Published in final edited form as:

Proc Hum Factors Ergon Soc Annu Meet. 2009 October ; 53(20): 1598–1602. doi:

10.1177/154193120905302013

Comprehension of Warning Symbols by Younger and Older Adults: Effects of Visual Degradation

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Abstract

The goal of this study was to investigate the effects of visual degradation on warning symbol comprehension across warning symbol types and age groups. Twenty-seven black and white ANSI symbols of four different types (prohibition, course of action, information, and hazard symbols) were presented to older ($N = 21$, $M = 73.1$) and younger adults ($N = 20$, $M = 21.4$) via computer at three degradation levels (0%, 30%, 40% of pixels inverted); accuracy and response time in answering yes-no questions about the symbols were recorded. Younger adults were more accurate and faster overall than older adults ($p < .01$). Regarding degradation, 0% and 30% inverted symbols did not significantly differ in comprehension ($p = .25$), but both were comprehended better than 40% inverted symbols ($p < .01$); no interactions were observed. For degraded warning symbols, results suggest symbols must be substantially degraded to affect base comprehensibility, and age differences exist. These data have practical implications for warnings in environments susceptible to degradation.

Prior warning research has largely ignored visual degradation effects (e.g., those elicited by corrosion, extensive sunlight, or product use). Additionally, no research has considered age effects using visually degraded warning symbols. Age-related perceptual and cognitive changes might exacerbate degradation effects; or, older adults' increased experience with symbols might mediate any negative effects. This experiment was designed to provide an initial investigation of how visually degrading warning symbols of various types affects ability to comprehend symbol information for different types of symbols and for younger and older adults.

Why Warning Symbols Are Used

Adults of a wide range of ages use products and items everyday that are potentially dangerous. To alert the public, warnings are frequently included to decrease the chances of misuse or accident. Unfortunately, complex language such as "injures mucous membranes on contact" is on everyday household products and the information is often misunderstood or ignored (Hancock, Bowles, Rogers & Fisk, 2006). Someone may not want to read a block of text about hazards, but may be willing to interpret a safety symbol (for a discussion of heuristics-systematic processing related to warning labels see Zuckerman & Chaiken, 1998). Hancock et al. proposed that symbols can clarify complex information and other research provides evidence that they can if the symbols are designed well (Morrow, Hier, Menard, &

Leirer, 1998; Young & Wogalter, 1990). In addition to clarifying complex information, warning symbols can serve as a cue in prompting recall of hazards and precautions associated with a product (Leonard & Wogalter, 2000; Lesch, 2008). Incorporating symbols also yields perceptual benefits such as an increased ability to notice warnings (Young, 1991) – from greater distances (Kline & Fuchs, 1993) and in reduced lighting conditions (Kline, Ghali, Kline, & Brown, 1990). And though a textual warning sign is incapable of communicating information to those who cannot read it, symbols may be able to communicate information across language barriers. In sum, warning symbols can be useful in alerting users about dangers.

Degradation

In actual use warning symbols are not always maintained in pristine condition; they sometimes remain in use even after their message has been rendered inscrutable by weathering. However, the effect of degradation on warnings is primarily unexplored (Glasscock & Dorris, 2006). Some of what is documented is that symbolic traffic signs' legibility distance is correlated with blur degradation (Schieber, 1994), that visibility for textual exit signs is impaired under smoky conditions (Collins, Dahir, & Madrzykowski, 1993), visibility of both textual and symbolic exit signs appears impaired at a lower illumination level (however no inferential statistical values were reported) (Wong & Lo, 2007), and different exit symbols exhibit differing comprehension levels under poor visual conditions (Lerner, Collins, 1983). No research has previously assessed degradation for a wide range of warning symbol types. To formulate the current experiment's hypotheses, the results of the exit symbol experiments were considered and the visual discrimination literature provided a theoretical basis.

Generally, discriminating objects from their background and identifying the objects has been thought of as a feature integration or visual binding process. Instead of processing a stimulus as a whole unit, it is divided into its components, or geons; the representation of the whole then being mentally constructed from the parts (Biederman, 1987; Treisman & Gormican, 1988). Some features that need to be bound together for constructing a representation of the whole are contours, axes, and vertices and degradation interferes with all of these features (Biederman). Therefore, extent of degradation was hypothesized to inversely correlate with comprehension. Two degradation questions were additionally posed: 1) At what level of degradation does comprehension significantly differ from comprehension under the ideal condition of no degradation? 2) Does degradation interact with symbol type and age group?

