CHAPTER 24

WARNINGS AND HAZARD COMMUNICATIONS

Michael S. Wogalter and Christopher B. Mayhorn
North Carolina State University
Raleigh, North Carolina

Kenneth R. Laughery, Sr.
Rice University
Houston, Texas

1 INTRODUCTION

Warnings are safety communications used to inform people about hazards and to provide instructions to avoid or minimize undesirable consequences such as injury or death. Warnings are used in a variety of contexts to address environmental and product-related hazards.

In the United States, interest in warnings is also associated with litigation concerns. The adequacy of warnings has become a prevalent issue in product liability and personal injury litigation. According to the Restatement of Torts (second) and to the Theory of Strict Liability, if a product needs a warning to use a product safely and the warning is absent or defective, then the product is defective (see, e.g., Madden, 1999). A number of case studies involving warnings in litigation are described in Wogalter (2019c).

Regulations, standards, and guidelines concerning when and how to warn have been developed more extensively in the last three and a half decades. During this time, there has been substantial research activity on various factors concerning warnings. Human factors professionals have played a substantial role in the technical literature that has resulted.

This chapter reviews some of the major concepts and findings regarding factors that influence warning effectiveness. Most of the research review is presented in the context of an overall Communication–Human Information Processing (C-HIP) model. The advantage of using the model is that it describes a coherent process and assists in organizing research findings. It can also be used as a predictive and investigative tool. Following the presentation of the model and the review of major concepts and findings, a collection of recommendations for designing warnings in applications is presented.

It should be noted that the main focus of this chapter is visual warnings though there is some discussion of other modalities at relevant points. Also in this chapter, we do not cover the growing area involving warnings in intelligent vehicle systems, but reviews can be found in Walker, Stanton, and Salmon (2016) or Vourgidis, Maglaras, Alfakeeh, Al-Bayatti, and Ferrag (2020).

2 BACKGROUND

In this section, several terms will be defined and the role of warnings in the broader context of hazard control is discussed.

In G. Salvendy and W. Karwowski (Eds.) *Handbook of Human Factors and Ergonomics, 5th Edition*. 2021. Chap. 23, pp. 644-667. Hoboken, NJ: John Wiley.

2.1 Definitions

It is important to establish a few definitions for terms that will be used in this chapter, particularly the concepts of hazard and danger. These terms are sometimes used in different ways with different meanings; hence, we want to be clear about their meaning in this context.

Hazard is defined as a set of circumstances that can result in consequences of injury, illness, or property damage. Such circumstances can be affected by the characteristics of the environment, of the equipment and products being used, by the task being performed, and the people involved. From a human factors perspective, it is well recognized that people have different characteristic abilities, limitations, and knowledge.

Danger is a term that is viewed as a combination of hazard and likelihood; that is, if one has quantified values of hazard and likelihood, multiplying these quantities would give a value for danger. Note that an implication of this definition is that if either value is zero, there is no danger. If the hazard and its consequence are serious but will not occur, there is no danger. Similarly, if the probability of an event occurring is high but there will be no resulting undesirable consequences, there is no danger. Despite these definitions, the words hazard and danger are commonly used interchangeably.

2.2 Hierarchy of Hazard Control

In the broad field of safety, particularly injury (and damage) prevention, there is the concept of hazard control. Hazard control involves a set of methods that differ in reliability and effectiveness, and thus preference and priority, yielding a hierarchy of hazard control (cf. Sanders & McCormick, 1993). The basic hazard-control hierarchy outlines a generalized ordering of approaches to deal with hazards where the highest priority or best approach in controlling a hazard is to try (1) to design it out, and then if that is not possible, then to try (2) to guard against the hazard, and if that is not possible, (3) to warn about the hazard. The first preference is to eliminate the hazard through alternative designs. If a nonflammable, nontoxic substance or solution can be used effectively to perform a cleaning task, then it is preferable compared to using a flammable solution that includes a warning to avoid all ignition sources. While it is the best method, it is not possible to eliminate some hazards from useful products and equipment or change established environments. Guarding, whether physical or procedural, is a second set of prioritized strategies to control hazards. The purpose of guarding is to prevent contact between people and the hazard. Physical barriers and personal protective equipment (PPE) are examples of physical barriers. Sometimes tasks can be designed so that people are kept out of an area of danger; it is a procedural guard. However, guarding is not always a feasible solution, and so a third line of defense is to warn about the hazard. Warnings are last in this priority scheme because influencing people's behavior reliably can be difficult. There is another implication of this priority scheme; namely, warnings are not a substitute for good design or adequate guarding. Do not use warnings if there are better solutions through design and guarding. Yet warnings may be needed for other reasons as a method of providing informed consent to users. Indeed, warnings can be viewed as a supplement, not a substitute, to other approaches to safety (Lehto & Salvendy, 1995).

