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RESEARCH ON WARNING SIGNS

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ABSTRACT

Environmental and facility warning signs are displays that are placed in public areas to warn people of potential hazard. This chapter examines empirical research on warning signs and organizes this research based on the stages of (a) noticing, (b) comprehending, and (c) complying with the warning. Additionally, this chapter identifies gaps in warning sign research and suggests possible topics for future research.

INTRODUCTION

According to a National Institute of Occupational Safety and Health (NIOSH) report there were more than 93,000 work-related deaths between 1980 and 1995 in the United States (Marsh & Layne, 2001). This figure translates into approximately 16 people being killed at work every day. Estimates for nonfatal workplace injuries are much higher with totals in the millions annually. For example, the Bureau of Labor Statistics (2004) reported that in 2002 there were 1.4 million workplace injuries requiring missed work time. The high numbers of fatalities and injuries show a critical need for innovations in workplace safety.

How might safety improvements be achieved? One approach to enhancing safety is to use the classical hazard-control hierarchy. This approach emphasizes a sequence of steps in order of priority: (a) hazards should be eliminated through design; (b) if hazards cannot be eliminated, then they should be guarded against through physical barriers or procedures (e.g., a dead man switch that disengages power when the operator releases a control); and (c) if hazards cannot be designed out or guarded against, then the persons at risk should be warned about the hazards and be informed of the precautionary measures that they should take. Eliminating and guarding against hazards are the best methods and should be used if feasible and practical. However, when hazards have not been designed out or guarded against, this means that the third option, warning people, should be used.

Sometimes the hazard control hierarchy also includes training. Like warnings, training is a form of safety communication but usually entails demonstrative and formal safety presentations. Training is clearly an important option for safety communications in workplaces because employers have considerable control and responsibility for their workers' safety. In this chapter, however, we will limit our discussion primarily to safety communications involving facility and environmental warning signs.

In workplaces and in other environments, warning signs can take many forms. They may be a poster, placard, decal, tag, or sign placed on or near a hazard. The sources of warnings in workplaces may originate from: (a) manufacturers on equipment and products that they produced; (b) employers for local concerns about the particular hazardous environments and tasks; and (c) government through regulation and guidance to manufacturers and employers.

This chapter reviews research on warning signs and how they may influence safety in workplaces. Initially, the American National Standard Institute's warning sign standard is described (American National Standards Institute, 2002) because it has direct applicability to the topic of this chapter. Next, to organize research on warning signs, a three-stage information-processing

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model is used with the stages: (a) noticing, (b) comprehending, and (c) complying with the warning. Although this review primarily focuses on sign research and issues, occasionally we draw results from consumer product label and traffic sign research areas to fill in gaps of coverage regarding the model's three stages. Other chapters in this Handbook describe research associated with consumer product warning labels (Lesch, chap. 10, this volume) and traffic signs (Dewar, chap. 13, this volume). Later, gaps in standards/guidelines and research are explored.

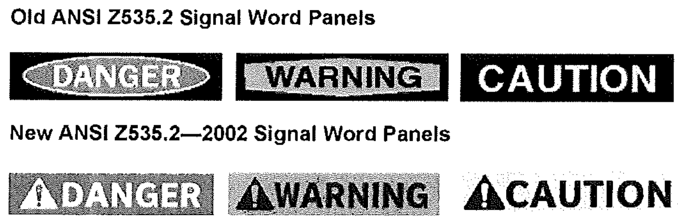

FIGURE 11.1. Old and new ANSI Z535.2 signal word panels for warning signs for facilities and environments.

ANSI Z535.2 Warning Sign Standard

Signs are defined in the American National Standards Institute (ANSI) Z535.2 *Standard for Environmental and Facility Safety Signs* as a "sign or placard in a work or public area that provides safety information about the immediate environment" (ANSI, 2002). These signs are intended to make people aware of a hazard, to provide guidance on how to avoid the hazard, and to provide information about the hazard's consequences. The ANSI Z535 standard also includes several other parts that are applicable to environmental and facility signs. Two pertain to specific design aspects or components of warning signs, Z535.1 *Standard for Safety Color Codes* and Z535.3 *Standard for Criteria for Safety Symbols*. In addition, another part is Z535.5 *Standard for Safety Tags and Barricade Tapes (for Temporary Hazards)*, which may be employed in workplaces for preventing use of machinery while it is being serviced and limiting entry into hazardous areas.

The ANSI standards seek to foster consistent warning design to enable recognition of hazards. The standards are voluntary; they are not regulations. However, in the United States the Occupational Safety and Health Administration (OSHA) hazard communications statutes are enforceable laws. OSHA references ANSI warning standards in its hazard communication regulations, but the specific reference is to an older and out-of-date standard. Nevertheless, OSHA generally accedes to the newest ANSI Z535 standards as acceptable and probably preferable to the older ones cited in the regulations.

In ANSI Z535.2, there are seven categories of safety-related signs including signs involving DANGER, WARNING, CAUTION, and NOTICE, as well as safety instructions and safety equipment location, fire safety, and directional arrows. Although all of the categories pertain to safety, only the first three categories concern warning about hazards.

In the 2002 version of the ANSI Z535.2 standard, dramatic changes to the specification of environmental and facility sign guidelines relative to the two earlier printings (1991 and 1998) of this standard were made. They are now fully adopted and require the same signal word panel formats as those for consumer products warning labels (i.e., ANSI Z535.4 *Standard for Product Signs and Labels*). The older set of signal word configurations and shapes that were required in the 1991 printing were moved to optional status in the 1998 standard and were eliminated in 2002. One still very common signal word panel is the oval shape around the signal word DANGER. This was eliminated and replaced with the ANSI Z535.4 style with the safety alert symbol (an exclamation mark enclosed in a triangle). Other changes included removing colored backgrounds on text-message panels to enhance legibility and promoting greater use of optional symbols. Figure 11.1 displays the old and new formats for the DANGER, WARNING, and CAUTION signal panels.

