CHAPTER 8

Designing Effective Warnings

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Since the early 1980s there has been an increased interest in research on warnings. This chapter has several objectives. First, we describe the purpose of warnings and where warnings fit with other safety considerations, such as design and guarding. Next, we present a model that incorporates both communication and information-processing concepts, which is characteristic of theoretical orientations that have guided much of the warning research. The research and application issues have generally focused on two themes: design factors and nondesign factors that influence warning effectiveness. Third, we review the progress and status of research and application, with an emphasis on identifying those factors that appear to be most important in determining warning effectiveness. Finally, we conclude with a discussion of some of the challenges and opportunities facing warning designers and researchers in the future.

Concern for public safety has increased in the United States since the 1960s. This concern has been manifested in various ways. Local, state, and federal laws have been introduced to address safety issues. U.S. government agencies such as the Consumer Product Safety Commission (CPSC), the Occupational Safety and Health Administration (OSHA), the Food and Drug Administration (FDA), and the Environmental Protection Agency (EPA) have been assigned responsibilities for public safety in various domains. Regulations, standards, and guidelines concerning product and environmental safety have been promulgated by these agencies and by private organizations such as the American National Standards Institute (ANSI) and Underwriters Laboratories (UL).

Another outcome of the increased concern for safety is the greater attention to and use of warnings. A substantial body of published scientific research on topics related to warning design and effectiveness has accompanied the growing use of warnings as a tool for achieving environmental and product safety. A significant portion of this research has been carried out by human factors/ergonomics (HF/E) specialists and published in HF/E literature.

Several noteworthy reviews and collections of the research literature on warnings have been published. Lehto and Miller (1986) provided a review of early literature on warnings. DeJoy (1989) reported an analysis of the implications of the early warning effectiveness research. A text by Edworthy and Adams (1996) contains a general review of visual and auditory warnings. Other reviews published in the mid- and late-1990s include Laughery and Wogalter (1997); Parsons, Seminara, and Wogalter (1999); Wogalter, DeJoy, and Laughery (1999); and Wogalter and Laughery (1996).

More recent reviews of the warnings literature are Rogers, Lamson, and Rousseau (2000) and Wogalter and Laughery (in press, 2006). Two collections of papers published in the *Proceedings of the Human Factors and Ergonomics Society* have also been assembled and published (Laughery, Wogalter, & Young, 1994; Wogalter, Young, & Laughery, 2001).

Reviews of Human Factors and Ergonomics, Vol. 2, **(2006). R. Williges (Ed.), Chap. 8, pp. 241-271. Santa Monica, CA: Human Factors and Ergonomics Society.**

Finally, a substantial collection of papers reviewing the warnings literature was prepared specifically for a handbook edited by Wogalter (2006).

Warning research questions have tended to focus on factors that influence whether or not a warning will be effective. At the same time, however, a generally accepted underlying theoretical context for the research drawing on communication theory and human information-processing theory has served as a means for organizing the research and as a tool for explaining and predicting warning failures. This theoretical orientation will be described in a separate section.

In order for a warning to be effective, it must accomplish certain things. Generally, a warning must capture attention; that is, it must be noticed and encoded. With some exceptions, people do not typically search for or seek out warnings. Thus, warnings must be sufficiently conspicuous, and they must have characteristics that encourage encoding the content. Warnings must also provide the information needed for recipients to make informed decisions regarding compliance. Compliance decisions can be viewed as based on cost-benefit trade-offs. The costs involved can take the form of effort, time, money, and so on. The benefits of compliance can include avoiding negative health effects, injuries, or property damage. One reason that people do not comply with a warning is that the perceived costs of compliance are judged to outweigh the benefits. Thus, a focus in warning design is to provide the information needed for compliance decisions to be made rationally and wisely. Efforts have been made to apply signal detection and decision theory to warnings (Lehto, 2006).

Whether or not (and how) a person complies with a warning depends not merely on the warning's characteristics but also on many additional factors, such as the user's experience, familiarity with the product or situation, competence or ability to carry out the action, and the perceived costs (effort, time, money) of complying. Others have addressed warning compliance from a similar perspective. Edworthy (1998) developed a decision model based on utility theory for evaluating decisions in the warning process. Similarly, Riley (2006) and Cameron and DeJoy (2006) addressed motivational processes in compliance decisions.

In the language of communication theory, the concept of the medium (or channel) directly relates to warnings. Warnings can be conveyed directly in many media, such as on labels, in product manuals, on signs, in videos, and on computer screens. Alternatively, warnings may be conveyed indirectly, such as from another person who had been exposed to a warning earlier. Regardless of the methods of conveyance, warnings are usually delivered to individuals through the visual or auditory modality, although other sensory modalities are occasionally employed. For example, the propane and natural gas delivered to consumers can be neither seen nor smelled; therefore, an odorant (ethyl mercaptan) is added to allow the use of olfaction to detect leaks. The tactual (including the kinesthetic and haptic) senses are used for built-in vibratory feedback in airplanes when path and speed might result in a dangerous stall.

In this chapter, we review research addressing the design and effectiveness of warnings for products and environments. With some exceptions, these are warnings presented through the visual modality. Chapter 6 by Morrow, North, and Wickens (2006) in *Reviews of Human Factors and Ergonomics, Volume 1* and Chapter 7 by Casali and Gerges (2006) in the current volume describe research and application of auditory warnings in the

contexts of hospital procedures and hearing protection. Because of the existence of these substantial reviews and because research on warnings in the visual and auditory modalities has not greatly overlapped (in part because they are different modalities and have substantially different properties), in this chapter, we focus on visual warnings.

It is important to note the concept of a warning system. The notion of a warning being a sign, a label, a paragraph or picture in a manual, or an auditory alarm is too narrow a view of how such safety information does, or should, get transmitted. A warning system for a particular setting or product may consist of a number of components. The system may include a printed statement on a box, a package insert, a sign on a barrier, a verbal message at the point of purchase, a siren, flashing lights, and so forth. How the components of the warning system interact and complement each other is one of the significant aspects of warning design.

The different components may play different roles in the communication process. Some components may be intended to capture attention and direct the person to another component where more information is presented. A prominent statement on the front label of a toxic solvent container may direct the consumer to read the warning statement on the back label for more detailed information. An auditory alarm may alert (capture the attention of) the control room operator to access a visual display panel for emergency safety information.

Similarly, different components may be intended for different target audiences. Prescription drug warnings in the *Physician's Desk Reference* (an industry compendium of FDA-approved medicine labeling) under the headings of "contraindications" and "side effects" could (and should) employ terminology appropriate to prescribing physicians, whereas warnings on the label of a drug container intended for consumers should use less technical language.

Research on the design and effectiveness of warnings is neither simple nor easy. Ethical constraints and measurement issues abound. It is unethical to expose research participants to actual hazards while manipulating warning systems to assess effects on compliance. Dependent measures are often indirect, which may include assessments of comprehension, beliefs, behavioral intentions, and simulated performance. Although such methodologies play an important role in warnings research, they also leave one with concerns, such as the fidelity of simulations and the extent to which beliefs and intentions are valid predictors of behavior. These issues and related considerations have been addressed by researchers including Young and Lovvoll (1999), Wogalter and Dingus (1999), and Smith-Jackson and Wogalter (2006).

