Evaluating the Behavioral Effectiveness of a Multi-Modal Voice Warning Sign in a Visually Cluttered Environment

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ABSTRACT

This research examined the effects of a multi-modal warning sign on compliance behavior. Participants followed a set of printed instructions to perform a chemistry task that involved measuring and mixing disguised (nonhazardous) chemicals. Whether participants wore protective equipment as directed by the warning was measured. The environment around the sign was either visually cluttered or uncluttered. In some conditions, pictorials, a voice warning, and/or a flashing strobe light were added. The results showed that compliance was significantly greater when the warning was presented in an uncluttered environment compared to a cluttered environment. The results also showed that the presence of a voice warning produced a strong and reliable increase in compliance compared to conditions without a voice warning. No statistically reliable effects of pictorials or strobe were found though the results did show a trend of greater compliance when they were present. In addition, compliance was positively related to memory of the warning, perception of hazard, and reported carefulness. The results call attention to the importance of the context in which a warning is placed, and the potential benefits of voice warnings.

INTRODUCTION

In the past several years, issues of warning effectiveness have been a focus of human factors research. Because of the ethical constraints of exposing individuals to real dangers for experimental purposes, most of the early warning research used preference, legibility, memory, and comprehension tests as measures of effectiveness. Since the appearance of a review by McCarthy, Finnegan, Krumm-Scott, and McCarthy (1984) calling attention to the status of research at that time, new methodologies have been developed to assess warning effectiveness. One new methodology is the behavioral compliance paradigm.

The behavioral compliance paradigm places participants in settings that appear hazardous but are actually safe because precautions are taken in advance to ensure that the experimental situation is free from real danger. Compliance is assessed by observing the extent to which participants comply with a warning by performing some specific cautionary behavior (e.g., wearing of protective equipment). Since the mid 1980's, behavioral research has identified a number of factors that influence the effectiveness of warnings, including: warning placement (Wogalter, Godfrey, Fontenelle, Desaulniers, Rothstein, & Laughery 1987), embedding the warning in other text (Strawbridge, 1986), social influence of others (Wogalter, Allison, & McKenna 1989), severity of the consequences (Wogalter & Barlow, 1990), inclusion of pictorials (Jaynes & Boles, 1990), voice communication (Wogalter & Young, 1991), and effort needed to comply (Wogalter et al., 1989).

Most behavioral compliance research has been conducted in a laboratory situation in which a warning was embedded in a set of written task instructions (e.g., Jaynes & Boles, 1990; Wogalter et al., 1987, 1989). Only a few studies have examined the effects of a posted sign and all of this work has been done with field studies (Laner & Sell, 1960; Saarela, 1989; Wogalter et al., 1987; Wogalter & Young, 1991). No published research to date has examined the effect of a posted warning sign in a controlled laboratory situation. This was one purpose of the current study.

A second purpose was to examine the influence of the environmental context in which a warning is placed. In many real-world situations, warnings signs are located in cluttered environmental surroundings (e.g., amongst equipment and other printed materials). Although no previous study has examined the effects of visual clutter on warning compliance, related research indicates that irrelevant visual stimuli reduces detection of target stimuli (Cole & Hughes, 1984; Monk & Brown, 1975; Williams & Hoffmann, 1979). Because posted signs are often located outside the immediate field of view, a sign embedded in visual clutter increases the likelihood that it will be missed, and as a consequence, reducing compliance.

The current study also examined the effects of three other factors that might increase the salience of the sign in visual clutter. The variables were: pictorials, a voice warning, and a flashing strobe light. They were chosen because (a) previous research has shown increased compliance for pictorials and voice, and (b) related research suggests promising effects of a flashing strobe light. Jaynes and Boles (1990) showed greater compliance with pictorials present in a warning than when they were absent. Wogalter and Young (1991) showed greater compliance for a voice warning than a print warning inside a set of task instructions. No previous research has specifically examined the effect of a flashing light on warning compliance, but other research suggests that it might increase warning effectiveness. Guzy (1991) has recently shown that an amplitude-modulated stoplight increased the detection distance of a stoplight compared to a conventional continuous-on stop light. Moreover, human factors guidelines and general perceptual principles (e.g., Sanders & McCormick, 1987) suggest that a flashing light could be an effective means of gaining attention. Thus, it was expected that the presence of pictorials, a voice warning, and a flashing strobe light would increase the salience of a warning sign in visual clutter and thereby, reduce any camouflaging effect clutter might have.