In addition to sign format, the ANSI Z535.2 standard specifies the general content of the message panel. The message text is to contain information about the nature of the hazard, instructions on how to avoid the hazard, and the consequences of not following the instructions. An understandable symbol can be used to substitute or reinforce one or more aspects of that content. Although the ANSI Z535 standards are intended to foster consistent warning signs, they do not necessarily cover all aspects involved in designing and displaying effective warnings. For example, the ANSI Z535.2 standard does not cover how to determine whether the target audience at risk correctly understands the warning message. More attention to this last issue will be given later in this chapter.

Despite increased consistency in the signal word panel between posted signs and product labels, these two forms of warning differ. The most obvious difference is that, warning signs (as opposed to product labels) are usually larger and have larger sized fonts so they can be read from a distance. Signs usually contain fewer words than product labels to make them easier and faster to read from a distance. Figure 11.2 displays two warning sign layouts based on the 2002 ANSI Z535.2 standards.

Information Processing

A warning sign's effectiveness depends on a series of events taking place. There are a number of models that have been proposed that divide up the information processing stages involved, including Lehto and Miller (1986), Rogers, Lamson, and Rousseau (2000) and Wogalter, DeJoy, and Laughery (1999). Several chapters in this Handbook give detailed descriptions

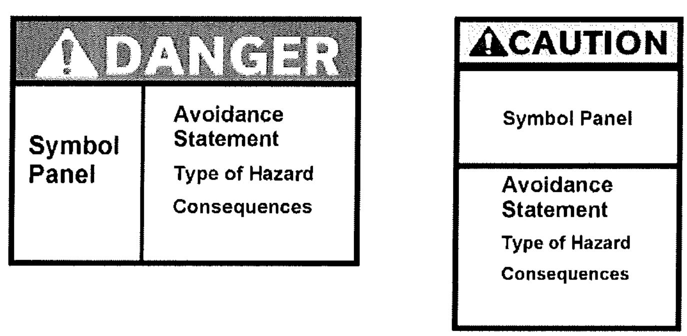

FIGURE 11.2. Example sign formats based on ANSI Z535.2 (2002).

of these models (Lehto, chap. 7, this volume; Wogalter, chap. 5, this volume). Typically these processing models include within them three basic events: noticing the warning, comprehending the information, and complying with the warning. These stages also provide a useful tool for organizing empirical research on warnings. We use them to structure our discussion of warning sign research. Later, we describe gaps in the research literature and opportunities for future research contributions within each processing stage.

NOTICING THE WARNING

Initially warnings need to be noticed. If people fail to notice a warning, then the warning itself, except for indirect communications from other sources, will have little or no utility. If people never detect the warning, then the other processing stages that follow noticing will not be initiated. In other words, if a person does not see a warning then he or she will not receive (at least not directly) any information to assist in understanding the hazard and will be unable to make informed decisions regarding the compliance instructions. Thus, the warning needs to be noticed for the receiver to start warning processing.

It is interesting to note that research specifically concerning the noticeability of environmental and facility warnings is relatively limited compared to research on the noticeability of warnings on product labels (Lesch, chap. 10, this volume) and traffic signs (Dewar, chap. 13, this volume). There is a growing research base on warning signs, but research specifically on warning sign noticeability is relatively limited, particularly if one limits the search to specific objective measurement criteria, such as eye movement and looking behavior. Measurement on warning sign noticeability is mainly found in research primarily concerned with compliance (see Kalsher & Williams, chap. 23, this volume). The noticing measures in these experiments are often retrospective reports on a questionnaire after the primary behavior phase is over. In other words, the data on noticeability has been collected secondarily to the primary measure of compliance. Nevertheless, many of the compliance studies have manipulated factors that would tend to affect detection and one can learn from those experiments something about noticeability by the independent variables used in them. Most other warning research has involved nonsign materials such as owner's manuals (Young & Wogalter, 1990), warning labels (Wogalter, Magurno, Dietrich, & Scott, 1999) and advertisements (Wogalter, Smith-Jackson, Mills, & Paine, 2002). Fortunately, many of the results are consistent across methods of study and methods of warning delivery. In the following, some of the main ways to increase conspicuity are described.

A fairly consistent finding across warning research is that increasing conspicuity increases the likelihood that a warning will be noticed. Conspicuity (also called salience and prominence) attracts attention. One way to increase conspicuity is to make the sign itself larger with larger print components (e.g., Godfrey, Rothstein, & Laughery, 1985). Color is another method of enhancing noticeability. ANSI design standards use three main colors to indicate danger level (i.e., from red to orange to yellow—see Fig. 11.1), but color can also help signs stand out from most environments in which they are placed (Bzostek & Wogalter, 1999). Features such as the addition of symbols and borders may also assist in adding conspicuity. For example, the alert symbol that depicts an exclamation point within a triangle (see the new ANSI signal word panels in Fig. 11.1 has been found to attract attention to warnings on product labels using measures of response time and eye movements (Laughery, Young, Vaubel, & Brelsford, 1993b). Bzostek and Wogalter found that symbols can facilitate search time for warning information on pharmaceutical labels. Wogalter and Rashid (1998) found that thick colored borders around a warning sign increased looking behavior.