PURPOSE OF WARNINGS

Warnings can be thought of as safety communications. There are four levels of analysis at which the purpose of warnings may be addressed.

Safer World

At the most general level of analysis, a purpose of warnings is to make the world a safer

place. At this level, warnings play a societal role. Improved health and reduced accidents and injuries are ways of measuring and talking about the intent of warnings. Government requirements such as warnings on cigarette packages are examples of efforts to reduce long-term health effects associated with the product. The warning requirements regarding air bags in vehicles can be thought of as an effort to make vehicles safer for the public.

Provide Information

Another purpose of warnings is to provide information. They are, after all, communications. Among the issues here is what should be communicated. Much research and analysis has been reported in recent years addressing such matters. A fair amount of agreement seems to have emerged regarding some of the kinds of information that a warning should provide; included are information about the hazard, information about the potential consequences, and instructions regarding safe and unsafe behavior. In other words, the warning should provide the information people need to make judgments regarding the level of risk involved in a particular environment or use of a product so they can then use that information in making judgments about the level of risk they are willing to accept or not accept (a cost-benefit analysis).

Influence Behavior

A third purpose of warnings can be viewed as an effort to influence or control the behavior of the persons to whom it is directed; that is, to promote safe behavior. Consider the implementation of a "fasten seat belt" warning. If the vehicle occupant does not fasten the seat belt, the warning with respect to its behavioral purpose could be viewed as a failure. If a homeowner using a drain cleaner containing sulfuric acid to clear a clogged drain does not wear rubber gloves and goggles as instructed by the warning, then the attainment of the behavioral goal of a warning could be viewed as a failure. In short, this purpose of the warning focuses on behavior and whether it achieves that intent. It is closely tied to the instructions component of the warning (i.e., what the warning tells people to do or not do).

Reminder

A fourth purpose of warnings is to serve as a reminder. This point can be thought of in terms of a distinction between knowledge and awareness. A person may *know* about a hazard, its consequences, and the appropriate safety behavior, but the critical issue is whether he or she is aware of it at the proper time. Thus, warnings may be intended as reminders; that is, to call into awareness the hazard information that may otherwise be latent in long-term memory or unavailable because of other demands on attention. An example is the auditory signal and visual symbol in automobiles intended to remind occupants to fasten their seat belts.

BRIEF HISTORY OF WARNINGS RESEARCH AND APPLICATIONS

Egilman and Bohme (2006) provided a brief but interesting history of warnings during the period 1900–1980. They noted that the precursors to warnings during this period were auditory and visual signals designed to prevent rail accidents. They pointed out that major legislation, trends in tort law, and corporate strategies concerning warnings were factors in the development of warnings during the first half of the 20th century in the United States. Examples of legislation are the Pure Food and Drug Act in 1906, which was significant in establishing the federal government's regulatory role, and the Federal Caustic Poison Act (FCPA) in 1927, which addressed the effects of chemicals used in households.

During the period 1900–1910, warnings also started to gain prominence when employees began to be successful in suing employers for injuries at work. The introduction of warnings offered employers a defense based on the assumption of risk; more specifically, after being warned, the worker knows the dangers and accepts the risk.

Some of the early efforts to formulate guidelines for warning signs occurred during the first half of the century. Hansen (1914) published a book that included guidelines for the use of warning signs in the industrial workplace. In 1928, the National Safety Council (NSC) published a pamphlet that provided guidelines for the design and use of warning signs (NSC, 1928). The *Manual on Uniform Traffic Control Devices for Streets and Highways* was published in 1935 and contained new guidelines for the construction of warning signs (American Association of State Highway Officials and National Conference on Street and Highway Safety, 1935). Another example a decade later was the first *Manual L-1: A Guide for the Preparation of Warning Labels for Hazardous Chemicals* published by the Manufacturing Chemists Association (MCA, 1945).

The period 1950 through 1980 witnessed a number of developments on the warnings front, including an increased role of government regulation. The Federal Insecticide and Rodenticide Act dealt with government regulation of pesticides and provided warning language for toxic pesticides. The 1960 Federal Hazardous Substances Labeling Act covered a broad array of flammable, toxic, irritating, or corrosive substances. The role of the FDA in warning regulations was increased after public concern in 1962 over thalidomide, a tranquilizer that caused birth defects in children whose mothers took the drug during pregnancy (Pina & Pines, 2002).

One of the outcomes of this increased FDA role was the greater use of the patient package insert as a means of warning consumers. Soon thereafter came the introduction of warning labels on cigarettes, which followed the 1964 Surgeon General's report on the dangers of smoking. Despite intense opposition from the tobacco industry, warnings on cigarette packages and on cigarette advertisements were ultimately required, including rotating warnings (Kluger, 1997).

Two additional government developments in the 1950 to 1980 time frame were the 1970 Act that established OSHA and the 1972 legislation creating CPSC. OSHA has been instrumental in requiring warnings for substances used in industrial work settings, and CPSC has set warning requirements for consumer products.

In addition to the role U.S. government agencies have played in the history of warning guidelines and requirements, the American National Standards Institute (ANSI) has

been influential in establishing voluntary standards for warning signs and labels. Its standards for accident prevention signs (ANSI, 1972), labeling for industrial chemicals (ANSI, 1988), and product safety signs and labels (ANSI, 1991) have provided guidelines for warning design.

Although the foregoing sample of historical events reflects some of the developments of warnings design requirements, guidelines, and use from 1900 to 1980, relatively little formal research was carried out to serve as the basis for these efforts. Then, as mentioned earlier, in the mid-1980s there was a noteworthy upsurge in warnings research. The years since then have produced a substantial body of knowledge regarding warning design and effectiveness. During this period, the types of issues and questions addressed have broadened. Initially, the research questions were straightforward—"Do warnings work?" The research quickly began to focus on design issues that influence when they work. Issues such as how big, what colors, which signal word, and what reading level were typical of the questions addressed. A few years later, the research issues broadened to encompass other questions of effectiveness. What are the factors that influence whether or not warnings make a difference? Dependent measures included behavioral intentions as well as actual behavior. Also, theoretical contexts were introduced such as communication theory and human information-processing theory. It is this research since the 1980s that is the focus of the current chapter.

WHERE DO WARNINGS FIT IN? A SYSTEMS APPROACH

There is a concept in safety (and in human factors) called the *safety hierarchy* or, alternatively, the *hazard control hierarchy.* This concept concerns a sequence or priority of approaches for dealing with hazards. The basic sequence is first to design it out, second to guard, and third to warn. If a hazard exists with a product or in an environment, the first approach is to try to eliminate it through alternative design. If a nonflammable propellant in a can of hair spray can be substituted for a flammable carrier and still adequately function, such an alternative design would be preferred. Eliminating sharp edges on product parts or pinch points on industrial equipment are examples of eliminating hazards. But safe alternative designs are not always technologically or economically feasible.

The second approach is guarding, and the purpose is to prevent contact between people and the hazard. Guards may take several forms. Personal protective equipment such as rubber gloves and goggles, barricades on the highway, and a fence around an electrical station are examples of physical guards. Designing a task so as to prevent people from contacting the hazard is a procedural guard. An example would be the controls on a punch press that require the operator to simultaneously make two control inputs, one with each hand, thus ensuring that fingers will not be under the piston when it strokes. However, guarding—like hazard elimination through design—is not always a feasible solution.