Aging

Warning symbols are encountered by people of all ages (Hancock, Rogers, & Fisk, 2001) and age differences in the user population must be considered in the warning design process (Rousseau, Lamson, & Rogers, 1998). As individuals grow older, their ability to respond effectively to warnings may be affected by reduced cognitive and perceptual abilities (Hancock et al., 2006). And indeed, aging has been shown to correlate with reduced warning comprehension (e.g., Easterby & Hakiel, 1981; Hancock et al., 2001; Hancock, Rogers, Schroeder, & Fisk, 2004; Morrell, Park, & Poon, 1990). However, the potential interaction of age and warning symbol degradation has only minimally been explored (Wong and Lo,

2007, did investigate age differences but provided no inferential statistical analysis). Because older adults have already been documented as having difficulty with warnings viewed under ideal, non-visually degraded conditions, and because the effect of degradation is expected to demand even greater cognitive and perceptual compensation, degradation was predicted to interact with age group. Older adults were expected to be more affected by degradation than younger adults. Also, the previously documented age difference results – older adults faring worse than younger adults in comprehending non-degraded warnings – were expected to be replicated in the current experiment with degraded warning symbols.

ANSI – Symbol Types

The American National Standards Institute employs four categories of symbols: prohibition, mandatory action, hazard, and information symbols (Peckham, 2006). Prohibition symbols indicate an action that should be avoided because of potential hazards (e.g., no smoking symbol). Mandatory action symbols indicate an action that should be taken to avoid potential hazards (e.g., wear ear protection symbol). Hazard symbols warn against specific hazards (e.g., poison symbol). Information symbols provide relevant information in the case of danger (e.g., exit symbol). In the past, a main effect has been documented for symbol type. Hancock et al. (2004) found hazard symbols comprehended worst and prohibition symbols comprehended best. We included these symbol categories in the present study to determine if degradation had differential effects.

Experiment Goals

The goals of this experiment were to (a) determine effects of degradation across symbol types and age groups, (b) assess interactive effects of these variables.

METHOD

Participants

Twenty younger adults – 8 female, 14 male – ranging in age from 18–23 ($M = 21.4$, $SD = 2.3$), were recruited from the Georgia Institute of Technology via Experimentix, an online experiment sign-up website. The younger adult participants received class credit for an introductory psychology class. Twenty-one older adults – 12 female, 7 male – ranging in age from 68–75 ($M = 73.1$, $SD = 2.0$), were recruited from a database of volunteers maintained by the Human Factors and Aging Laboratory. Older adult participants received compensation of \$25 for two hours of participation. All participants had normal or corrected near vision of 20/40 or better (assessed via a Reduced Snelling Chart) and were native English speakers.

Materials and Procedure

Symbols—A total of 28 ANSI safety symbols were used, seven from each of the four ANSI categories: Prohibition, hazard alerting, recommended course of action, and information symbols. All symbols from the 1991 and 1998 ANSI standards were used except for 12 hazard alerting symbols. Seven hazard symbols which passed a greater-than-chance recognition criterion and which do not require text accompaniment (as specified by ANSI) were used (National Electrical Manufacturers Association, 1991, 1998).

According to the ANSI standards of 2002, a surround shape is not required with symbol design (Peckham, 2006). Thus symbols were not presented with a surrounding shape other than the prohibition symbols which intrinsically utilize a surrounding circle with a diagonal bar superimposed over prohibited actions or items. In addition to these symbols, an ANSI approved hazard symbol for fall hazard was used for practice trials.

Degradation—Degradation level was operationalized for the symbols as follows: Non-degraded (0% of pixels inverted), partially degraded (30% of pixels randomly inverted), and heavily degraded (40% of pixels randomly inverted). Figure 1 shows an example of an information symbol at the three levels of degradation.

Degradation was the result of inverting individual pixels from black to white and white to black on a pixel by pixel determination using a computer program written in BlitzPlus (2003). For each degradation level, the percentage of pixels inverted was held constant while the individual pixels to be inverted were randomly selected. The pixel inversion levels of 0%, 30%, and 40% were chosen based on pilot testing that revealed mean differences in comprehension at those levels.

Labels—All of the symbols were assigned two labels to be used in the experiment – a correct label (the published ANSI one) and an incorrect label (a lure). In multiple-choice testing, plausible alternatives (versus implausible alternatives) have elicited performance similar to that exhibited via open-ended testing procedures (Wolff & Wogalter, 1998). Thus, a systematic method was devised to select plausible lures from Hancock et al.'s (2004) unpublished, raw data.

In Hancock et al. (2004) the participants viewed the same set of warning symbols used in the current experiment and generated multiple phrases as to the potential meaning of each symbol. To create plausible, but incorrect lures, the Hancock et al. data were analyzed to determine the most commonly occurring incorrect response for each symbol. An interrater reliability of 83.2% was achieved for this coding. In the case of conflict, the second-most common response was used.