The warning's location can influence whether people notice it. Frantz and Rhoades (1993) increased a warning's noticeability by placing the warning at a location where it would be seen when the information would be most needed. Duffy, Kalsher, and Wogalter (1993) had participants work with electronic equipment and extension cords and observed whether an extension cord warning was heeded (not to use it with multiple pieces of high-power-consuming equipment). Duffy et al. found that noticing dramatically improved when tag labels required interaction to use the product compared to the same labels being attached to the cord and not requiring interaction.

In some situations, warnings signs are noticed at relatively low rates. For example, Goldhaber and deTurck (1989) found that fewer than half of high school and middle school students reported being aware of a warning sign about diving in the shallow end of a swimming pool. Wogalter, Racicot, Kalsher, and Simpson (1994) had participants take part in a mock chemistry experiment and compared noticeability for two nearly identical warning signs comprised of light emitting diodes (LED) stating either "CAUTION! IRRITANT Use Mask and Gloves" or in the other condition the "CAUTION" replaced with the participant's name. Use of a person's name is well known in the auditory attention research literature (e.g., Moray, 1959) to attract and orient individual's attention. In this experiment 61% recalled seeing the sign with their name on it compared to 36% for the nonpersonalized version. Note that approximately one third of the participants in one condition and nearly two thirds in the other condition did not recall seeing the sign.

Why do some studies report relatively low rates of noticing? Some insight can be drawn from a closer examination of the purposes of these studies and their methodology for measuring noticeability. First, the purpose of these two studies (Goldhaber & deTurck, 1989; Wogalter et al., 1994) and other research like it (e.g., Wogalter, Kalsher, & Racicot, 1993) is mainly to examine and measure compliance effects of manipulated warning factors. The measurement of noticeability is usually examined by an after-the-fact (post hoc) questionnaire given to collect some information about the participants' experiences. Thus, in compliance studies, the noticing data often comes from self-reports following exposure to a sign when participants are asked whether they noticed the sign. Caution should be employed in taking these self-reports as an accurate measure of noticing. Self-reports can sometimes be influenced by other factors. These influences include after-the-fact rationalizations by the participants to give a reason why they did not comply, perceived pressures to give socially acceptable answers, inaccurate understanding of the question, inaccurate memory, and others.

A study by Smith-Jackson and Durak (2000) also gave insight on noticeability failures. Their experiment used two signs in a similar kind of chemistry laboratory to that described in Wogalter et al. (1994). One sign was comprised of text-only (with black, 16-point font and a white background) and the other was an ANSI-compliant warning sign (with an orange WARNING signal word panel). In describing their results, Smith-Jackson and Durak reported that, "No participants looked at or read the warning signs in the posted warning conditions before beginning (p. 4-117)." Participant self-reports that asked for reasons why they failed to notice the signs were collected after the study. The answers had two general themes. Some participants said they perceived the hazard to be low and were not motivated to seek additional information. Others said that they were too busy working on the experimental task to notice the warning sign. Both of these types of responses suggest that other factors are at work besides the warning sign itself. If people do not perceive a risk, they may not look for or notice a warning (Wogalter, Brelsford, Desaulniers, & Laughery, 1991). Also if workload is too high, it may be difficult for people to shift attention to a critical warning sign when the information is needed (Wogalter & Usher, 1999). There is little doubt that many accidents in the workplace and elsewhere occur because of worker overconfidence and high workload. However, in results noted earlier (Duffy et al., 1993; Frantz & Rhodes, 1993), there are ways to counteract low noticeability, such as conspicuity features, interactivity, and location.

There are also other ways of increasing noticeability. One is to increase people's level of perceived hazard. Low-hazard perception is associated with a lower likelihood of looking for and reading warnings. Therefore, if the level of perceived hazard is raised, it may compel a person to look for and read warnings, which in effect increases the warning's noticeability. This process relates to feedback from the comprehension stage (discussed in detail later) or more specifically, the beliefs and attitudes stage (see Wogalter, chap. 5, this volume), which provide feedback to the attention stage. For example, Otsubo (1988) found that people reported noticing a warning on a power tool that was perceived more hazardous more frequently than the same warning on a similar power tool perceived as less hazardous. Methods of increasing perceived hazard could include training and educational campaigns. For example, in workplace settings the establishment of a positive safety culture could result in encouraging coworkers to look for and explicitly point out to others warning signs to facilitate the noticing process. A positive safety culture could help to foster appropriate levels of hazard perception in which workers are more likely to search for and notice warnings.

In addition, research described earlier suggests that taking both an intrinsic as well as an extrinsic approach may be beneficial for facilitating the noticing process. Intrinsic factors are those aspects related to the design of the warning sign itself such as size, color, borders, and symbols. Extrinsic factors are aspects outside of the warning design that affect noticing. They can be person factors such as hazard perception, stress, mental workload, and task involvement. They can also be environmental factors. Visual clutter is another extrinsic nondesign factor that could influence noticeability. Decreased clutter in the areas around the signage may facilitate the warning sign's relative salience (Wogalter et al., 1993). Thus, various strategies could be undertaken to affect not only the intrinsic design of the warning sign but also influence extrinsic factors. Another promising area is the addition of sound (including voice) to help direct people's attention to a visual warning display (e.g., Wogalter, Kalsher & Racicot, 1993; Wogalter & Young, 1991). We will have more to say about the use of auditory cues later in this chapter.