The third line of hazard defense is to warn. Warnings are third in the priority sequence because they are generally less reliable than design or guarding solutions. Even the best warnings are not likely to be 100% effective. People at risk may not see or hear a warning, they may not understand it, or they may not be motivated to comply. Influencing human behavior is often difficult and seldom foolproof. But these concerns about reliability

should not be regarded as a basis for not warning. Rather, warnings are one tool available to manufacturers and designers for dealing with environment and product safety. If they are used, their design should involve characteristics that maximize their effectiveness in reducing or preventing personal injury and property damage.

There are other approaches to dealing with hazards, such as training and personnel selection. These approaches are viewed as similar to warnings in that they mostly involve efforts intended to inform and influence behavior.

THEORETICAL APPROACHES

Two theoretical approaches or models that have been employed for theorizing about and organizing warning research and applications are communication theory and human information-processing theory. It is not our intent to provide a detailed discussion of these theoretical approaches in this chapter. Rather, we briefly describe how these approaches have been employed in organizing how warnings are viewed and researched.

The typical, basic communications model can be represented as consisting of four components: the source, the medium, the message, and the receiver. In the warnings context, these components can be viewed as follows:

- *Source*—the designer, originator, or sender of the warning message
- *Medium*—how the message is presented or displayed (visual, auditory, etc.)
- *Message*—the content of the warning
- *Receiver*—the target audience of the warning

The human information-processing framework is essentially a stages model. It consists of a sequence of stages through which warning information flows. At each stage, the information is processed and, if successful at that stage, "flows" to the next stage. If processing at any stage is not successful, it can block the flow and result in failure of the warning.

Wogalter, DeJoy, and Laughery (1999) combined the communications and human information-processing models into a single framework for warnings. A representation of their Communications-Human Information Processing (C-HIP) model is displayed in Figure 8.1. Similar models have been presented by others (Lehto & Miller, 1986; Rogers et al., 2000).

From Figure 8.1, five receiver stages are defined: attention (notice and encode), comprehension, attitudes/beliefs, motivation, and behavior. As noted, one implication of the model is that if information flowing through the processing stages is blocked or fails at any stage, the warning may fail. However, the process may not be so simple as this linear process might suggest. The feedback loops shown on the right of the diagram are intended to indicate that what happens at one stage may influence the processing at other stages. For example, if a warning is noticed and encoded (the attention stage) but the person realizes that he or she did not understand it (the comprehension stage), or if there is uncertainty about the potential consequences in making a compliance decision (the attitudes/beliefs stage), that person may go back and read it again.

The C-HIP model has been useful in organizing and describing factors that influence

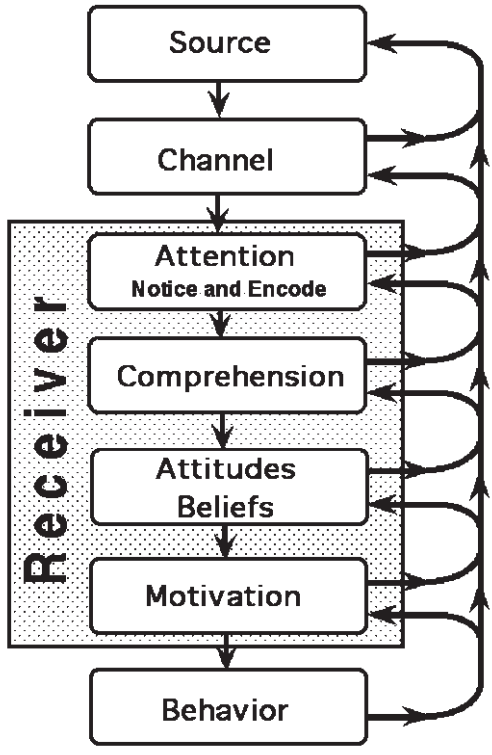

Figure 8.1. *C-HIP model.*

warning effectiveness. Wogalter and Laughery (2006) employed a model similar to the one shown in Figure 8.1 as a basis for organizing their review of the warnings research literature. For example, considerations at the attention stage include warning design factors such as location, size, color, and pictorials that influence whether or not a warning gets noticed and encoded. Similarly, Rogers, Lamson, and Rousseau (2000) organized their review of the literature on the basis of four components of the warning process: notice, encode, comprehend, and comply. They identified 19 person and 38 warning variable effects on the four stages of warning processing and compliance.

Although such analyses have proven useful in organizing and describing factors that influence warning effectiveness, they are also useful in diagnosing warning inadequacies. For example, a warning may be noticed, read, and understood but still fail to elicit the appropriate safety behavior because of discrepant beliefs and attitudes held by the receiver. According to the C-HIP model, a warning will be processed successfully at this stage if it agrees with the receiver's existing beliefs and attitudes. If the warning information does not concur with existing attitudes and beliefs, however, it will have to alter the receiver's attitudes and beliefs in order to be effective.

It is not our intent in this chapter to attempt another review of all the warning design variables and all the target audience variables that influence warning effectiveness. As

already noted, several reviews—some very recent—have been published. Rather, our goal is to identify relevant factors and emphasize those that appear to be most important. Although one can always state "more work needs to be done," it is our conclusion that much has been accomplished in the last 20–25 years in understanding the warning process. It is what can be gleaned from this understanding that this chapter attempts to present.

In the introduction, we noted that in order for a warning to be effective, it must capture attention and must provide the information needed for the receiver to make an informed decision regarding compliance. This latter point can be regarded as a cost-benefit trade-off decision. We also noted that nondesign factors (situation and target audience characteristics) influence whether a warning is attended as well as the outcome of the cost-benefit decision. The following review and analysis is organized around design factors and nondesign factors and their influence on warning effectiveness.

DESIGN FACTORS THAT INFLUENCE WARNING EFFECTIVENESS

In this section, we review research that has addressed the characteristics of warning systems that have a role in whether or not they are effective. The focus is on those design factors that influence the attention goal of warnings and the costs-benefit trade-off decisions regarding compliance.

Attention (Noticing and Encoding)

A number of design factors influence whether or not a warning will be noticed and encoded. *Attention* in this context includes not only whether the warning is seen, heard, smelled, and so on but also whether the information in the warning is encoded (read, listened to, stored in memory, etc.). Several of the influential design factors are what one would expect: size, location/placement, color/contrast, signal word, and the presence of a pictorial. Other factors have also been studied, including length and interactivity.

Size. Bigger is generally better, although what usually matters is the size of the warning relative to other displayed information. Boldness—a form of size—can also be a factor. Barlow and Wogalter (1991, 1993) showed that bigger print size benefited subsequent recall (encoding), and Young and Wogalter (1990) found that print warnings with bigger, bolder print led to better memory for owner's manual warnings. It is likely that such effects are partly attributable to the print's bigger size making it more conspicuous to the reader.

Location/placement. A general principle is that warnings located close to the hazard both physically and in time are more likely to be noticed and encoded. Frantz and Rhoades (1993) found that a warning label placed on a product (file drawer) was noticed more often than when the label was on the shipping carton. Alcohol warnings located on the front of a beverage container are more likely to be noticed than warnings on secondary (back or side) labels (Laughery, Young, Vaubel, & Brelsford, 1993).