Apparatus—Pentium IV computers running at 3.2 GHz with 1 GB of RAM were used with a 17-inch monitor. Participants were seated approximately 18 inches from the monitor. Two keys on the keyboards – 'f' and 'j' – were labeled with stickers reading 'yes' and 'no', which corresponded to yes-no answers about whether the warning label matched the warning symbol. The experiment was programmed and run via Inquisit 2.0 (2006).

General Procedure—The experiment consisted of a two-hour session with up to eight participants tested at a time. Participants first filled out a demographic questionnaire while individuals were taken aside for vision testing in another room. Next, instructions for the warning symbol semantic task (a task similar to that of Lesch, 2008) were provided and a keyboard familiarization program (for the keys used in the experiment) was administered. Finally, two runs through a computerized warning symbol semantic relatedness task were completed – each time followed by a warning symbol familiarity measure (those data are not reported here).

Symbol Semantic Relatedness Task—Participants were instructed that they would first be presented a textual label and then, after reading it and pressing the spacebar, presented a warning symbol that would sometimes be hard to see. They were to decide as quickly and accurately as possible whether the preceding label matched the meaning of the symbol. If the labels matched, they were to press the key labeled “Yes” and if the labels did not match, they were to press the key labeled “No.” Participants were provided six practice trials with the fall symbol to become acquainted with the three levels of degradation and the yes-no answer method. Then there were a total of 56 trials: for each of the 28 warning symbols, two trials (a matching and a non-matching). Participants were allowed 15 seconds to respond to every screen. Neither response time nor accuracy feedback was provided to participants.

Counterbalancing—For the warning symbol semantic relatedness task, to avoid priming effects potentially induced by presenting the same warning symbol in multiple degradation conditions to the same participant, stimuli orders were created. In all orders, participants saw only one level of degradation for each individual symbol, but were exposed to all three levels of degradation (non-degraded, partially degraded, heavily degraded) in viewing the entire set of symbols. As there were 28 symbols and three levels of degradation it was impossible to evenly divide the levels of degradation across the symbols presented. Thus three orders were created, alternating in which degradation level was presented ten times (as opposed to the other two degradation levels’ nine presentations). Each symbol trial was chosen randomly and without replacement from within an order. The order that participants received was modularly based on their participant number – a number assigned according to enrolling order in the experiment.

RESULTS

A 3 (degradation level) $\times$ 4 (symbol type) $\times$ 2 (age) repeated measures multivariate analyses of variance (MANOVA) was conducted – accuracy and response time as dependent measures. Symbol type means were first computed for each participant. Planned contrasts were conducted for degradation level to investigate whether means differed as expected.

Neither for accuracy or reaction time was there a main effect for symbol type ($p = .11$; $\eta_p^2 = .05$). Symbol type also did not interact with degradation ($p = .75$; $\eta_p^2 = .01$), or age group, ($p = .22$; $\eta_p^2 = .04$) nor was the three way interaction significant ($p = .65$; $\eta_p^2 = .02$). Moreover, there was not a significant degradation $\times$ age group effect ($p = .16$; $\eta_p^2 = .03$) so we will thus focus on the main effects of degradation and age.

As expected, degradation did influence performance both in terms of accuracy: $F(2, 78) = 25.6$, $p < .01$; $\eta_p^2 = .39$, and response time: $F(2, 78) = 10.6$, $p < .01$; $\eta_p^2 = .21$. Planned contrasts further revealed that compared to the heavily degraded symbols, the non-degraded and the partially degraded symbols were more accurately responded to: $F(1, 39) = 42.1$, $p < .01$; $\eta_p^2 = .52$, and elicited faster responses: $F(1, 39) = 16.0$, $p < .01$; $\eta_p^2 = .29$ (these statistics refer to contrasting partially degraded with heavily degraded symbols). Non-degraded symbols did not differ from partially degraded for either accuracy or response time: $p = .25$; $\eta_p^2 = .03$. Degradation level means are provided in Table 1.

Compared to older adults, younger adults were significantly more accurate: $F(1, 39) = 46.5$, $p < .01$; $\eta_p^2 = .544$, and faster to respond: $F(1, 35) = 12.2$, $p < .01$; $\eta_p^2 = .24$. See “Overall (across degradation levels)” in Table 1 for means.