These factors were not only studied individually but also

in combination (i.e., a multi-modal sign). Simultaneous investigation has certain advantages: (a) it allows the determination of each variable's strength in relation to other variables, and (b) it enables examination of any interaction effects. For example, it is possible that the presence of more than one method of enhancing salience produces a synergistic effect on compliance that is greater than would be predicted by their individual effects.

METHOD

Design

The experiment consisted of the 12 between-subjects conditions shown in Table 1. The primary dependent variable was whether participants complied with the warning by putting on the protective gear (wore mask and gloves).

Participants

Approximately half of the 198 participants were Rensselaer Polytechnic Institute (RPI) undergraduates and half were high school students taking undergraduate courses at RPI. They either received credit in their introductory psychology courses or remuneration of $5.00 for their participation. Participants were assigned randomly to conditions. All conditions had 18 participants except for the two control conditions which had nine each.

Materials and apparatus

The laboratory materials were similar to those described in Wogalter et al. (1987, 1989). Actual chemistry laboratory equipment was used such as a triple-beam balance, beakers, flasks, and graduated cylinders. A large supply of plastic gloves and face masks were also available on a laboratory table next to the equipment. A set of written instructions directed participants to weigh, measure, and mix several substances and solutions in a certain order. The substances and solutions were available in large glass containers and labeled by a letter to disguise their true nature. The chemicals were actually harmless: food coloring, colored water, cooking oil, and powdered soap.

The basic print warning sign (31 x 31 cm) appeared in black bold print on a bright, highly saturated yellow background. A signal icon (triangle-exclamation point) was located to the left of the signal word CAUTION on the top of the sign. Signal word letter height was 4 cm and the remaining message had letter height of 1.5 cm. In some conditions, this print sign: (1) was present or absent, (2) contained two pictorials illustrating the wearing of mask and gloves immediately below the printed statements, (3) had a strobe light attached to the sign that flashed for 8.25 s at a rate of 8 Hz with a duration of 2.2 ms per flash with a peak illuminance of 200,000 lux at 1.22 m, and/or (4) included a digitized male voice vocalizing the identical message as the printed sign. The 8.25 s vocal warning was stored on an EPROM chip and was presented at an average sound level of 83 dBA. The sign apparatus allowed the voice warning and strobe to be activated separately or together. The total dimensions of the sign apparatus were 53 cm high, 31 cm wide, and 16 cm deep. The printed sign was positioned on the front upper two-thirds of the apparatus. Below was the 15 cm diameter strobe light on the left and a speaker (for the voice) on the right. The entire apparatus was custom built by Accuform, Inc., Brooksville, Florida. The print warning

FIGURE 1. *Print Warning Sign with Pictorials.*

containing the two pictorials is shown in Figure 1. The sign lacking the pictorials was identical except that the line spacing of the verbal message was increased to fill the area taken by the pictorials in the sign shown in the figure.

The area immediately surrounding the laboratory table was either uncluttered (only the warning and the chemistry laboratory materials and equipment) or was cluttered with various kinds of extraneous tools and electronic equipment scattered in front of and on both sides of the laboratory demonstration table.

The strobe and voice were activated by the breaking of an infrared beam when participants crossed the area from the doorway entrance to the laboratory table. The warning sign (when present) was always positioned directly facing the doorway. Relative to the front of the laboratory table, the sign was at an angle of 35 degrees. The sign's placement was slightly offset to the right of the participants' forward position, approximately aimed at the participants' left shoulder, and was 1.0 m from the rim of the laboratory table. Table height was .95 m. The demonstration area was 1.7 m from the door.