There may be times when space for a warning is limited, as with small product containers such as pharmaceuticals. Methods available to increase the surface area for print warnings include adding tags or extended labels (Barlow & Wogalter, 1991; Wogalter, Magurno, Dietrich, & Scott, 1999). Another method is to put some minimum critical information on a primary label and direct the user to additional warning information in a secondary source, such as an owner's manual or package insert. Wogalter, Barlow, and Murphy (1995) showed that such procedures can be effective.

Other location/placement factors that influence attention to warnings have been studied. For a more complete review of these factors and their effects, see Rogers et al. (2000) and Wogalter and Laughery (2006). Overall, the principle to be kept in mind in deciding location/placement of a warning is to place it physically and temporally where and when it is most likely to be encountered.

Color/contrast. Generally, color or other forms of contrast are associated with greater noticeability of warnings (Braun & Silver, 1995; Young, 1991). Also, color seems to have influences beyond attracting attention. The color red has been consistently found to have the highest hazard connotation (e.g., Klein, Braun, Peterson, & Silver, 1993).

It is not surprising that the ANSI Z535 (2002) standard relies on color in the signal word panel of warnings to attract attention, given that color or other forms of contrast result in a greater likelihood that a warning will be noticed and encoded. Besides the color red, the ANSI Z535 (2002) standard notes other colors that should be used in warnings, most notably orange and yellow.

Signal word. Signal words in warnings are used to attract attention and provide a general indication of hazard level. In the United States, standards such as ANSI Z535 (2002) and guidelines such as those by FMC Corporation (1985) recommend that warnings include one of the signal words "CAUTION," "WARNING," or "DANGER." These signal words are widely employed in product and environmental warnings. The word CAUTION is intended for hazards in which minor injury or damage to property *might* occur; WARNING is intended for hazards that *might* cause serious injury; and, DANGER is intended for hazards that *will* cause serious injury.

Research indicates that the presence of the word DANGER is more likely to attract attention than CAUTION and WARNING or no signal word (e.g., Adams, Bochner, & Bilik, 1998). People do not readily differentiate between CAUTION and WARNING with regard to hazard level, but both terms are interpreted as connoting lower hazard levels than DANGER (Wogalter & Silver, 1995).

Pictorials. Pictorials (also known as *symbols, graphics,* and other names) in a warning may take several forms, among them actual photographs, directly representative drawings, and abstract symbols. Generally, research shows that pictorials can serve two primary functions in warnings: They can help to attract attention to the warning, and they can convey content information. Guidelines such as ANSI Z535 (2002) and FMC (1985) place considerable emphasis on the use of pictorials to communicate hazard information.

A number of studies have shown that pictorials in warnings can be effective in capturing attention (e.g., Davies, Haines, Norris, & Wilson, 1998; Jaynes & Boles, 1990; Kalsher,

Wogalter, & Racicot, 1996; Laughery & Young, 1991; Laughery, Young, Vaubel, & Brelsford, 1993; Young, 1991). Perhaps related to the effects of pictorials on attention is the finding that people prefer warnings that contain pictorials compared with warnings without them (Kalsher et al., 1996). Generally, pictorials enhance the conspicuousness of a warning. For example, Laughery and Young (1991) reported that pictorials combined with color and borders were more effective in attracting attention than the individual features separately.

Pictorials are also useful in enhancing encoding and helping to increase comprehension (e.g., Boersema & Zwaga, 1989; Collins, 1983; Laux, Mayer, & Thompson, 1989; Wolff & Wogalter, 1998; Zwaga & Easterby, 1984). Pictorials may be especially helpful when the target audience includes those who are illiterate and/or non-English readers. Also, pictorials can potentially be useful in circumstances when ideas need to be conveyed quickly, such as during highway travel.

As in text, pictorials may communicate the hazard, consequences, and instructional information. Two pictorials intended to communicate slip and fall and vapor inhalation hazards are shown in Figure 8.2. Figure 8.3 presents two pictorials intended to communicate consequences: electrocution and a hand injury resulting from a pinch point hazard. Figure 8.4 shows two pictorials that communicate instructional information: "Do not drink water" and "Wear a face shield."

The pictorials in Figures 8.2, 8.3, and 8.4 are examples of direct representation; that is, the information represented by the pictorial is expected to be recognized and understood by the target audience on the basis of general experience and knowledge. Figure 8.5, on the other hand, presents a pictorial for biohazard that must be learned in order to be understood. Some pictorials, such as a skull and crossbones, may fall in between, in the sense many people may relate the image to safety or health hazard information, but the connection to a poison hazard may require considerable inference or learning. For this reason, when the skull-and-crossbones hazard is used, it is often accompanied by the signal word POISON, which makes it adequate to readers of English.

As a general principle, pictorials that directly represent the information are preferred, particularly for general target audiences. Pictorials that require inference or learning are less likely to be recognized or understood.

Pictorials are an exceptionally valuable tool for communicating warning information, and they may be particularly useful in warning those who are illiterate or those who do not read English, but it is not always simple to develop pictorials that can be understood.

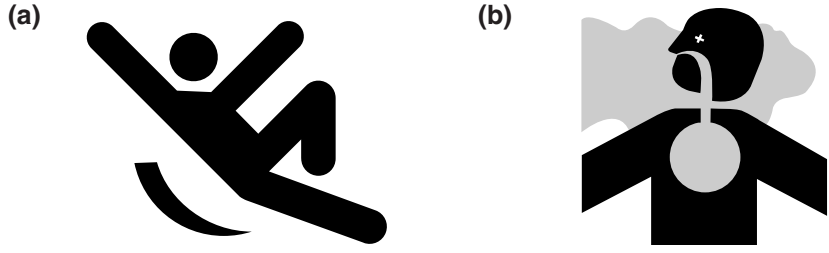

Figure 8.2. *Symbols displaying hazards: (a) slip-and-fall hazard, (b) inhalation hazard.*

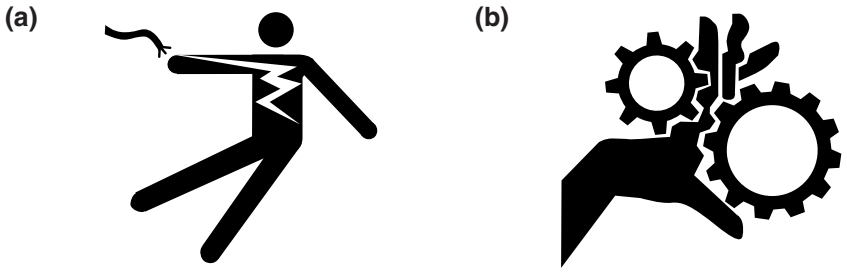

Figure 8.3. *Symbols displaying consequences: (a) electrocution, (b) hand injury.*

The question of an acceptable level of comprehension has been addressed in the ANSI Z535 (2002) standard. This standard suggests an acceptability criterion of 85% correct comprehension. However, this value is a goal, and if comprehension is less than 85%, the pictorial may still be helpful for attracting attention.

An important consideration is that the pictorial should not communicate incorrect information; that is, the probability of misinterpretation should be at a minimum. ANSI Z535 (2002) recommends having no more than 5% critical confusion errors (opposite or potentially dangerous answers). Indeed, the error rate is more important than the simple correct comprehension rate.