Most research examining the effects of characteristics that perceptually enhance the noticeability of warning signs and labels are laboratory studies using indirect measures of self-reports and memory. A more direct, ecologically valid measure of visual attention is whether a person directs his or her view to the warning and the amount of time he or she spends examining it; in other words, looking behavior. Wogalter and Rashid (1998) used a looking behavior measure in a field observational experiment to determine whether adding a rectangular border around the warning text would improve the warning sign's salience. Six conditions were tested. Four different borders surrounded warning text, and two control conditions were text with no border and no text/no border. The signs were individually posted in a university campus building and data were recorded from more than 1,200 people on whether they looked at the sign and the amount of time they spent examining the sign. The results showed that signs with thick red and thick yellow/black diagonal stripes were noticed more frequently and were examined for a longer time period than signs with thin red or black borders or no border.

Generally, characteristics that help a warning stand out (such as increased size, color) from the environment in which the sign is placed increase the likelihood that it will be noticed, although not all studies show this effect. Noticeability can be influenced by extrinsic factors including hazard perception, task involvement, workload, stress, and environmental clutter. Another important factor that lies in a gray area between intrinsic and extrinsic factors is location. Clearly, if the warning is in a place where a person is unlikely to look, then it is less likely to capture attention. Task analysis should help in determining locations that persons at risk are more likely to look (Frantz, Rhoades & Lehto, 1999). In addition, sound cues coming from the direction of a sign would likely assist in capturing attention to a sign not previously in view.

COMPREHENDING THE WARNING

Once noticed, the receiver must understand or comprehend the message in order to make appropriate decisions regarding the hazard and how to avoid it. As mentioned earlier, the ANSI Z535.2 warning standard recommends that a warning message panel should convey (a) what the hazard is; (b) instructions as to how to avoid the hazard; and (c) the consequences of not avoiding the hazard. The general need for these three components for effective warnings has been supported in research (e.g., Wogalter et al., 1987). In this section, findings related to warning sign comprehension will focus on two components of warning comprehension, text and symbols, as well as messages that combine both symbols and text.

Text Components

A considerable body of research has been accumulated on various aspects of the textual portions of the warnings such as signal words and text messages (for a review see Rogers et al., 2000; Parsons, Seminara, & Wogalter, 1999). Several findings on research specific to warning signs will be discussed.

Wogalter et al. (1987) developed a large number of signs that varied in content. Signs having four components (i.e., signal word, hazard, consequence, and instructions) were compared to signs with three components (i.e., lacking one component). Wogalter et al. examined how the component statements contributed to a complete sign of all four statements on people's ratings of perceived hazard. In general, the results showed that the highest levels of perceived hazard occurred when all four sign components were present than when there were just three. However, in some cases three component signs were rated higher than their corresponding four component ones. Wogalter et al. argued this latter result was due to portions of the four statement signs that were redundant or already implied by the other parts of the signs. Signs with the extraneous information received lower evaluations than their briefer counterparts without the extraneous information. The point is that all four parts are important but the wording can be abbreviated if the information is already implied by the sign. However, care should be taken when eliminating components to ensure that the sign still conveys all of the necessary points.

Although signal word panels (including color and the alert symbol) benefit noticeability, they can also benefit comprehension with respect to their connoted perceived level of hazard. In the ANSI Z535 standards, the signal words DANGER, WARNING, and CAUTION have specific definitions assigning them different levels of hazard based on severity and probability (see also Peckham, chap. 33, this volume). DANGER is for the highest level of hazard, and CAUTION is for the lowest level of hazard. However, research has indicated that people's perceptions of these terms may be different than the defined hierarchy (for a review see Leonard, Otani, & Wogalter, 1999). Although studies have found DANGER connotes a higher level of hazard than the other two words (which concurs with the standard), most studies show that people do not differentiate between WARNING and CAUTION (e.g., Leonard et al., 1999). Thus, according to people's perceptions, there may be only two levels of signal words with DANGER being higher than WARNING and CAUTION, with no difference between them.

Drake, Conzola, and Wogalter (1998) compared these three signal words and two additional terms, NOTICE and DEADLY. NOTICE is a signal word defined in the ANSI Z535.2 standard for important, but not hazard-related information. DEADLY is not one of the signal words used in the ANSI S535 standard but has been suggested in previous research to be an understandable, high-hazard connoting term (e.g., Wogalter & Silver, 1995). Participants were given several definitions of the terms derived from different sources, such as ANSI Z535.2 and Webster's Dictionary, and then they were asked to match these definitions to the set of signal words (i.e., DEADLY, DANGER, WARNING, CAUTION, and NOTICE). The two extremes, DEADLY/DANGER and NOTICE resulted in the easiest matching between the definitions and signal words. Participants had difficulty with the terms in the middle, namely, WARNING and CAUTION. The results also showed that DEADLY connoted the highest hazard level and was more frequently assigned to the ANSI Z535 definition of DANGER than was the term DANGER itself.

In most signal word research, the terms' connoted hazard levels have been studied in isolation from other components of the warning sign. In Wogalter, Kalsher, Frederick, Magurno, and Brewster (1998), signal words were presented in entire panels including the alert symbol (triangle, exclamation point), color and in other configurations, as well as in context of full warning signs. The results showed that, in context with other components of a warning, DEADLY was again found to have a higher level of hazard than DANGER, which in turn was higher than WARNING and CAUTION. The latter terms did not differ, as was reported in other research described earlier.

Wogalter et al. (1998) noted that DEADLY may be a good signal word choice to consider for extremely hazardous situations (e.g., see also Wogalter & Silver, 1995). Some of the reasons include: (a) it is understandable to low literates, non-English users, and elementary school children (Wogalter, Frederick, Magurno, & Herrera, 1997); (b) its connoted hazard is higher than the currently highest level ANSI Z535.2 signal word, DANGER; and (c) it is likely to be used selectively for hazards that are particularly extreme. In workplaces with many signs having the term DANGER, there may be a problem of workers becoming habituated to the term. Using signs with DEADLY only for the most potentially egregious hazards may be more effective.