In addition to the three-part hierarchy, there are other approaches that may be effective in dealing with hazards (see, e.g., Laughery & Wogalter, 2011). Generally, they fall into the same category as warnings as a means of informing people about hazards and influencing people's behavior. Personnel selection, training, and supervisory control are examples from employment settings.

3 WARNINGS

In this section the purposes of warnings and some general criteria are discussed.

3.1 Purpose of Warnings

The purpose of warnings can be explained at several levels. Generally, warnings are intended to improve safety, that is, to decrease incidents that result in injury or property damage. At another level, warnings are intended to influence or modify people's behavior to improve safety. At still another level, warnings are intended to provide information that enables people to understand hazards, consequences, and appropriate behaviors that in turn enable them to make informed decisions.

There are two additional points associated with the purposes of warnings. First, warnings are sometimes used as a means of shifting responsibility for safety to the product user or worker. Of course, the warnings need to be effective for responsibility to be successfully shifted. Users and workers have a responsibility for safety. Thus, a main purpose of warnings is to provide the information necessary to enable them to carry out such responsibilities.

The second point regarding warnings' communication purpose concerns an issue that has received little attention in the technical literature, namely, people's right to know. Even in situations where the warnings do not produce high compliance, there is also the aspect that people have the right to be informed about safety problems confronting them. This aspect of warnings relates to personal, societal, and legal concerns.

3.2 General Criteria for Warnings

An important criterion for warnings is that their design should be an integral part of the overall system design process. While safety warnings are a third line of defense behind design and guarding, they should not be considered for the first time after the design (including guards) of the product (and environment) are already established. Too many warnings are developed at a late stage, close to the time of the product's release, which can present problems with finding warning solutions. Unfortunately, it is not uncommon for warnings to be given little, if any, considered thought by product manufacturers and property owners and managers. Rarely are their quality and effectiveness assessed. With untested and unrealistic assumptions or expectations, the resulting warnings are destined to be inadequate. This is unfortunate because in situations where warnings are needed, inadequate ones can result in injury or death. Numerous personal injury lawsuits in the United States concern warning inadequacy. In these cases, manufacturer's warnings may be found deficient based on form and/or content.

3.2.1 When/What to Warn?

There are several principles or rules that guide when a warning should be used. They include:

1. A significant hazard exists.
2. The hazard, consequences, and appropriate safe modes of behavior are not known by the people exposed to the hazard.

3. The hazards are not open and obvious; that is, the appearance and function of the product or environment do not convey the hazards.
4. A reminder is needed to assure awareness of the hazard at the proper time. This concern is especially important in situations of high task loading or when there is the potential for distractions.

3.2.2 Who to Warn

The general principle regarding who should be warned is that it should include everyone who may be exposed to the hazard and everyone who may be able to do something about it. There are occasions when people in the latter category may not themselves be exposed to the hazard. An example would be the industrial toxicologist who receives warning information regarding a chemical product to be used by employees and who then defines job procedures and/or protective equipment to be employed in handling the material. Another example is the physician who prescribes medications to patients having labeling that warns of side effects.

There are, of course, situations and products where the target audience is the general public. The hazards could be those in the public environment, in over-the-counter products in a drugstore, or on a shelf of a hardware store. Other warnings may be directed to a specific audience. Warnings about the risk of birth defects associated with taking a prescription medication would be directed primarily to women of childbearing age; although others such as spouses or parents might also receive the warning (Mayhorn & Goldsworthy, 2007). Likewise, as noted above, health care professionals such as physicians or pharmacists should receive the warnings about the medication regarding potential birth defects when treating patients who are or may become pregnant. In general, the characteristics of the target audience should be taken into account. Additional discussion on this topic appears in Section 4.4.

4 COMMUNICATION-HUMAN INFORMATION PROCESSING (C-HIP) MODEL

In this section the Communication-Human Information Processing (C-HIP) model is presented as an organizing framework for reviewing some of the major concepts and findings that influence warning effectiveness (Wogalter, 1999, 2006b, 2019a).