In a preliminary study, the two pictorials were tested by placing them with nine other pictorials, and 12 RPI students were asked to write a description of what each represented. The responses were scored in two ways, using strict and lenient criteria. Correct responses with the strict criterion needed an indication that gloves or mask should be put on for protection against hazards (i.e., skin and hand for gloves, or lung and respiratory for mask), and with the lenient criterion, needed an indication that one should put on the gloves or mask. The test showed the gloves pictorial received 100% correct for both the strict and liberal criterions. The mask pictorial received 83% and 100% correct for the strict and liberal criterions, respectively.

Procedure

Initially, participants were asked to read and sign a consent form which described the study as investigating the procedures and equipment involved in a chemistry laboratory demonstration task. Participants were then asked to wear a white lab coat and shown how to use a triple-beam balance. Next, participants were told that they would be performing the laboratory task in the next room, and that they would be receiving a set of task instructions. Participants were told that they should try to complete the tasks as quickly and as accurately as possible. They were also told that once they began the task they should not ask any questions, and that if any problems arose they should recheck the instructions and do the best that they could. However, they were also informed that if it ever became necessary, they could ask the experimenter for assistance.

The experimenter accompanied the participant to the doorway of a second room which contained the chemistry equipment and told the participant to enter the room and begin. The experimenter stood in the doorway and recorded whether the participant complied with the warning (wore mask and gloves) before mixing the substances and solutions. After five minutes had elapsed, the participant was told to stop, was returned to the first room, and was asked to complete a questionnaire. The questionnaire asked: (a) whether they saw masks and gloves, (b) whether they saw or heard warnings of any kind, and (c) if so, what was the specific content of the warning. The questionnaire also requested ratings on the following items: (a) "How *hazardous* were the chemicals?" (b) "How *careful* were you in the task?" and (c) "How *accurate* were you in the task?" All three rating scales were Likert-type 8-point scales verbally anchored at the two ends with (0) "not at all" to (7) "very." After the questionnaire was completed, participants were debriefed and thanked for their participation.

RESULTS

Behavioral compliance

The primary dependent variable was whether participants put on and wore protective equipment (mask and gloves) during the demonstration procedure. Participants that put on one piece of protective gear also tended to put on the other piece ($\Phi = .91$). In the analyses presented below, participants were considered to have complied if they wore at least one piece of protective gear. Analyses considering masks and gloves separately, as well as compliance defined as having put on both pieces of equipment, showed essentially the same pattern of results although the scores were somewhat lower.

Compliance proportion means for the 12 conditions are shown in Table 1. Because there were no differences between the two control conditions ($p > .05$), in most of the remaining analyses, these two conditions were collapsed into a single No-Warning control condition.

A one-way between-subjects analysis of variance (ANOVA) showed a significant effect of conditions, $F(10, 187) = 7.12$, $p < .0001$. As can be seen in Table 2, the structure of the conditions allowed several 2 X 2 analyses. For example, using conditions 3, 4, 5, and 6 enables one to examine the effects of presence vs. absence of pictorials and clutter and their possible interaction (with the other variables held constant). In this particular analysis, a main effect of visual clutter was found, $F(1, 68) = 4.90$, $p < .05$). The presence of a cluttered environment ($M = .14$) significantly lowered compliance compared to the absence of clutter ($M = .36$). There was no effect of pictorials, nor was the interaction significant ($ps > .05$).

Every analysis involving the the voice warning showed significant effects ($ps < .0001$). As can be seen in Table 1, compliance in conditions with the voice warning present was substantially (and significantly) greater than comparable conditions with the voice warning absent. Voice did not interact with the other variables ($ps > .05$). In addition, no other significant effects were found in the analyses shown in Table 2 ($ps > .05$). Although the presence of pictorials and strobe appeared to show greater compliance compared to

TABLE 1

Mean Proportion Compliance as a Function of Warning Conditions

Condition Number	Condition Description	Mean Compliance
(1)	Control-No Warning-No Clutter	.111
(2)	Control-No Warning-Clutter	.000
(3)	Print warning-No Clutter	.278
(4)	Print warning-Clutter	.111
(5)	Print warning-Pictorials-No Clutter	.444
(6)	Print warning-Pictorials-Clutter	.167
(7)	Voice warning only-Clutter	.611
(8)	Print warning-Voice warning-Clutter	.667
(9)	Print warning-Voice warning-Pictorials-Clutter	.722
(10)	Print warning-Strobe-Clutter	.222
(11)	Print warning-Pictorials-Strobe-Clutter	.278
(12)	Print warning-Voice warning-Pictorials-Strobe-Clutter	.833

Note. Control conditions 1 and 2 each had 9 participants. All other conditions had 18 participants.