Message length. Brevity has been a generally accepted criterion for warnings; that is, the warnings should be no longer than necessary to communicate the needed information (Laughery & Wogalter, 1997). One frequent assumption is that the longer a warning message, the less likely it is to be read and encoded. However, research addressing this issue is inconclusive. Silver, Leonard, Ponsi, and Wogalter (1991) reported a positive correlation between warning message length and willingness to read. One explanation offered was that a longer warning suggests a greater hazard level, thus resulting in a greater willingness to read. On the other hand, Chen, Gilson, and Mouloua (1997) manipulated the number of warning messages on consumer products and found that the perceived risk declined as the number of low-risk messages increased beyond five.

A concept related to message length is *overwarning.* Overwarning typically refers to a large number of warnings associated with a product or with an environment. The assumption is that people may not attend to them or may become highly selective, attending

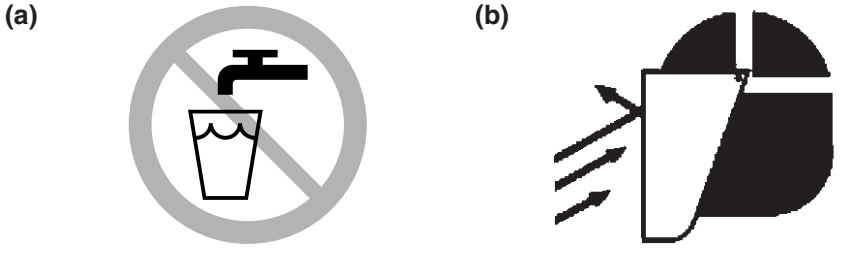

Figure 8.4. *Symbols displaying instructions: (a) Do not drink the water, (b) Wear face shield.*

Figure 8.5. *Symbol for biohazard.*

only to some. Sometimes the term is applied more broadly, referring to the notion that the world is filled with warnings. Although both notions of overwarning have some face validity, the former interpretation has some empirical support (Chen et al., 1997). There are few empirical data on the issue of "the world is filled with warnings." Nevertheless, overwarning in the latter respect may be a valid concern, and unnecessary warnings should be avoided.

Physical interactivity. A technique that has been somewhat successful in increasing the likelihood that people will notice and encode a warning is to require them to interact with the warning physically in some way. Frantz and Rhoades (1993) reported that a warning that had to be removed before the file drawers could be used increased its noticeability compared with other locations without the required physical interaction. Gill, Barbera, and Precht (1987) and Duffy, Kalsher, and Wogalter (1995) also reported studies showing that a warning label that had to be moved before a product could be used resulted in the label being noticed and read more than when the label was simply on the product.

Compliance Decisions

Research on warning compliance has generally employed one or both of two dependent measures: behavioral intentions and behavior. Two reviews have specifically addressed this research (Kalsher & Williams, 2006; Silver & Braun, 1999).

In the preceding section, we focused on a number of factors that affect noticeability and encoding. Obviously, factors that influence noticeability and encoding are important in determining whether compliance behavior occurs. If a given warning label or sign is not noticed or encoded, it cannot have a direct effect on behavior. Thus, one would correctly expect that the factors reviewed earlier would also be positively correlated with likelihood to comply. Research results have generally supported this expectation (Kalsher & Williams, 2006; Rogers et al., 2000; Silver & Braun, 1999).

In this section, we address the issue of compliance likelihood in terms of people's cost-benefit trade-off decisions. This decision making occurs as a consequence of warning information that interacts with people's attitudes and beliefs and that then feeds into the cost-benefit analysis determining the compliance outcome. In the following subsections, we focus on the information that makes up the content of warnings and how compliance is influenced by this information.

Pictorials. Although most studies on pictorials have been concerned with attention and

comprehension, some research has also explored the effects of pictorials on warning compliance. For example, Jaynes and Boles (1990); Otsubo, 1988; and Wogalter, Begley, Scancorelli, and Brelsford (1997) reported studies showing that the presence of pictorials increased compliance, compared with warnings without pictorials.

Explicitness. A design factor that has emerged as especially important to warning effectiveness is explicitness of content information. A recent review by Laughery and Smith (2006) summarized the findings of a number of studies addressing this topic. *Explicitness* in this context is defined as information that is specific, detailed, clearly stated, and leaves nothing implied. One of the first investigations to refer to this concept was by Sherer and Rogers (1984). In their study, concreteness (explicitness) appeared to increase the perceived severity of possible injury and concrete information was better remembered than abstract information. Lehto and Miller (1988) also suggested using explicit over abstract or general formulation of warnings.

As an example, suppose a person working in a job environment uses a chemical product that emits toxic vapors, the inhalation of which can lead to severe and permanent lung damage. Also, suppose it is important to wear a particular type of respirator when working with or around the chemical. The following warning text contains hazard, consequence, and instruction information:

> Dangerous Environment
> May Cause Health Problems
> Take Precautionary Measures

Certainly this warning will be of little or no use to the person exposed to the hazard. It could be considered a classic example of a vague or nonexplicit warning. The hazard statement "Dangerous Environment" reveals little about what the safety problem is; the consequences statement, "May Cause Health Problems," only notes a potential problem having to do with health; and the instruction "Take Precautionary Measures" is virtually useless in telling the user what to do or what not to do.

Consider the following as a possible alternative warning:

> Toxic Vapors
> Can Lead to Severe Lung Damage
> Always Wear Type 1234 Respirator in Area

The point of contrasting these two examples is to emphasize the importance of providing information at a level of specificity or explicitness that will enable people to make informed judgments and decisions.

In their review of the research, Laughery and Smith (2006) addressed the importance of explicit information for all three warning content categories: hazards, consequences, and instructions. They concluded that explicitness in all three categories plays an important

role in compliance, and they offered the following principles regarding explicitness that may be useful for the warnings designer:

- Do not assume "everybody knows."
- Do not rely on inference.
- Be careful about assuming that hazards and consequences are open and obvious.
- People do not always remember the appropriate safety information at the appropriate time. Reminders may be needed.
- *Explicit* is not necessarily synonymous with *quantitative.*
- Technical jargon is usually not a good way to achieve explicitness, especially for a general target audience.

From a motivational perspective, it is not surprising that more explicit information influences compliance. More specific information about hazards and consequences enables people to make better-informed cost-benefit trade-off decisions regarding the need to comply. Thus, one would expect explicit information to be especially important when the consequences are more severe, an expectation the research shows to be valid. Further, more explicit instructions enable people to better understand and carry out appropriate actions, which is also a common research finding.

NONDESIGN FACTORS THAT INFLUENCE WARNING EFFECTIVENESS

In this section, we review research that has addressed the characteristics of target audiences and situations that have a role in whether or not warnings are effective. The focus is on those factors that influence attention to warnings and the cost-benefit trade-off decisions regarding compliance.

Attention (Noticing and Encoding)

A number of target audience factors influence whether or not a warning will be noticed and encoded. Sensory capabilities or limitations as well as cognitive competencies are relevant factors. Two other factors that have been found to be important are perceived hazard and familiarity.