Based on all of the research on signal words, it would seem that if the desire is to have three distinctive levels of signal words that people can discriminate without training, then the terms from highest to lowest should be DEADLY, DANGER, and WARNING/CAUTION, with the latter two having the same hazard connoting value.

Comprehension may also benefit from formatting. Desaulniers (1987) found that warnings in a bullet point outline-type list are rated higher on perceived effectiveness than continuous paragraph prose. Warning label research suggests that it is beneficial to use white spacing to break up the text into "chunks" of information (Wogalter & Vigilante, 2003). Formatting can be used to show the organization of the message.

With regard to content, we have already mentioned that research has supported the use of the four components of a warning: the signal word and the three elements of the message panel (i.e., information on the hazard, consequences, and instructions) with the possible exception of redundancy. There has also been extensive research concerning explicitness of the text message panel (Laughery, Vaubel, Young, Brelsford, & Rowe, 1993). Specific messages benefit comprehension because there is less to infer compared to general messages. Consider the non-explicit statement "Adequate ventilation needed." This phrase is open to interpretation and some of the interpretations that are generated may be incorrect. For example, does it mean to use a respirator, to open a window, to open two windows or doors for flow-through ventilation, or to turn on an exhaust fan? Table 11.1 presents some of the text messages used in a study of explicitness by Braun and Shaver (1999) together with the mean hazard ratings assigned by participants. Overall, the more

TABLE 11.1. Text Messages that Vary in Explicitness

Explicitness	Warning Message for Electric Shock Hazard	Warning Message for Hand Entrapment Hazard	Mean Hazard Perception Ratings*
None	Turn off power before servicing.	Do not operate without guards in place.	9.34
Low	To prevent electrical shock, turn off power before servicing.	Do not operate without guards in place, gears can injure hands.	10.29
High	To prevent electrocution and death, turn off power before servicing.	Do not operate without guards in place, gears can crush hands.	11.42

Note. There was no prespecified ratings scale (e.g., a 5-point scale). Instead participants assigned any value they thought indicated the perceived hazard level. Adapted with permission from *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, 1999.

explicit text messages resulted in higher hazard ratings. In addition to hazard ratings, explicitness also appears to positively benefit other measures of warning effectiveness (Laughery, Vaubel et al., 1993). In general, more explicit warnings better communicate hazard-related information, but this must be tempered with the simultaneous consideration for brevity and relevance to the targeted group.

Symbols

Symbols may communicate a safety message to a wide range of people because they do not rely on written words to convey their meaning. Symbols offer the potential to communicate safety messages to illiterates or low skill and non-native language users. Despite this potential, there is the problem that a poorly developed symbol design could actually convey a hazard to fewer people than a text message would. ANSI Z535.3 recommends that symbols be submitted to a comprehension test. To be used on a warning without an accompanying text message (i.e., the hazard, instructions, and consequences), a symbol should meet or exceed a comprehension criterion of 85% correct answers with no more than 5% critical confusions with a sample of 50 participants. The appendix of the ANSI Z535.3 standard gives guidance on methods of conducting comprehension testing. An evaluation procedure is essential to determine whether it is appropriate for a symbol to be used on a warning. More about the evaluation of symbols can be found in other chapters in this Handbook (Deppa, chap. 37; Goldsworthy & Kaplan, chap. 59; Wogalter, Silver, Leonard & Zaikina, chap. 12; Johnson, chap. 36).

Wolff and Wogalter (1998) pointed out that context is an important aspect of symbol comprehension. They tested a large set of industrial safety pictorial symbols among other designs and presented the symbols either with or without a context. In this experiment, the context was a photograph of a setting where you might find the warning. The results showed that context provided a significant benefit to comprehension performance. This research highlights the need to consider context when evaluating safety symbols as some symbols presented without context may fail to meet the ANSI criterion despite being effective in their actual setting. Wolff and Wogalter also argued that open-ended test formats are superior to multiple-choice tests. Multiple-choice tests suffer from several difficulties that open-ended questions do not. Multiple-choice tests increase the likelihood that participants can guess the correct answer by chance. They require the development of a set of plausible alternative answers, which can be difficult. Implausible alternatives will not be selected by participants and so may overestimate comprehension by higher selections of the correct answer. Last, the multiple-choice test itself does not approximate how people go about recognizing a symbol's meaning in real settings. Thus, Wolff and Wogalter's research and ANSI Z535.3 (2002) strongly suggest the use of open-ended tests of symbol comprehension.

Combined Text and Symbols

Research has also examined the effectiveness of having both text and symbols in warnings. For example, Young (1997) asked people to pick from a set of signal words, symbols, and text messages to create warning signs they thought would best convey information about several different types of safety hazards. Participants generally included symbols that conveyed a specific meaning and augmented a text message. That is, the symbol content provided the same information as the text portion of a warning sign instead of signifying a more generic concept such as danger.

Dewar and Arthur (1994) also found that using both symbols and text was beneficial in warning people about water safety hazards near a hydroelectric utility plant. They examined comprehension by working with a diverse group of research participants comprising different age groups, education levels, and reading ability (e.g., including illiterate participants). In Dewar and Arthur's study, some symbols were difficult to understand in the absence of a text message. The diversity of this research sample demonstrates why redundant usage of a symbol and text could be beneficial. However, Winter (1963) suggested that text messages do not necessarily improve comprehension when poorly designed symbols are used.