TABLE 2

Planned 2 X 2 Tests

Independent Variables	Conditions
Print X Clutter	1, 2, 3, 4
Pictorials X Clutter	3, 4, 5, 6
Print X Voice	2, 4, 7, 8
Pictorials X Voice	4, 6, 8, 9
Pictorials X Strobe	4, 6, 10, 11
Voice X Strobe	6, 10, 9, 12

Note. All 2 X 2 analyses involved the manipulation of presence vs. absence of the independent variables. Condition numbers refer to the list in Table 1.

their absence, they never showed a significant effect. Analyses with greater statistical power were also performed. For the pictorials, a contrast compared conditions 5, 6, 9, and 11 (pictorials present) to conditions 3, 4, 8, 10 (pictorials absent). For the strobe, conditions 10, 11, and 12 (strobe present) were contrasted with conditions 4, 6, and 9 (strobe absent). However, neither contrast showed a significant effect (*ps* > .05).

Questionnaire analysis

Analysis of the questionnaire considered only the data for participants who were in the warning-present conditions (n = 180). The results showed that if participants complied with the warning, they also reported: (a) seeing the protective equipment (Φ = .45, $p < .0001$), (b) seeing or hearing a warning (Φ = .57, $p < .0001$), (c) believing the situation to be more hazardous (Φ = .36, $p < .0001$), and (d) being more careful (Φ = .28, $p < .0001$). There was no relation between accuracy and compliance (Φ = .004, $p > .05$).

For the questionnaire item asking what the warning said, memory for the content of the warning was scored in two ways, strictly and leniently. For the strict criterion, the warning message was divided into idea elements and one point was awarded for each element that was present in an answer. The accumulated points for each participant were then converted to proportion scores. For the lenient criterion, the entire response was scored as correct if there was some indication that a hazard was present or that there was some potential for harm. Both memory measures showed strong positive relations to compliance (r = .59 and Φ = .55, *ps* < .0001, for the strict and lenient criteria, respectively). The reliability of the scores was assessed by having another person who was unaware of conditions re-score a random sample of 30% of the responses (n = 59). Inter-rater agreement was calculated by dividing the number of agreements by the number of agreements plus disagreements and then multiplying by 100. Reliability was 94.1% and 98.3% for the strict and lenient scoring, respectively.

A similar pattern was found when comparing participants who complied or did not comply to the warning. Table 3 shows the means as a function of participant compliance. All comparisons between compliers and non-compliers were significant (*ps* < .0001) except for accuracy ($p > .05$).

A progressive drop was seen in the proportion of persons who reported seeing the protective equipment (M = .79), who reported seeing/hearing a warning (M = .59), and who actually complied with the warning (M = .43).

TABLE 3

Mean Proportions for Questionnaire Items as a Function of Participant Compliance

	see mask/ gloves	see/hear warning	hazard rating	careful rating	accuracy rating	strict memory	lenient memory
compliers	1.00	.91	2.86	4.66	3.91	.25	.71
non-compliers	.64	.34	1.39	3.20	3.90	.04	.17

DISCUSSION

The results showed that a warning sign placed in surrounding visual clutter is complied with less often than the same sign in a less cluttered surrounding. The implication is that the effectiveness of a warning depends on the context in which it is placed. This result supports a previously untested guideline that warning signs should stand out from the environment in order to attract attention (e.g., Cunitz, 1981; Peters, 1984, 1989; Wogalter et al., 1987). It also supports related research indicating that irrelevant visual stimuli reduces target detection (e.g., Cole & Hughes, 1984; Monk & Brown, 1975; Williams & Hoffmann, 1979).