Perceived hazard. An important variable in whether or not people will look for and read warnings is their a priori hazard perceptions associated with a product or environment. In much of the research, perceived hazard or hazardousness has been defined as a composite variable that takes into account the likelihood of the hazard and the severity of the potential consequences. The greater the level of perceived hazard, the more likely people will look for, notice, and process a warning (Wogalter, Brelsford, Desaulniers, & Laughery, 1991; Wogalter, Brems, & Martin, 1993). Otsubo (1988) found that individuals were more likely to report having noticed a warning on a product (circular saw) that was perceived as more dangerous than another product (jigsaw). Other studies have

reported a similar relationship between perceived hazard and attention to warnings (e.g., Wogalter, Jarrard, & Simpson, 1994).

Familiarity. Familiarity refers to experience with a particular or similar product or environment from which relevant information has been acquired. The concept of familiarity in the context of warnings is related to perceived hazard. Godfrey and Laughery (1984) found that the more familiar women were with tampons, the less likely they were to notice warnings regarding toxic shock syndrome. Similarly, Godfrey, Allender, Laughery, and Smith (1983) reported that people who had greater familiarity with products rated them to be less hazardous and were less likely to look at warning labels. Others have reported a negative relationship between familiarity and warning-related processes (e.g., Johnson, 1992).

A related and converse point should be kept in mind; namely, people more familiar with a product or environment may be more likely to notice a warning because they are more frequently exposed to it. Goldhaber and deTurck (1988) reported that middle school students who dove into the shallow ends of pools were more likely to have noticed (but ignored) a no-diving warning at the shallow end. Similarly, Greenfield and Kaskutas (1993) found that heavy drinkers were more likely to report having noticed the warning labels on alcoholic beverages than were moderate drinkers or nondrinkers. These two studies have implications for the effects of familiarity and perceived hazard on compliance decisions.

A likely explanation for the effects of perceived hazard and familiarity on attention to warnings is simply that people are more likely to seek such information when a threat is perceived to be greater. Greater familiarity, assuming no negative experiences in the past, may result in lower levels of perceived hazard and, in turn, less motivation to seek warning information. More simply, if people are looking for a warning, they are more likely to notice and encode one that is present.

Other nondesign or target audience variables such as gender and age have been shown to influence attention to warnings, but these effects have not been nearly as consistent or robust as the effects of perceived hazard and familiarity. For a review of the gender and age variables, see Rogers et al. (2000) and Smith-Jackson (2006a).

Compliance Decisions

We address the issue of compliance with warnings in terms of cost-benefit trade-off decisions. Several target audience or situational variables have been found to influence compliance. A general review of this research can be found in Rogers et al. (2000) and Wogalter and Laughery (in press, 2006). We focus on three factors: familiarity, modeling, and cost of compliance.

Familiarity. In warning research, familiarity has been found to have somewhat equivocal results. Assuming there have been no negative experiences with a product or environment, research mostly seems to indicate that people who have greater familiarity with a product or environment are less likely to comply with a warning. For example, Wogalter, Barlow, and Murphy (1995) found that experienced computer users were less likely to

comply with antistatic warnings associated with the installation of a disk drive than were less experienced users. Harrell (2003) found that mothers who had reported previously allowing their children to stand in grocery carts were less likely to comply with a warning not to allow this behavior than mothers who were not so experienced. Other studies reporting similar findings include Burnett, Purswell, Purswell, and Krenek (1988); Goldhaber and DeTurck (1988); Lehto and Foley (1991); and Wogalter, Brelsford, Desaulniers, and Laughery (1991).

However, some research has also shown that familiarity with a product increases compliance with warning information. For example, Ortiz, Resnick, and Kengskiil (2000) found that when participants were asked to apply pesticides to plants, those who were familiar with the product were more likely to comply with a warning to use personal protective equipment than were those who were less familiar. As noted in our earlier discussion of familiarity, the effects of this variable are probably mediated by the level of perceived hazard. The state of affairs described by the notion "familiarity breeds contempt" may be at work because greater familiarity leads to lower levels of perceived threat, which, in turn, results in less compliance. Stated differently, in the cost-benefit trade-off decision, familiarity results in lower perceived costs associated with noncompliance.

Modeling. People's behavior, including warning compliance, is influenced by their social context and the behavior of others. People tend to model the safe or unsafe behaviors of others they observe. A number of studies have been reported showing a robust effect of modeling as a factor in warning compliance. The use of protective equipment has been a context for several studies addressing the modeling issue. Wogalter, Allison, and McKenna (1989); deTurck, Chich, and Hsu (1999); and Edworthy and Dale (2000) all reported results showing greater compliance in using protective equipment when others were observed using the equipment.

How does the modeling concept and effect fit with the cost-benefit trade-off decision addressed here? One possible explanation is that observing the behavior of others is a form of instruction regarding what is appropriate or inappropriate behavior in a particular context. If a passenger gets into the vehicle and observes the driver fasten the seat belt, the passenger is more likely to do the same. The effect may also be a form of social influence; that is, one may be motivated to behave the same as others.

Cost of compliance. The cost of complying with a warning may take many forms, including money, time, effort, and convenience. A substantial amount of research has explored the effects of such costs on compliance and generally has found that the effects are robust. If one views the decision to comply or not comply with a warning as a cost-benefit analysis, then the compliance costs represent half the equation, and such costs have an important influence on the decision outcome.

Research on the cost of compliance was reviewed by Silver and Braun (1999) as well as by Rogers et al. (2000). We will not review details of specific studies here, except to note that researchers have explored this variable and its effects on warning compliance in a variety of settings. These settings include the use of goggles on racquetball courts (Dingus, Wreggit, & Hathaway, 1993; Hathaway & Dingus, 1992), using cleaning solvents (Dingus, Hathaway, & Hunn, 1991), avoiding broken doors (Godfrey, Rothstein, &

Laughery, 1985), using office equipment (Wogalter et al., 1987), working with power tools (Zeitlin, 1994), working in a chemistry lab (Magurno & Wogalter, 1994), and wearing helmets with all-terrain vehicles (Lehto & Foley, 1991). Almost without exception, the research shows that lower costs of compliance lead to significantly greater compliance with warnings.

DISCUSSION

At the outset of this chapter, we pointed out that two primary goals a warning should accomplish are to capture attention and to provide the information needed for people to make informed decisions regarding compliance. Attention is viewed here as concerned with both noticing and encoding the warning. The compliance decisions are viewed as cost-benefit trade-offs in which the pluses and minuses of complying are taken into account. Following brief background coverage of purpose, history, system context, and theoretical perspective, we focused on the design variables and the situational/target audience variables that have emerged as most significant to accomplishing the attention and informed decision goals.

Generally, the design variables that influence attention to warnings are those one would expect—size, location, color/contrast, and the use of signal words. Others that have been researched and found to be important are pictorials, length, and interactivity. Target audience variables also influence a warning's success in being noticed and encoded. Two that seem to matter most are the level of perceived hazard and familiarity. We suggest that if the warning system designer appropriately takes into account these various factors, the probability that the intended audience will notice and encode the warning will be relatively high.

Regarding the decision to comply, for a warning to be effective, clearly, it must be noticed, encoded, and understood. The various attention variables and the use of pictorials have been shown to have a positive effect on compliance. Regarding content, the explicitness of the hazard, consequences, and instructional variables appears to be important. This conclusion seems to be especially true with regard to the explicitness of consequences information when the negative outcome may be severe. Three situational or target audience factors seem to merit special emphasis regarding their effects on the compliance decision outcome: familiarity, modeling, and cost of compliance. Indeed, the consistent and robust cost of compliance effect marks it as one of the most important considerations for the warning designer to keep in mind.