Communications Warnings are a form of safety communication. Communication models have been around since the last century (Lasswell, 1948; Shannon & Weaver, 1949). A basic model shows a sequence starting with a source that sends a message that is encoded into a channel that is transmitted to a recipient who receives a decoded version of that message. Noise may enter into the system at several points in the sequence, reducing the correspondence between the message sent and the one received. The warning sender may be a product manufacturer, government agency, or employer. The receiver is the user of the product or any other person at risk. The receiver is the target of the message. The message, of course, is the safety information communicated. The medium refers to the channels or routes through which information gets to the receiver from the sender. Understanding and improving these components increases the probability that the message will be successfully conveyed.

Warnings communication is seldom as simple as implied by a sequential communication model. Frequently more than one medium or channel may be involved such that multiple messages might include different formats or contain different information sent over time. Figure 1 illustrates a communication model involving employees receiving warnings about an

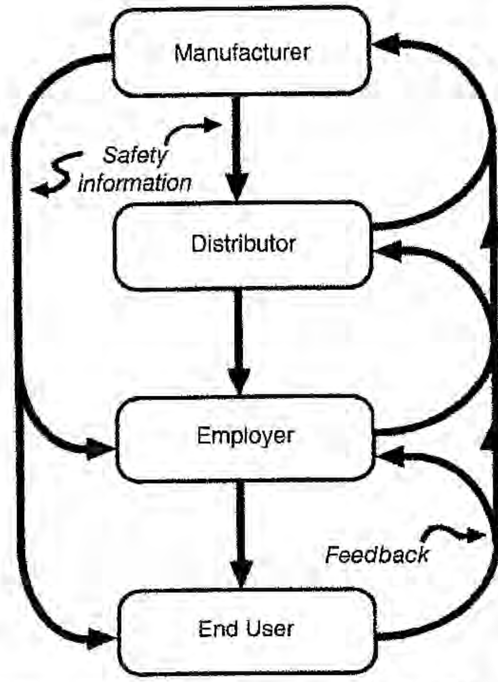


Figure 1 Distribution of safety information and feedback.

equipment hazard. It shows the distribution of safety information from several entities to the receiver (the employee) and that feedback may influence the kind of safety information given. In addition to the sender (manufacturer) and receiver (end user), other people or entities may be involved such as distributors and employers. Further, each of these entities may be both receivers and senders of safety information. The routes through which warnings may travel include transfer from the manufacturer to the distributor who then sends warnings to an employer who then transfers (e.g., through training) it to the user, from the manufacturer directly to the users (e.g., through product labels), or through the employer. Also, warnings may take different forms. One example includes safety rules that an employer sets to govern the behavior of employees. Entities other than the manufacturer may pass on product/equipment warnings to others. The concepts of warning systems and indirect warnings are discussed further at a later point in the chapter. Wogalter (2019b) describes a version of this model applicable to the transmission of product warnings from a manufacturer, distributor, and retailer to users.

Human Information Processing Cognitive psychology is concerned with mental processes such as attention, memory, and decision-making. Since the 1960s, much of the theoretical work has been described in terms of stages of processing. Numerous models have been developed and tested. In the context of warnings, there are similar models described by Lehto and Miller (1986; Laughery & Wogalter, 2006, 2014; Rogers et al., 2000; Wogalter, 1999b). In Chapter 5 in this volume, Wickens and Carswell present an in-depth description of human information processing in a broader array of contexts than warning.

C-HIP Model The C-HIP model (Wogalter, 2006b, 2019a), depicted in Figure 2, is a framework for showing stages of information flow from a source to a receiver of that message who in turn may process the information to subsequently produce overt empirical behavior.

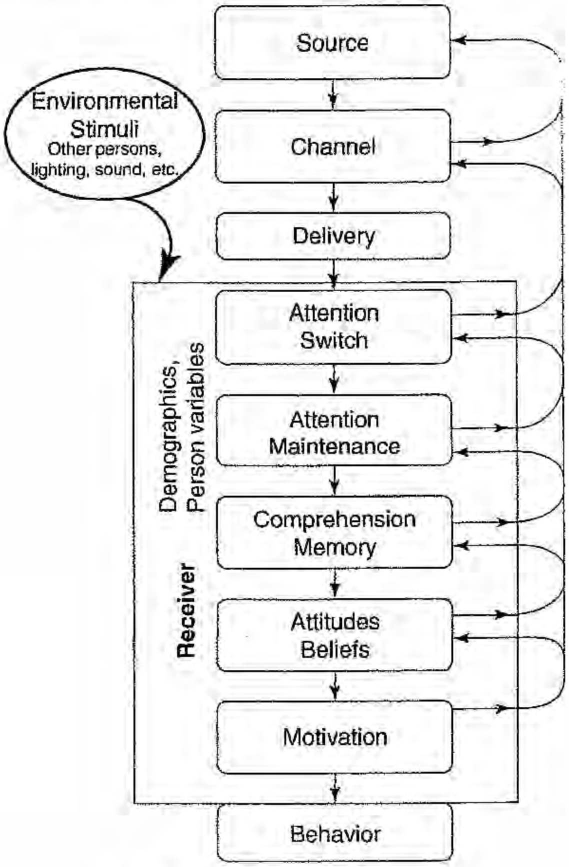


Figure 2 The C-HIP model.