DISCUSSION

Effects of Degradation

Expanding the results of studies of visual degradation and exit signs (Collins et al., 1993; Lerner, Collins, 1983; Wong & Lo, 2007), degradation did influence performance, although it did not interact with symbol type. Performance was best at the non-degradation condition and did not decline significantly when the symbols were partially degraded (30% of pixels inverted). However, when symbols were heavily degraded (40% of pixels inverted) younger and older participants were both less accurate and slower to comprehend their meaning. These results suggest that it takes a substantial amount of visual degradation for symbol comprehension to be significantly reduced from base-performance on a non-degraded symbol. ANSI and other symbol standardizing organizations should consider providing guidance for replacement of warning labels after a certain amount of degradation has occurred. The present data provide an initial assessment of what that point might be.

Effects of Age

With respect to age group differences, as expected, younger adults were faster and more accurate than older adults. This finding is consistent with previous reports of age-related differences in warning comprehension (e.g., Easterby & Hakiel, 1981; Hancock, et al., 2001; Hancock et al., 2004; Morrell et al. 1990). However, perhaps somewhat surprisingly, the effects of degradation did not differ as a function of age. Both younger and older adults maintained the same level of performance for the non-degraded and partially degraded conditions and only showed severe decrements at the heavy degradation level. These data indicate that symbol degradation results in a general reduction of performance for both younger and older adults.

Effects of Symbol Type

Prior studies have found overall differences in the comprehension of different symbol types. For example, Hancock et al. (2004) found that hazard symbols were comprehended less well than prohibition symbols. This pattern was not observed in the present data, perhaps due to the nature of the procedure. The task was made very difficult by using only *plausible* incorrect answers from the Hancock et al. data. Moreover, the relative difficulty of the lures could not be established and may have varied across symbol types thereby masking any symbol differences.

Future Considerations

As Rogers, Lamson, and Russeau (2000) discussed in their comprehensive review of the warning literature and warning processes, there are a great number of factors that have been shown to affect warning comprehension – both warning variables and person variables. In regard to warning *symbols*, many of the same factors are relevant; for example: color, surround shape, text accompaniment, placement context, as well as person variables:

familiarity, gender, hazard perception, to name a few. Any and all of these variables could be considered in tandem with degradation in future research.

An aspect of this experiment that encourages future variations is the method of degradation. Symbols become degraded in a variety of ways, many of which our manipulation did not represent by simply inverting proportions of black and white pixels. As an alternative one might be interested in replicate smoky viewing conditions and could reduce contrast evenly for the test symbol images. Other conditions that could elicit varying degradation patterns include glare, sun bleaching, wear, corrosion, or rust. Degradation literature has investigated algorithms and other methods to generate realistic degradation which could be applied in future studies (e.g., Collins et al., 1993; Ishida, Takahashi, Ide, Mekada, & Murase, 2007; Schieber, 1994; Lerner, Collins, 1983; Wong & Lo, 2007).

Another direction degradation research could proceed would be to begin investigating compliance to warning symbols at different levels of degradation in context. Some interesting warning research has already begun considering the compliance part of the warning process (see Rogers et al., 2000) and many of the methodologies would easily lend themselves to additionally assessing degradation. Recently, one inventive experiment manipulated warning colors, sign types, and symbol explicitness on a warning sign displayed on a college campus to gauge effect on college student behavior (Shaver & Braun, 2007). Follow-up degradation research utilizing similar methodology may uncover issues related to sign placement as it interacts with degradation. In general the field of warning degradation research remains wide open for further study.

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Figure 1.
Extinguisher symbol at the three degradation levels with pixel inversion percentages listed.

Table 1

Mean (and Standard Deviation) Values for Degradation Levels by Age Group

	Accuracy ^a	Response Time (s) ^b
Non-degraded (0% inverted)		
Younger Adults	82.2 (9.6)	2.08 (0.63)
Older Adults	63.8 (13.)	3.31 (0.97)
Mean across age groups	72.8 (15.)	2.71 (1.02)
Partially Degraded (30% inverted)		
Younger Adults	78.1 (11.5)	1.72 (0.69)
Older Adults	64.7 (9.4)	2.50 (0.80)
Mean across age groups	71.2 (12.)	2.12 (0.84)
Heavily Degraded (40% inverted)		
Younger Adults	63.1 (11.)	2.16 (0.93)
Older Adults	52.3 (10.5)	2.68 (1.10)
Mean across age groups	57.6 (12.)	2.43 (1.04)
Overall (across all degradation levels)		
Younger Adults	74.5 (4.6)	2.39 (0.81)
Older Adults	60.3 (8.2)	3.42 (1.05)
Mean across age groups	67.2 (9.8)	2.92 (1.06)

^aPercent correct.^bMean response time (includes response time for both correct and incorrect responses).