The fact that a person does not follow the actions recommended in the instructions of a warning does not necessarily mean the warning has not been successful. Although, as noted, one of the purposes of a warning is to describe and motivate safe behavior, there may be occasions when it is rational—or at least understandable—for someone not to comply even though the warning information has been encoded and understood. In short, the person may decide to take the risk.

For example, assume the drain of your sink is clogged. You go to the store and buy drain cleaner (sulfuric acid), take it home, and then read the label. You read that the material is toxic and that you could suffer chemical burns if you get it on your skin. You learn

from the warning that you should wear rubber gloves and goggles while using it. But you do not have rubber gloves or goggles, and the store where you might be able to get them is some distance away. So there are costs of complying: some money, some time, and some inconvenience. Instead of complying by going and purchasing the protective items, you simply decide to be very careful in handling the drain cleaner while using it. In doing so, you would have made the decision that the compliance costs are greater than the noncompliance costs. Although the desired compliance goals have not been fulfilled (rubber gloves and goggles were not worn), in terms of the informed decision goal for warnings, this warning has been successful.

The principles of warnings are not product- or environment-specific. There is no separate set of guidelines or criteria for warnings that address hazards, consequences, and instructions for an environment containing toxic gas or a slippery walking surface. Similarly, the same principles apply to products, whether one is dealing with lawnmowers, toxic solvents, vehicle air bags, prescriptive medications, or punch presses. The specifics for how a warning is presented to capture attention and the content of the hazard, consequence, and instructional information will vary with the product, the environment, and the target audience, but the general guidelines apply.

THE FUTURE

Although warning research to date has resulted in good progress in understanding design and effectiveness issues, its focus has been somewhat traditional. The issues and variables explored have merited the time and attention they have received, but there are several challenges and opportunities that can and should move closer to the center of the research stage. Among the challenges are target audience diversity, and the opportunities include the greater use of technology in warnings.

Target Audience Diversity

One of the challenges in warnings design concerns the need to communicate to larger and more diverse target audiences; this is a consequence of factors such as growing international trade. Language barriers, illiteracy, and cultural considerations represent a part of this more global challenge. One approach to dealing with language barriers is to present warnings in more than one language. It is common to find warnings accompanying products marketed in Canada printed in both English and French. In some areas of the United States with substantial Hispanic populations, warnings are often presented in both English and Spanish. But the warning designer must be mindful of the potential that too much information will make it difficult to access the warning in the language appropriate for a particular recipient. In other words, the structure and organization of the warning system may become more important as a result of increasing the number of languages. How to organize and present such information merits research attention to determine effective multilanguage warnings.

Pictorials are an obvious approach to addressing language barrier and literacy issues. As noted earlier, research has been reported indicating that pictorials can enhance the

likelihood of noticing warnings. An ongoing challenge for using pictorials in communicating warning information is comprehension. At the international level, research is needed to better establish how various pictorials are understood across cultures. Are there universals? Is it widely understood that the red circle with a slash (or a slash by itself) means prohibition? Certainly a common method across the world is the use of pictorials. Figure 8.6 shows several signs photographed in various countries that make use of pictorial communication.

Cultural differences may represent a variety of challenges to the warning designer. For example, there may be a range of views or customs regarding the amount of responsibility an individual is expected to take for his or her own safety. Differences in belief systems may influence how warning systems should be designed and what may be expected in terms of their effectiveness (Smith-Jackson, 2006b).

Another domain that warrants research effort is in the area of children and their caregivers. Although very young children cannot be expected to understand warnings (and their health and safety must be the responsibility of caregivers), older children with developing cognitive capacities might be able to assist in the goal of injury reduction if warnings are developed within those capacities. A warning about airbag dangers to smaller passengers sitting in the front seat that is understandable by 8- to 12-year-olds may enhance consequent compliance likelihood. Considerations regarding children's warnings are provided in Kalsher and Wogalter (in press).

Technology and Warnings

In this chapter, we have considered what has been learned about warnings from the upsurge in interest and research that began in the early 1980s. There are exceptions, but most visual warnings for products and environments are signs, labels, manuals, and so on. Further, such warnings are generally static and passive. However, in this context it is noteworthy that people's perceptual and cognitive systems are less attuned to stimuli that do not change. Current and new technology provides opportunities for more dynamic ways of warning people that would be potentially more effective. Several recent papers have explored this topic (Smith-Jackson & Wogalter, 2004; Wogalter & Conzola, 2002; Wogalter & Mayhorn, 2005, 2006). Here we focus on a few of the ways that technology may enhance warnings.

We are beginning to see warnings in different contexts, such as on television and the Internet. TV commercials about prescription drug products in the United States now include warnings. On TV, warnings can combine both visual and auditory modalities. Research by Shaver (2004) and Barlow and Wogalter (1993) showed that the dual-modality presentation of both print and voice warnings enhances the communication of warning information compared with either method alone. The Internet has taken hold as a source for information acquisition and communication; research by Hicks, Wogalter, and Vigilante (2005) revealed that the Internet is one of the main sources people report they would use when seeking information about risks associated with prescription medicines (ranked third behind physicians and pharmacists).

Some potential approaches for applying technology to warnings are discussed in the following sections. The topics include dynamic warnings, use of new technology displays,

Figure 8.6. *Pictorial signs from around the world.*

hazard detection using sensors, and tailoring warnings to fit individual users. In the last section, we address possible barriers to implementing technology in warnings.

Dynamic warnings. Dynamic warnings are generally more noticeable than static warnings. Human sensory and perceptual systems are better able to detect change than constancy. When something does not change over time or is no longer novel, it is less likely to attract attention because of habituation. Adding dynamic qualities to warnings will enhance their ability to attract and maintain attention. The urgency of a relatively simple fire alarm can be enhanced by adding more dynamic qualities, such as varying the frequency and temporal aspects of the auditory signal (Edworthy & Hellier, 2006; Haas & Edworthy, 2006).

Dynamic aspects of warnings should be conspicuous to attract and sustain attention. Consider the image of the school signs shown in Figure 8.7. The purpose of the static (unchanging) school zone sign in Figure 8.7a is to warn drivers to decrease their speed during the time students are in the area. The reduced speed limit is not applicable most of the time, so drivers may inadvertently violate the speed limit because in past experiences, the sign is irrelevant when they are in the area. Figure 8.7b illustrates two additional traffic lights mounted on either side of the school zone sign; these are programmed to flash only during relevant hours. The dynamic sign in Figure 8.7b will likely result in fewer violations and provide greater safety to children than the static school zone sign because the flashing light attracts attention at the appropriate times.

Displays. Unconventional methods of displaying warnings have been made possible by new technology. One relatively recent technological innovation is the availability of flat-panel displays. High-resolution plasma and liquid crystal displays are now as common as computer monitors and high-definition televisions. Large versions of flat-panel displays

Figure 8.7. *School zone signs: (a) static, (b) dynamic.*

are being used in sports stadiums and as advertisement billboards in cities. These new electronic display technologies can be considered for warning applications. One such use is changeable message signs on highways. An example of such a sign in Rio de Janeiro is shown in Figure 8.8. Eventually, warning signs on highways and smaller signs in other applications will use high-resolution flat panel technologies. Backlit and with high contrast, electronic signs are more likely to attract attention in most ambient environmental conditions compared with static conventional signs.