At each stage of the model, warning information is processed and, if successful, "flows through" to the next stage. If processing is unsuccessful, it can produce a bottleneck, blocking the flow from getting to the next stage. If all of the stages are successful, the process ends in behavior (compliance to the warning). In cases where warning processing does not make it to the last stage, it still may be effective at influencing earlier stages. For example, a warning might positively influence hazard comprehension but not change behavior. Such a warning cannot be said to be totally "ineffective" because better understanding can potentially lead to informed decisions. However, it is ineffective in the sense that it does not reliably curtail certain unsafe behaviors.

The C-HIP model can be helpful in diagnosing warning failures. If a source (e.g., manufacturer) does not issue a warning, no information will be transmitted and nothing will be communicated to the receiver. Even if a warning were issued by the source, it may not be effective if the channel or transmission medium is poorly matched with the message, the receiver, or the environment. Each of the processing stages within the receiver can also produce a bottleneck preventing further processing. Consider the potential breakdowns. Assume that a source issues a warning in a product manual. The receiver might not notice the warning embedded within it, and thus may not be affected by it. Even if the warning was noticed, it might not maintain attention and thus the information is not encoded. Even if read, the warning message may not be understood. Even if a warning is understood, the recipient might not believe it or evoke adequate motivation to comply with the warning's directive. Thus, there are a number of potential barriers that must be overcome for a warning to work.

Although the processing described is linear, it is more complex. Figure 2 shows the model with feedback loops from the later stages to earlier stages. One example involves the memory stage influencing the attention stages. Repeated or continuous warning exposure might lead to reduced attention on subsequent viewing opportunities. Another feedback loop example is beliefs affecting attention. If people believe a product is not hazardous, they may not look for a warning or maintain attention on it even if noticed. These nonlinear effects between the stages due to feedback show that later stages in the model can influence earlier stages in ongoing cognitive processing.

In the following sections, each stage of the C-HIP model is described along with some of the factors that influence it. Table 1 shows a summary of some of the primary considerations associated with successful processing at each stage.

4.1 Source

The source is the transmitter of warning information. The source can be a person or an organization (e.g., company or government). Research shows that differences in the perceived characteristics of the source can influence people's beliefs about the credibility and relevance of the warning (Wogalter, Kalsher, et al., 1999). Information from a reliable, expert source (e.g., the Surgeon General, the U.S. Food and Drug Administration (FDA)) is given greater credibility, particularly when the expertise is relevant (e.g., the American Medical Association for a health-related warning) (Wogalter,, Kalsher, et al., 1999). Indeed, Internet users are more likely to believe facts from websites that have domain suffixes such as .edu and .gov than .com as the former tend to be reserved for educational- or governmental-related sources as opposed to for-profit companies (Wogalter & Mayhorn, 2008). Unfortunately, however, seemingly official sounding, but illegitimate, organizations can fool people into believing the conveyed information is credible and checked for accuracy (Wogalter & Mayhorn, 2006a). As will be discussed in detail later, a warning attributed to an expert source may aid in changing erroneous beliefs and attitudes to more accurate ones. For example, warning content on the Covid-19 pandemic given by experts in infectious diseases like Anthony Fauci, MD (U.S. National Institutes of Health) is considered trustworthy and is considered more credible than messages from persons with less or no expertise on the topic. The source should be considered by using a number of perspectives.

A critical role of the source is to determine whether there is a need for a warning and, if so, what and who should be warned. This decision typically hinges on the outcomes of hazard analyses that determine foreseeable ways injuries could occur.

4.2 Channel

Assuming that the product or environment has been determined to need a warning, one or more methods or channels may be used to relay the warning to the receiver. The channel is the medium where information is transmitted from the source to one or more receivers. Typically, most visual warnings are presented on product labels, on signs, or in manuals (as text and symbols). Warnings are also commonly given in the auditory (alarm tones, live voice, and voice recordings) modality. Additional methods include: (1) adding an odor to propane for detection in the olfactory modality (e.g., Wogalter & Laughery, 2010), and (2) shaking of a pilot's control stick when entering a potentially dangerous stall cuing tactile, haptic, and kinesthetic senses (cf. Salzar, Oron-Gilad, Ronen, & Parmet, 2011).