The effect of visual clutter was probably enhanced by the sign's location relative to the participants' field of view. Although the warning could be clearly seen at the table and was within 1 m of the chemistry materials, it was not directly in front of them while standing at the table. Previous research indicates that warning location (Wogalter et al., 1987) and displacement of target stimuli away from the line of sight (outside the visual field) are important determinants of attention and search conspicuity (e.g., Monk & Brown, 1975). Additionally, an unpublished study in the first author's laboratory indicates that a warning placed in a set of written instructions is more often complied with than a similar warning placed on a nearby sign. Lowered compliance is probably due to the sign's separation from the participants' main field of view, reducing its noticeability.

The most striking finding was the large effect of the voice warning. Its power to influence compliance relative to the other variables indicates that voice warnings may be a very effective means of gaining behavioral compliance. This result supports the finding of Wogalter and Young (1991) showing greater compliance for voice warnings than comparable print warnings.

Although there was a tendency for greater compliance when the pictorials and strobe were present, no significant effects were found. The null finding for the pictorial is somewhat surprising given recent results by Jaynes and Boles (1990) who found that the presence of pictorials significantly increased compliance to a warning. One salient difference between the two studies is that Jaynes and Boles' warning (and pictorials) was placed in a set of printed instructions, whereas, it was on a sign in the current study. Pictorials may facilitate compliance only when the warning is placed in a visible location.

The failure to show an effect of the flashing light was also somewhat surprising because the flash rate (8 Hz) was within the acceptable range of most display guidelines (e.g., Mortimer & Kupec, 1983; Woodson & Conover, 1964). Two possible explanations can be offered. First, the strobe flashed for only a few seconds after being tripped by the participant entering the laboratory room. Second, the light was very intense. Although the on-duration of each flash cycle was very short, its illuminance was very high. Most participants looked in the direction of the sign when it started to flash, but almost immediately turned their head away (presumably because it was annoying and bright). Thus, while the strobe was able to attract attention, it did not hold attention. Had the flashing light been less luminous and the

overall duration longer, it might have been an effective means of promoting compliance.

Compliance behavior was significantly related to memory of the warning, perception of hazard, and carefulness. These findings are not unexpected given that these are indications that the warning message was received. There was also a progressive drop in the proportion of participants who saw the protective equipment, who reported seeing/ hearing a warning, and who actually complied with the warning. Thus, there were more participants who were aware of the warning than who subsequently complied. A similar trend was noted by DeJoy (1989) in a review of other compliance research (Friedmann, 1988; Otsubo, 1988; Strawbridge 1986).

Finally, the potential advantages and disadvantages of voice warnings should be mentioned. The two foremost advantages are its attention-getting and omnidirectional qualities. Both are important considerations when visual attention is occupied and focused on other objects or tasks, as was case in the current study. In addition, reception of a voice warning does not necessarily require reorientation of attention away from a visual task as would be the case for a visually presented warning. In addition, voice warnings can provide, in a direct manner, specific hazard information (unlike simple nonverbal auditory warnings). Although complex *nonverbal* auditory warnings can inform, effective communication requires extensive training (Patterson & Milroy, 1980). Voice warnings do not require such training because they take advantage of people's verbal capabilities and their preexisting knowledge. Voice warnings can also benefit certain populations who have difficulty with printed language such as the blind and the illiterate.

However, there are some potential problems with the use of voice warnings. For example, voice warnings take time to be transmitted, and thus, very long messages should not be presented auditorily. In situations where many voice warnings could be activated, simultaneous presentation could make them virtually unintelligible. These disadvantages might be overcome by making the different messages and voices discriminable or by prioritizing the order of the messages. When large amounts of complex information must be communicated, the combination of a concise voice warning and a more complex print warning could be implemented. For example, a brief voice warning could be used to: (a) capture attention, (b) communicate the most important information concisely, and (c) cue the user to orient to a more detailed print warning. Where practical, redundant visual and voice warnings should be used so that when part of the voice message is missed, the full message can be reviewed visually.

Improvements in voice recognition and synthesis technology in recent years has made voice warnings more feasible by the development of voice generation chips and digitized sound processors. Together with the numerous kinds of tripping devices available to initiate a warning, voice warnings may be an effective means of gaining compliance in situations where a printed warning alone is inadequate.

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