Wogalter, Sojourner, and Brelsford (1997) found that participants who did not comprehend the meaning of industrial safety symbols on an initial comprehension test, dramatically improved their comprehension after being given a short training period involving the correct verbal description. Lesch (2003) reported similar findings. Cairney and Sless (1982) reported the benefits of symbol training with non-native English speaking immigrants in Australia. Thus, several studies have shown that poorly comprehended symbols can be significantly better understood following training (Cairney & Sless, 1982; Lesch, 2003; Wogalter et al., 1997). Such training can be given in many workplace settings.

COMPLYING WITH THE WARNING

Compliance is perhaps the ultimate outcome measure on whether a warning sign has been successful. In most models of warning processing, it is the culmination of the previous processing stages; for compliance to be attributable to a specific warning sign, the sign must have been noticed and comprehended. From a research standpoint, compliance behavior is the most difficult to investigate. The reasons include: (a) one cannot expose persons to real risks because of ethical and safety concerns; (b) events that could lead to injury are relatively rare; (c) the constructed situation must appear to have a believable risk, yet at the same time must be safe; and (d) there is cost involved in running such research in terms of time, money, and effort. Nevertheless, compliance is an important criterion in determining which warning methods work better than others.

A number of studies have used a chemistry experiment procedure as described earlier (e.g., Smith-Jackson & Durak, 2000; Wogalter et al., 1993). These experiments were designed to simulate a hazardous task where participants mix and measure colored liquids or other nontoxic materials. The experiments used an incidental exposure method in which the participants were not cued beforehand that the purpose of their activity was to measure their compliance to a warning. Rather they were told that they were participating in a study that had some other purpose, for example, the accuracy of the chemical mixing performance. In the situation, a manipulated warning was presented telling the participants to don protective equipment (e.g., mask and gloves). Wogalter et al. (1993) found that a voice warning improved compliance rates in their chemistry task, but found no additional benefit of adding symbols to the signs, probably because compliance was already very high without the symbols (i.e., ceiling effect). Jaynes and Boles (1990) also examined the effects of using text only, symbols only, or combined text and symbol warnings on compliance for wearing protective gear during a chemistry experiment. In their study, Jaynes and Boles were able to show that the addition of symbols benefitted compliance and found the highest compliance rate occurred with the combined symbol and text warning.

The findings from the chemistry laboratory experiments are useful because they highlight some general principles of warning processing. Over the years, other methodologies to measure compliance have been used, although not all involve warning signs. Some of these methods have involved product-related labeling in scenarios where participants installed electronic equipment or used power tools. These and other methods may be criticized in terms of generalizability to other situations. However, across numerous laboratory studies using different methodologies, there is a general overall concordance in results using comparable manipulations. This suggests that there are some general warning principles.

Observational Research

In addition to laboratory research, warning compliance has been measured outside of the laboratory—in field settings. For example, Laner and Sell (1960) examined the benefits of safety posters in an industrial work setting and found a significant increase in compliance (i.e., hooking a chain sling onto a crane to prevent injury or damage) after the safety posters were installed. Wogalter et al. (1987) provided demonstrations of multiple instances where a warning can be effective in the real world. In one group of studies, they found that in the presence of a sign indicating that a telephone or copy machine was "out of order" there were very few attempts to use the machines, but attempts were made when the sign was absent. Wogalter et al. also showed that in the presence of a conspicuous warning on a water fountain regarding questionable purity, fewer persons attempted to drink from it compared to times when the sign was absent.

Also, in the Wogalter et al. (1987) report, there was a field demonstration of a particularly important factor for warning sign effectiveness, cost of compliance. Signs were posted on doors of buildings on a university campus indicating that the door was broken and directing persons to another working door. When the alternative door was nearby, a greater percentage of people complied with the directive to use the alternative door compared to when the alternative door was farther away. A similar finding is given in Dingus, Wreggit, and Hathaway (1993) involving compliance to warning sign conditions for the use of eyewear at a racquetball facility. Dingus et al. compared conditions differing on the difficulty (effort and time) of procuring protective equipment. Higher compliance (88% compared to 25%) was found when the directed behavior was easy to perform than when it was difficult.

Field research has shown that other factors also influence warning sign compliance. One such factor is social influence, that is, when others in the immediate environment influence what a person does by modeling behavior, or in this case whether the other person complies or not. Wogalter, Allison, and McKenna (1989) showed the effects of social influence using not only the chemistry laboratory paradigm described previously but also in a field observational study. Wogalter et al. (1989) posted warning signs next to elevator buttons indicating the elevator was not working properly and to use the adjacent stairs. When a participant walked up to the elevator, a confederate working with the experimenters pushed the button and then looked directly at the sign and either used the adjacent stairs or waited for the elevator. The results showed that when the confederate complied with the sign by using the stairs so did many of the participants, but when the confederate did not comply by continuing to wait for the elevator, neither did the participants. In another elevator study, Wogalter, Begley, Scancorelli, and Brelsford (1997) used four different signs and a no-sign baseline condition to compare three black and white text-only signs each having a different version of the same message (to use the stairs instead of the elevator if only going up one floor or down two floors) in comparison to an enhanced "NOTICE" sign having many of the characteristics of the ANSI Z535.2 format including a signal word panel, color, and symbols. The results indicated that fewer persons rode the elevator to go up one floor or down two floors when the enhanced sign was used (i.e., more people complied). There was a trend showing that the text-only signs produced higher compliance than the baseline no-sign condition; however, there was no statistically significant compliance difference between these conditions.

Wogalter and Young (1991) compared compliance differences for a written warning, an auditory warning (i.e., the warning was read aloud), and a combined written and auditory warning pertaining to a wet floor hazard at a shopping mall. They found that compliance rates were best for the combined written and auditory condition (76%), with some indications that the voice-only warning (64%) was better than the print-only warning (42%).