Table 1 Influences and Measurement Examples of C-HIP Stages

C-HIP stage (chapter section)	Influences and measurement examples
Source (4.1)	Makes hazard determination. Performs hazard analysis. Hazards that have not been designed out or guarded should be warned.
	Source is usually product manufacturer or employer having superior knowledge
	Measurement: Ratings of Expertness, Credibility, knowledge
Channel (4.2)	Visual (signs, labels, tags, inserts, manuals, video, etc.)
	Auditory (simple and complex nonverbal; voice; live or recorded)
	Other senses: vibration, smell, pain
	Transmission in more than one modality is better
	Print media (label, manual, brochure, magazine advertisements)
	Alarms, Voice (radio, live), Video (TV), Internet
	Measurement: Single vs. Multiple modes with latter being generally better, Interference with ongoing tasks
Delivery (4.3)	Message should actually get to receiver
	Measurement: Did it arrive at one or more of the receiver's sensory modalities?
Receiver (4.4)	Consider demographics and limitations of target audiences (e.g., older adults, cultural and language differences, persons with impairments)
	Remaining stages in C-HIP model are internally processed by receiver
Attention Switch (4.5)	Should be high salience (conspicuous/prominent) in potentially cluttered and noisy environments (e.g., using distinctive coloration, and dynamic qualities such as motion/movement)
	Visual: high contrast, large
	Presence of pictorial symbols and other graphics can aid noticeability
	Auditory: louder and distinguishable from surroundings
	Present when and where needed (placed close in time and space)
	Avoid habituation by changing the warning
	Measurement: Recording eye and head movements
Attention Maintenance (4.6)	Enables message encoding through examination or reading or listening. Working memory, processing over time.
	Visual: legible font and symbols, high-contrast aesthetic formatting, brevity
	Auditory: intelligible and distinguishable from other sounds
	Measurement: duration of looking/listening and subsequent recall and recognition
Comprehension and Memory (4.7)	Message comprehension, Long-term memory. Enables informed judgment
	Understandable message that provides necessary and complete information to avoid hazard
	Try to relate information to knowledge already in users' heads
	Explicitness enables elaborative rehearsal and storage of information
	Pictorials can benefit understanding and substitute for some wording; may be useful for certain demographic groups (low literates or unskilled in language)
	At subsequent exposures, warning can remind user of information
	Comprehension testing needed to determine whether warning communicates intended/needed information
	Measurement: Testing understanding of intended message after exposure
Beliefs and Attitudes (4.8)	Perceived hazard and familiarity are beliefs that affect warning processing
	Persuasive argument and prominent warning design are needed when beliefs are discrepant with truth
	Can influence receiver's earlier stages
	Measurement: Determine beliefs (pre-/post-)
Motivation (4.9)	Energizes person to carry out next stage (behavior)
	Perceived low cost (time, effort, money) increases compliance. Likewise, perceived high cost reduces compliance
	Warning explicitness and perceptions of higher injury severity increase compliance
	Affected by social influence, time stress, mental workload
	Measurement: Ratings of willingness to carry out the directed behavior
Behavior (4.10)	Carrying out safe behavior that does not result in injury or property damage. Effect is outside receiver.
	Measurement: Empirical overt and indirect behavioral compliance, also behavioral intentions and subjective ratings
Environmental Factors (4.11)	Includes all other sources of information outside of the receiver and the specific warning being processed including all non-warning information such as other tasks, other persons, the characteristics of the environment, etc.
	Measurement: Do external environmental factors (context) affect warning effectiveness measures?

4.2.1 Media and Modality

There are two dimensions of the channel. The first concerns the media where the information is embedded. The second dimension is the sensory modality used to capture the information by the receiver. Media and modalities are closely tied. Some studies have examined whether presentation of a language-based warning is more effective when presented in the visual (text) or the auditory (speech) modality. The results are conflicting (although generally either one is better than no presentation whatsoever). Some research (Penney, 1989) suggests that longer, more complex messages may be better presented visually and shorter messages auditorily. The auditory modality is usually better for attracting attention. However, voice can be less effective than text particularly for lengthy, complex messages because (1) of its temporal/sequential nature; (2) its slower processing speed; and (3) and the inability to review previously presented material (cf. Taylor & Wogalter, 2019).