In addition to attracting attention, an important benefit of such displays is that the information content displayed can be changed as needed. Roadway sign displays can be changed to give timely, pertinent information about specific traffic and road conditions ahead and what to do to reduce delays. Displays could be mounted in or outside buildings or facilities (e.g., on walls or posts) or in work environments to display warning information as appropriate. For example, electronic signs could alert factory workers to noise, hazardous airborne particles, and respiratory hazards when such hazardous conditions exist.

Flat-panel displays can also be used to present video warnings. Are warning videos useful? Some initial research in this area was conducted by Racicot and Wogalter (1995). In their study, participants were asked to mix several chemicals. Before starting, they were assigned to one of three conditions in which they either (a) watched a video of a model demonstrating the proper safe behavior of putting on protective equipment (e.g., face mask and gloves), (b) viewed a static warning sign displaying the same warning instructions as on the video monitor, or (c) saw nothing relevant to safety on the video monitor. More people wore the protective equipment in the video model condition than in the other two conditions.

Dynamic warnings have been used in vehicles for many years. Most vehicles contain simple warnings, such as a flashing light or an intermittent tone, as a reminder to wear

Figure 8.8. *Changeable-message highway sign in Rio de Janeiro, Brazil.*

seat belts. Although more noticeable than static stimuli, these warnings often become habituated over time. A better reminder for wearing seat belts would be a talking car or a sound that changes to maintain the conspicuity of the signal. Many newer vehicles have navigation systems with touch screen LCD displays (for example, see Figure 8.9). Although most navigation systems store and display information such as points of interest and restaurants, they could also communicate safety information and warnings. Examples are directions on how to properly install child safety seats and whether and how much one can recline the passenger seat when the vehicle is in motion.

Detectors/sensing devices. Warning effectiveness may be benefited by detection and sensing methods that are available now or likely to be available in the future. A fundamental principle is that warnings should be presented when and where the information is needed. If the warning is presented too distant from the hazard in terms of location and time, people may not recognize the connection or may not remember the hazard.

Earlier we noted that humans have sensory, perceptual, and cognitive limitations. Warning systems that include detector (sensing) devices can take on the burden of noticing when a warning is needed (Wogalter & Mayhorn, 2005, 2006). Numerous kinds of sensor systems are available to detect heat, cold, wet, gas vapors, motion, weight, and so forth. One example of a warning sign that could use a sensing system is the caution sign used in the United States that states "Bridge Ices Before Road." Some of these signs are permanently placed and displayed. The photograph in Figure 8.10 was taken in the middle of summer during a heat wave in Raleigh, North Carolina. A better method would be to use a temperature detector that presents the message when conditions are conducive for the hazard; in other words, the message is displayed only when the temperature is near or below freezing. Another example concerns inexpensive motion detectors that are sold in stores for outdoor security lighting. Such detectors could also be used to initiate warnings when individuals enter a specific hazardous area, such as might exist in work environments.

Figure 8.9. *In-vehicle navigation system displaying a warning.*

Figure 8.10. *Static sign for a bridge in Raleigh, North Carolina.*

A significant benefit of using detectors and sensing systems is that they can supplement peoples' sensory, perceptual, and cognitive abilities. Humans do not have a natural capability to detect radiation and carbon monoxide (CO), so there are devices to do that job (Geiger counters and CO detectors). These and other kinds of detection equipment can play an important role in safety by compensating for peoples' limitations. When hazardous conditions are detected, warning systems can then be activated.

Tailoring warnings to the user. In this section, we describe examples of tailoring warnings to users. The idea is that different people have different needs, and as a result, different warnings should be presented. Sometimes these differences are attributable to varying individual characteristics or capabilities, but the differences may also be based on varying situations.

Warnings could also be personalized. Research by Wogalter, Racicot, Kalsher, and Simpson (1994) suggests that relevance is associated with warning compliance. Relevance is a belief that the warning is applicable. In the Wogalter et al. (1994) study, when a participant's name was included within an electronically presented warning, compliance was greater than when the warning was generic and nonpersonalized. Information from smart cards can provide personal information by, for example, embedding the name of the targeted individual into a presented warning. Automated check-in terminals at airports that note the passenger's name after inserting a credit card are examples of such a technique. This approach shortcuts the decision-making process on whether the message is intended for, or applicable to, the individual personally.

A sophisticated extension of tailoring is to modify the warning based on the person's experience and skill level. An expert may not need a warning, or if a warning is to be given, it can be more technical and contain abbreviated information to inform and remind. For the novice, the information may need to be simple and limited in scope to avoid overloading attention resources and memory capacity. Use of a prioritization strategy would

limit the presentation of certain information so that only the most critical is given. However, warning systems could also make linked information available if a more detailed description is desired.

Potential barriers. Although the potential for future technology-based warning systems is substantial, there are a number of barriers that could delay or prevent implementation. Some of the systems described in this chapter are simple, but some are more complex. Further, some may be expensive. Undoubtedly, however, the cost will go down and the sophistication will go up. As a consequence of display and other technological advancements, along with reduced costs, technology's involvement with warnings will eventually be more widespread.

However, the methods of implementation and their appropriateness must also be considered. Some of the issues of concern are warning intrusiveness and annoyance as well as maintenance. Inappropriate or false warnings must be avoided. Likewise, failure to present necessary warnings could be disastrous, and so backup systems may be needed. As the sophistication of electronic warning systems improves, the control of presentations that are in error, such as false alarms and misses, should also decrease.

Some sophisticated systems involve the collection of personal information that could generate privacy concerns. Such issues are complex, and a balance will be needed between maintaining privacy and promoting safety.

CONCLUSIONS

Future technology-enriched warning systems will have properties different from and better than those of traditional static warnings. These improved capabilities will include dynamic modification of message content, compensation for human limitations, interactivity, and personalization through tailoring warnings to meet the needs of particular users. The end result will be an increased capacity to warn users of potential or existing hazards.

We have presented a number of ways in which technology can enhance warning effectiveness. The use of flat-panel displays, video technology, and in-vehicle systems were described as examples of technology that might be implemented to improve warning delivery and presentation. Moreover, the inclusion of detectors and sensor technology in future warning systems should facilitate identification and earlier detection of potential hazards. Future warning systems can provide assistive support for sensory, perceptual, and cognitive limitations that is tailored to meet the needs of specific users. The goal is to deliver accurate, appropriate warning information in a timely fashion where and when it is needed to prevent injury, illness, and damage to property.

Although the promise of next-generation, technology-enhanced warning systems for improving safety is exciting, there are potential barriers to implementation. Besides financial costs, the largest barrier is the balance between privacy concerns stemming from acquisition of user information and the need to effectively warn users about hazards. Although such ethical considerations are beyond the scope of this chapter, warning designers should be aware of this issue when implementing new warning designs.

In this final section, we have addressed how technology-based warning systems might be developed and enhance hazard communications. We started by describing why dynamic systems would likely be more effective than common, static warnings. Future warnings can benefit users by supplementing and compensating for various limitations in the detection, identification, and comprehension of hazards. Clearly, this aspect of warnings and the future pursuit of advanced, technology-based warning systems promise to be an interesting and challenging area for research. It will also benefit safety.

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