Like the Wogalter and Young (1991) study, some studies show mixed effects for certain warning format manipulations. Shaver and Braun (2000) conducted one such study. They placed scaffolding in front of a university campus building to simulate a construction hazard and examined compliance for different warning sign configurations. The signs contained a safety alert symbol (i.e., an exclamation point in a triangle), the signal word CAUTION (which had either a yellow or orange background), a text warning (i.e., Overhead Construction—Please Use Center Door), and one of two symbols (i.e., a block falling on a person's head or simply a block falling). Shaver and Braun also used a blank or experimental control sign. In general the presence of a warning increased compliance over the control condition, but none of the different warning sign formats produced better compliance than another.

Virtual Reality

New research techniques have been made possible by technological advances and less expensive development costs, and some researchers have employed these new and promising techniques to test warnings and to overcome some safety limitations. Glover and Wogalter (1997) developed a computerized virtual world to examine how well different warning sign formats helped to guide participants out of a simulated coal mine. They compared egress during an emergency situation versus a low-stress exit to leave for lunch. Glover and Wogalter examined compliance with the six warning signs while participants attempted to egress (e.g., "Unsupported Roof—Keep Out" and "High Voltage—Keep Out"). Half the signs also had a signal word (e.g., DANGER) or directional arrow according to ANSI Z535.2 standards. Although the findings of this particular project were somewhat limited, the research technique clearly holds promise for future warnings research. It is easy to imagine virtual hazardous manufacturing settings where workers can be brought in to test different warning sign locations and configurations.

Systems Approach to Warnings

Research (e.g., Wogalter et al., 1993; Wogalter, Magurno et al., 1998) has shown in several instances that posted warning signs produce lower compliance rates than warnings embedded within task instructions. Other research using product labeling has also shown location to be a critical variable (e.g., Frantz & Rhoades, 1993; Wogalter, Barlow, & Murphy, 1995). Earlier we noted that participants may be focusing on the tasks that they need to perform and may never see a sign that is posted nearby. These results suggest that a systems approach should be used to improve warning effectiveness. A systems-like approach can be illustrated using pharmaceutical product labeling. For example, consider the warning system for children's pain relievers. Typically this type of product includes printed warning statements on the exterior cardboard packaging and on the bottle container that address the most serious hazards posed by the product. More detailed information is presented in a printed package insert. The warning system for this product could also include any warnings in advertisements and on the manufacturer's Web site. The individual components of a warning system may not be identical in terms of content or purpose; some components may be intended to capture attention and direct the person to another component where more detailed information concerning product hazards is available. The outside packaging may serve primarily in assisting purchase decisions and may give less specific information compared to labeling on the container itself or on the insert. Similarly, different components may be intended for different target audiences. Some components of a warning system for prescription drugs may be directed to the prescribing pediatrician or the pharmacist who fills the prescription, and still others may target parents who will ultimately administer the medicine to the child. The systems approach to warnings helps to ensure that different end-users in different situations receive the safety information they need.

Research by Kalsher, Rodocker, Racicot, and Wogalter (1993) provided a good example of a systems approach. They attempted to improve recycling practices (e.g., placing colored or white papers in the appropriate bins) in an office environment through the use of educational pamphlets, group discussions, and posters. They were able to vastly increase the total amount of recycling and at the same time increase the percent of successfully sorted recycling materials.

The ANSI Z535.2 standards support a systems approach as they mention that training and multiple warning messages may be necessary in some situations.

Thus, with respect to environmental and facilities signs, it is somewhat wishful to expect a single warning to be effective at conveying all that is necessary within some instant of time of exposure. Ideally, people should have the opportunity to receive warning information from multiple sources such as instruction manuals, material safety data sheets (MSDS), as well as posted warnings. Not all of these materials are necessarily intended for everyone who may be exposed to a chemical hazard. For example, the MSDS might be useful to an industrial hygienist, but the worker handling the chemical might not read the MSDS. However, other materials could reach the worker such as posted signs and poster/placards as well as warnings from supervisors who may know the personal protection equipment from other sources.

Clearly, safety training is another important vehicle in communicating warnings. It is a way to familiarize employees with a variety of safety information. But the system needs redundancy because not everyone who may be at risk will be given quality training or views other materials. Ideally, everyone would receive exposure to the chemical hazard warning from multiple sources. In the warning system, signs might serve as a reminder and reinforce knowledge already instilled from exposure to supporting materials viewed at an earlier time.

In such cases, warning signs are no longer viewed as the primary safety control systems, but as an effective reminder. Prior training eases the demand placed on a warning to convey all of the information in the instant that it is seen.

This set of complex interactions among multiple sources of warnings stands in contrast to the notion that a single warning sign posted on a wall will be sufficient to prevent hazardous exposure. It is better to have the sign be considered as functioning as just one component in the system. This is not to say that signs are inadequate or unnecessary compared to other sources of warnings, as each of these components serve different purposes and each is limited in its capabilities. Clearly, the posted warning sign is one of the most important sources because it may serve as the only point of contact for persons who have not received information from other sources.

Sign research also suggests the importance of providing warning information in multiple locations or having them emanate from multiple sources. The use of multiple warnings increases the chances that people will see at least one warning and process the warning information when needed. This may be particularly important when people are engaged in absorbing work tasks (Wogalter, Magurno, Rashid, & Klein, 1998; Wogalter & Usher, 1999).