4.2.2 Multiple Methods and Redundancy

Research has generally found that presenting warnings in two modalities is better than one modality (e.g., Haas & van Erp, 2014; Wogalter & Young, 1991). Thus, a warning is better if the words are shown on a visual display while at the same time the same information is given verbally. This provides redundancy. Together they can be beneficial as it provides a way for persons who may be occupied on a task involving one or the other modality to be alerted by the warning. If an individual is not watching the display, people can still hear it. Or, if an individual is listening to something else (or is wearing hearing protection), they could potentially see the message on the visual display. Also, if the individual is blind or deaf, the information is available in the other modality. More than one modality is usually better (e.g., van Erp, Toet, & Janssen, 2015).

4.2.3 Warning Systems

Warning systems for a particular environment or product may consist of a number of components. In the context of the communication model presented in Figure 1, the components may include a variety of media and messages.

A warning system for a pharmaceutical product such as a prescription allergy medication may consist of several components: safety information from a physician, a printed statement on the box, a statement on the bottle, and a package insert. In addition, there may be text and/or speech warnings in television and radio advertisements. In the United States, direct-to-consumer (DTC) advertisements about prescription pharmaceuticals usually include warnings about side effects and contraindications. Due to their brevity, broadcast commercials only tell the drug's main warnings, and direct people to other sources of information such as manufacturer websites, a magazine ad, or a toll-free telephone number (Goldsworthy & Mayhorn, 2010; Vigilante et al., 2007).

Another example would be warnings for a solvent used in a work environment for cleaning metal parts. Here the components might include warnings printed on labels of the container, printed flyers that accompany the product, safety data sheets (SDS) and information on the Internet.

The components of a warning system typically have different contents or purposes. For example, some components may be intended to capture attention and direct the person to another component where more information is presented. Similarly, different components may be intended for different target audiences. In the above solvent example, the label on the product container may be intended for everyone who uses the product, including the end user, while the information in the SDS may be directed more to fire personnel or to a safety engineer working for the employer (Smith-Jackson & Wogalter, 2007).

4.2.4 Direct and Indirect Communications

The distinction between direct and indirect effects of warnings concerns the routes by which information gets to the target person. A direct effect of a manufacturer's warning is the user reading the warning and complying with it. Indirect transmission may also occur (Wogalter & Feng, 2010). Examples are the employer or physician who reads warnings and then verbally communicates the information to employees or patients. Moreover, the print and broadcast news media may present information that was given by the manufacturer in warning labels. The point is that a warning put out by a manufacturer may have utility even if the user is not directly exposed to the warning.

An example of an indirect warning concerns herbicides used in agricultural settings. Many U.S. farm workers better understand Spanish than English, so there is reason to present warnings in both languages (Smith-Jackson & Wogalter, 2000; Smith-Jackson, 2006a). A direct warning would be a manufacturer's label printed in Spanish. An indirect warning might involve a designated employee with bilingual skills that translates an English label into Spanish. Likewise, parents and caregivers convey product information to children (Mayhorn et al., 2006). Intentionally designing a warning system that supports indirect warnings could be a way to disseminate warning information beyond the reaches of a directly received manufacturer's warning.

4.3 Delivery

While the source may try to disseminate warnings in one or more channels, the warnings might not reach some at risk. For example, a safety brochure that is developed by a governmental agency that is never distributed is not very helpful. Product manuals may not be available due to having been discarded or not transferred to new owners when resold (Rhoades et al., 1991; Wogalter, Vigilante, et al., 1998). This can have a negative effect on safety because without the manual, the user may not know what the correct and incorrect uses of the product are or what maintenance should be done when. Williamson (2006) describes issues associated with communicating warnings on the flash-fire hazard associated with burning plastic-based building insulation. Although there are some warnings accompanying bulk lots of the insulation when shipped from the manufacturer/distributor to job sites and some technical warnings that may be seen by architects and high-level supervisors, these materials seldom make it downstream to construction workers who may be working around the product. Thus, while a warning may be developed by a source manufacturer, it may have limited utility if it does not reach relevant persons.

4.4 Receiver

The receiver is the person(s) or target audience to whom a warning is directed. Internally, within the receiver, the warning may or may not be processed when delivered. As noted above, warning information cannot be processed without being delivered. The warning as delivered needs to be within the sensory capabilities of targeted person. For example, a warning label or sign that is placed in a location where people are unlikely to see it, or is placed in an area where lighting is too dim for people to see or read it, has not been delivered.

