide a good indication of which fragments of a sign are critical to the structure of a particular safety sign for it to become a referent. For example, the sign 'wear safety belt' (S4) had an image level average of 8.4, because the pair of arrows were noticeable at around the seventh, eighth or ninth image levels. The critical element of the sign, the safety belt, appeared before those image levels, but, the participants were not able to make a decision based on the safety belt pictorial alone. It appears that without the pair of arrows the intended meaning of the sign could not be recognized with certainty. The pair of arrows, indicating the action of wearing a safety belt was a significant design feature of the sign.

The identification threshold at which the safety signs were correctly identified was at an image level of 8.23 ± 1.48. The corresponding ratio of number of white pixels to total number of pixels for the grand mean identification threshold was 80.68%. This implied that for a safety sign with pixel ratio lower than this percentage, the sign will not be identified with accuracy and certainty. Safety officers or other appropriate practitioners should remove and replace or restore such signs as soon as possible, so as to avoid any misinterpretation and consequent safety risks. At present, a sign is usually judged to be damaged based on the parameters of retroreflectivity, fluorescence luminance, and/or sign age [1, 3, 6, 26]. The findings of this study indicate that in future the service life of a safety sign may be determined with the additional consideration of the estimated user recognition threshold for damaged signs. Such an addition could help to better develop and implement safety sign maintenance programmes and

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management systems from the perspective of human factors and ergonomics.

There were limitations to be noted in this study. First, the research adopted the progressive stimulus revelation paradigm which consisted of a study phase and an identification phase to examine recognition performance for damaged signs. However, Viggiano and Kutas [25] showed that prior exposure can influence not only processing time but also identification performance for fragmented objects. They found that reaction time was faster and identification performance was better when complete objects had been studied beforehand than when they had not been studied beforehand. In daily life, it is likely that, at some time, most people will encounter a damaged sign without prior exposure to its intact form. It is possible that the estimated recognition threshold reported here could be a bit optimistic when compared to the real situation.

Second, the research only focused on investigating the recognition performance for damaged safety signs with different color deterioration levels. Apart from color fading, safety signs can be damaged due to, for example, vandalism, paintball marks, graffiti and vehicle scrapes. Further studies are necessary to examine user performance on safety signs with various kinds and extents of damage. The results could then provide safety officers and other professionals with a more comprehensive and in-depth understanding of user performance with damaged signs.

V. Conclusion

There has been only limited ergonomics research on damaged safety signs. This study sought to partly fill this gap in the literature by examining recognition performance for safety signs damaged by different color deterioration levels. It was found that the grand mean image level at which safety signs were correctly identified was 8.23, with an identification threshold (pixel ratio) of 80.68%. Because safety signs with pixel ratios lower than this identification threshold may not be accurately recognized, the signs should be restored or replaced immediately. In addition to the parameters of retroreflectivity, fluorescence luminance and sign age in current use, safety officers and practitioners should consider using the estimated prescribed level of identification threshold for damaged signs to determine the expected life of a safety sign. The findings of this study should be useful in helping to develop and implement better safety sign maintenance programmes and management systems. The type of findings reported here can also provide a good indication of which fragments of a design are critical for recognition of a particular safety sign.

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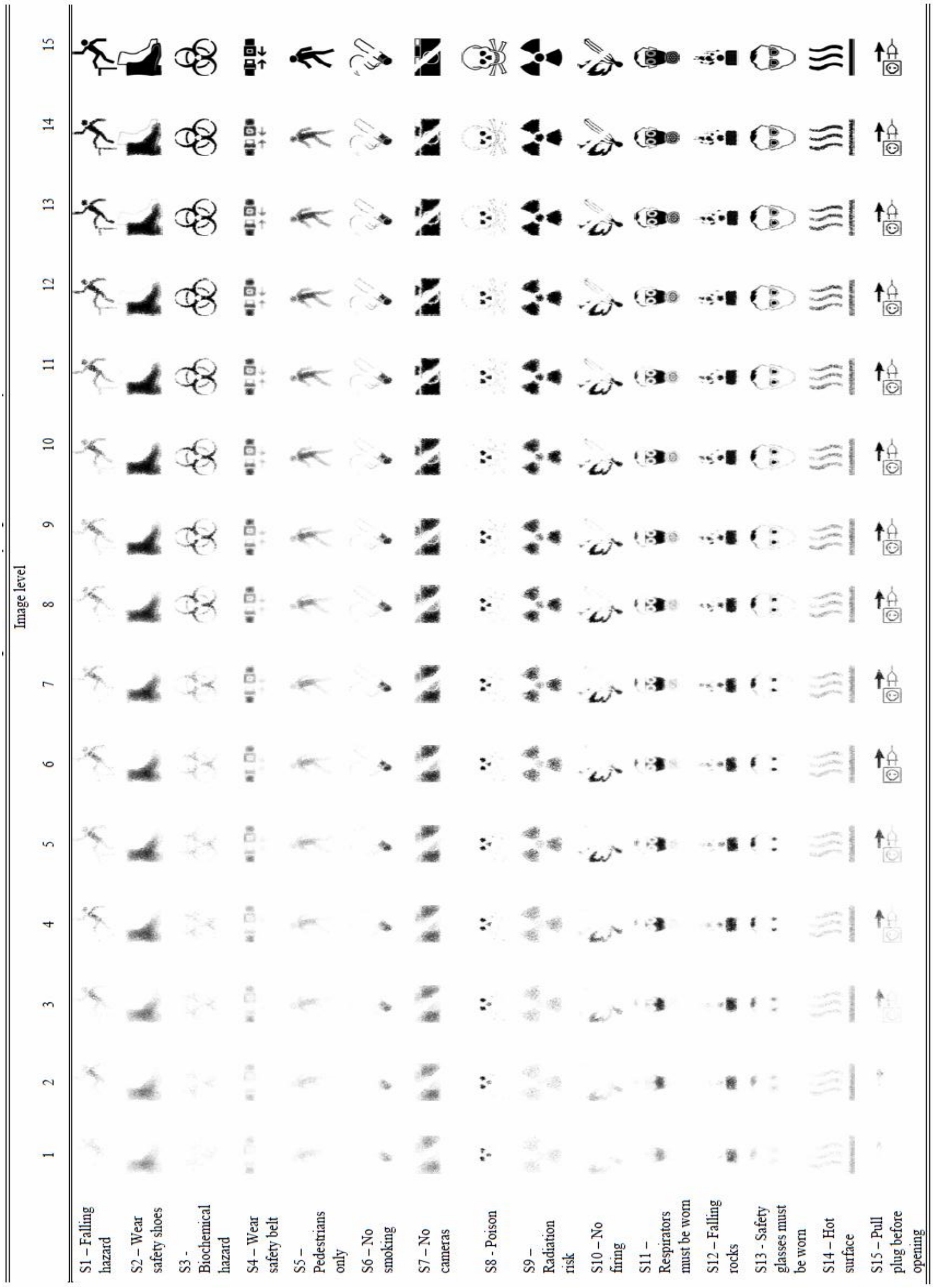
APPENDIX

The 15 different levels of filtering for each safety sign used in this study



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