Warnings in multiple locations increase the likelihood that people will be exposed to the warning and see it. At the same time, signs should not be placed everywhere—only in relevant locations (Frantz & Rhoades, 1993). Thus, it is important to consider the environment in which the warning will be placed. Some of the reasons for conflicting research results may pertain to the context in which the manipulations occur, including warning location, characteristics of the environment, target audience characteristics, and task involvement. Clearly, it is not just the sign but also other parts of the system that affect compliance behavior.

Alternative Warning Techniques

Just as new methods have emerged for studying compliance, there are also new techniques for presenting warning information that merit consideration in the future. Racicot and Wogalter (1995) demonstrated the potential for video warnings almost a decade ago. Technology, such as flat screen panels, may make it easier to develop dynamic warning signs that could be animated to show a series of safety steps. Other research projects have employed some untraditional or innovative warnings. As mentioned previously, Wogalter et al. (1994) used LED-warning signs that contained either a signal word (e.g., CAUTION) or the participant's name. They found increased compliance rates for the personalized condition.

Wogalter and Young (1991) and Wogalter et al. (1993) found substantial increases in warning compliance when voice warnings were added to a printed warning sign. Of course, auditory warnings will only be effective to the degree that the listeners understand the language that is spoken; further, these warnings may not provide a benefit in noisy environments or for the hearing impaired. However, they show promise and with the decreasing costs of voice chips and sensor systems, they may have utility in an increasing number of warning applications. More information on the ways that technology may benefit the future of warning signs is given in Wogalter and Mayhorn (chap. 63, this volume).

CONCLUSIONS

Safety researchers experience many challenges when studying information processing of warnings signs and other types of warnings. Sometimes it can be difficult to isolate causal relationships within the processing stages. For example, if researchers examining compliance effects do not also include attention and comprehension measures in the study, the underlying basis for failing to comply may go unrecognized. Compliance rates can be affected not only by the noticing and comprehension stages, but also by people's personal beliefs and motivations and situational and environmental factors. Further, compliance behavior can be especially difficult to study because of ethical and safety considerations. It can also be difficult to isolate effects because of indirect influences on warnings processing in some kinds of field studies, such as word-of-mouth among coworkers. For example, Laner and Sell (1960) found increased compliance rates after their safety posters were installed. Was this effect because of more of the signs being noticed directly by many workers or because of a few workers noticing them and spreading this information to their coworkers indirectly? Finally, because some compliance studies are difficult and time consuming to conduct, particularly those involving single-participant sessions combined with a single measure of compliance (or not), some studies may suffer from sample sizes too small to detect positive effects.

In behavioral compliance studies, it is clear that the presence of a warning sign compared to its absence produces the biggest effects on compliance behavior, for example, the wearing of personal protection equipment. Effects of sign design manipulations such as formatting are usually much smaller in comparison to the warning presence versus absence difference (e.g., Glover & Wogalter, 1997; Shaver & Braun, 2000). These findings indicate the importance of doing *something* to communicate hazard information to people. In other words, giving people information and ensuring that it is available may be the most important step.

The ANSI Z535.2 (2002) standards leave room for improvement. For example, regarding the sign placement locations, the standards say, "Safety signs shall be so placed that they are legible, non-distracting, and not hazardous in themselves (p. 12)." Certainly these are worthy goals, but how do can one be sure these goals are met and how can we guide people who are unfamiliar with warnings research to place warning signs in optimal locations? More specific guidelines for evaluating warning sign placement would be helpful. In addition, the current ANSI standards contain no evaluation criteria to determine if the warning is performing the role intended, except for comprehension testing of symbols in ANSI Z535.3. Clearly, evaluating the effectiveness of the warning message is critical for safety. Testing can provide meaningful information to improve the warning. Furthermore, the problems with the hierarchical structure of the signal words have been known in warning research for more than a decade. A large proportion of the public for whom the warnings are directed does not understand the ordering of WARNING and CAUTION. So although ANSI defines them as two separate levels, most people do not know this. In addition, research has revealed that DEADLY could be a good signal word that could be reserved for the most hazardous situations yet according to ANSI, DANGER is the highest level of signal word. Unfortunately, DANGER signs in the industrial workplace have become relatively common and for a highly critical hazard, they may no longer signal the extent of hazard that DEADLY might. Likewise, few people probably know that the presence of an alert symbol within a CAUTION signal word panel as defined by the ANSI Z535 standard indicates the risk of personal injury but that a CAUTION signal word panel without the alert symbol indicates property damage. We suggest that the standards be based on and modified using research on what people understand about warnings, rather than having to require training before the hidden secrets in the standards can be understood. It is apparently assumed that people will somehow learn the somewhat arbitrary distinctions. One of the most important principles in the human factors discipline is that designs that make use of what people already know will be more successful than designs requiring them to learn some artificial designation. Research on what people know and expect should serve as the basis for future changes in the standards.

Future Warning Signs Research

Several indications suggest that there will be future advances in warning sign application and research, especially in the use of new techniques for conducting research and for presenting warning information. Newer research techniques such as virtual reality hold promise for providing new ways to evaluate each warning stage. Virtual worlds can be created to test new warning designs and these computer-generated environments offer considerable potential for advancing the research in warnings. Some of the benefits include high degrees of experimental control, accurate monitoring of participant behavior throughout task performance, rich contexts, and the ability to examine a greater variety of hazardous activities while maintaining participant safety. In addition to changes in the methods that might be used, warning signs themselves may change because of technology advancements. As flat panel displays become less expensive and more reliable, it may be possible to use dynamic signs to develop interactive warning signs where people could actually ask for clarification, instructions, or more detailed information. (For more information on technology and warnings see Wogalter & Mayhorn, chap. 63, this volume.) Regardless of what types of developments transpire in warning sign research and design, the true measure of accomplishment will be better risk decisions and safer behavior.

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