It is not uncommon for directives in warnings to tell people to do something that cannot be done, indicating that people's abilities and limitations were not considered. Consider the common warning instruction found on containers of flammable or toxic chemical solvents: "Avoid breathing vapors." This directive might be difficult to carry out for several reasons. One difficulty in carrying out the instruction is in detecting the vapor, particularly if one cannot see or smell it.

4.4.1 Demographic Factors

The demographics of the receiver can influence warning processing and effectiveness. Rogers et al. (2000) discussed a number of relevant dimensions where intended receivers may differ. A number of studies have shown that gender and age may be related to how people respond to warnings. With gender, results suggest that women more than men look for and read warnings (Godfrey, Allender, Laughery, & Smith, 1983; LaRue & Cohen, 1987; Young, Martin, & Wogalter, 1989). Similarly, other results indicate women are more likely to comply with warnings (Goldhaber & deTurck, 1988). However, many studies do not report any gender differences. Some gender differences may be due to knowledge and familiarity of certain products (e.g., Young, et al., 1989).

Regarding age, the results are mixed. There are results suggesting that people older than 40 are more likely to take precautions in response to warnings (Hancock, Fisk, & Rogers, 2005; Mayhorn, Nichols, et al., 2004; McLaughlin & Mayhorn, 2014). Research (Wogalter & Vigilante, 2003; Wogalter, Magurno, et al., 1999) has shown that older adults have more difficulties reading small print on product labels than younger adults. Other research (Collins & Lerner, 1982; Lesch, Powell, Horrey, & Wogalter, 2013; Ringseis & Caird, 1995; Shorr, Ezer, Fisk, & Rogers, 2009) has shown that older participants had lower levels of comprehension for safety-related symbols than younger adults. Older adults may be more influenced by warnings than younger adults, but legibility, memory, and comprehension need to be considered in their design (Lesch, Horrey, Wogalter, & Powell, 2011). Age-related declines are found in other modalities, such as in audition (Kline & Scialfa, 1996), olfaction (Wysocki & Gilbert, 1989), and skin senses (Reuter, Voelcker-Rehage, Vieluf, & Godde, 2012), and should be considered in designs that use them. Likewise, children also possess a wide range of abilities. With the youngest children, warnings should be directed to caregivers (Kalsher & Wogalter, 2007), but in some cases they can be directed to children (Waterson & Monk, 2014; Waterson, Pilcher, Evans, & Moore, 2012).

Other demographics associated with warning related criteria include locus of control (Donner, 1991; Laux & Brelsford, 1989), self-efficacy (Lust et al., 1993), and culture (Mayhorn, Wogalter, Goldsworthy, and McDougald, 2014; Smith-Jackson & Wogalter, 2000). Persons who believe that they can control their destiny or who are less confident in a task are more likely to read available warnings than persons who believe that fate controls their lives or who are more confident. When designing warnings for the general population, it may be impossible to address all the needs of different people with a single warning; thus, a multi-method systems approach may be needed.

There are many dimensions of receiver competence that may be relevant to the design of warnings (e.g., Duarte, Rebelo, Teles, & Wogalter, 2014b). For example, sensory deficits in special target audiences must be considered. A blind person would not be able to receive a printed warning, nor would a deaf person receive an auditory warning.

There has been some suggestion in the literature that warning noncompliance is related to a greater propensity of risk taking. However, the measurements of the concept are often confounded with other factors and the components comprising the scoring are often based on collating behaviors considered to be risky. But if a person has done one potentially hazardous activity, that does not necessarily mean that person will take risks in another activity.

Assuming the warning is delivered, the receiver may then process the warning through several stages. The next sections deal with stages within the receiver: attention switch and maintenance, comprehension/memory, beliefs/attitudes, and motivation, and behavior.

4.5 Attention Switch

A warning must capture attention and then hold it long enough for the contents to be processed. The first of these two attention stages is the switch of attention from something else to the warning. This stage also leads off the human information-processing portion of the receiver in the C-HIP model. An effective warning attracts attention in contexts and environments where other stimuli are competing for attention.

For a warning to capture attention, it must first be available (i.e., delivered) to the recipient. This is not enough by itself, it needs to be sufficiently salient (conspicuous or prominent) to switch attention to it. Thus, it competes against other available stimuli.

Using eye-tracking technology, Kovacevic, Brozovic, and Mozina (2018) demonstrated how prominent warning pictograms that were large in size and used thick lines were more likely to be noticed on packaging than smaller, less prominent pictograms. Attention attraction is important because people typically do not actively seek hazard and warning information. Design factors, as described below, can influence how well warnings can draw attention within context.

4.5.1 Size and Contrast

Bigger is generally better. Increased print size and background contrast have been shown to benefit subsequent recall (Barlow & Wogalter, 1993; Wogalter, Magurno, Dietrich, & Scott, 1999; Wogalter & Vigilante, 2003). Young and Wogalter (1990) found that print warnings with highlighting and bigger, bolder print produced greater comprehension of and memory for owner's manual warnings.

Context plays an important role in how size affects salience. Not only is the size of the warning important but also its size relative to other information in the display. For some products, the available surface area for printing warnings can be limited. This is particularly true for small product containers such as pharmaceuticals or tubes of glue adhesives. Alternative feasible methods are available to increase the surface area for print warnings include adding tags or peel-off labels (Barlow & Wogalter, 1991; Wogalter, Magurno, et al., 1999). Another method is to put the most critical information on the front (primary display) label and then direct the user to additional warning information on the back panel or in a secondary source, such as an owner's manual or website (Wogalter et al., 1995).

4.5.2 Color

While there are some problems with the use of color such as color blindness and lack of contrast with certain other colors, good use of color can benefit warnings (Wogalter, Mayhorn, & Zielinska, 2015). Coloration differentiation is a perceptual process that can help attract attention more effectively than warning in the same color as its surroundings (e.g., Laughery, Young, et al., 1993).

4.5.3 Pictorial Symbols

Pictorial symbols and icons can be useful for attracting attention (Kalsher et al., 1996; Mayhorn, Wogalter, & Bell, 2004; Mayhorn & Goldsworthy, 2009). For example, Tao, Yafeng, and Lei (2017) demonstrated that icons with salient visual features capture attention.

A common icon used in warnings that can help attract attention is the safety alert symbol (triangle enclosing an exclamation point) (Laughery, Vaubel, et al., 1993). Symbols are usually large elements of a warning which aids its salience. Complex pictorial symbols may need highlighting on critical elements to draw viewer's attention (McDougald & Wogalter, 2014).

4.5.4 Placement

Warnings located close to the hazard both physically and in time will increase the likelihood of attention switch (Frantz & Rhoades, 1993; Wogalter et al., 1995). A label on a car battery warning of hydrogen gas explosion hazard is much more likely to be effective than a similar warning embedded in the owner's manual. A verbal warning given a week before a farm worker uses a hazardous pesticide is less likely to be remembered compared to one given immediately prior to using the product.

A warning that is located in an out-of-view location, drastically reduces the likelihood of an attention switch. In general, placement of warnings directly on a hazardous product is preferred (Wogalter et al., 1987). However, this may not be possible for certain products or circumstances of use. There are several factors to consider in warning placement. One is visibility; a warning should be placed so that users are likely to see it in the course of expected activity (Frantz & Rhoades, 1993). For example, a warning on a hard drive inside a computer's case will not be seen if the case is not opened. Proper locations for warnings can be determined by considering how people use the product through task analyses (see Chapter 13 in this volume by Hollnagel).

Wogalter et al. (1987) showed that a warning was more likely to be noticed and complied with if placed before task instructions than following them. Warnings should not be buried in the middle of other text or on a later page.

4.5.5 Formatting

Another factor that can influence attention is formatting. Aesthetically pleasing text with white space and conceptual information groupings (Hartley, 1994) are more likely to attract and hold attention (Wogalter & Vigilante, 2003). If a warning contains a large amount of dense text, individuals may decide too much effort is required to read it and thus may direct their attention elsewhere.

4.5.6 Repeated Exposure

A related issue is that repeated and long-term exposure to a warning may result in a loss of attention-capturing ability (Wogalter & Laughery, 1996). This habituation can occur over time, even with well-designed warnings. Where feasible, changing a warning's format or content can slow the habituation process (Wogalter & Brelsford, 1994; Wogalter & Mayhorn, 2005a).

4.5.7 Other Environmental Stimuli

Other environmental stimuli may compete with warnings for attention capture. These stimuli may include the presence of other persons, various objects that create context, and the tasks being performed. Thus, the warning must stand out from the background to make noticing more likely. Usually people are focused on the tasks they are trying to accomplish. Because safety considerations are not always on one's mind, warnings need to be prominent to give them the chance to be noticed.

4.5.8 Auditory Warnings

Auditory warnings are frequently used to attract attention. Auditory signals are omnidirectional, so the receiver does not have to be looking at a particular location to be alerted, unlike visual warnings. But like visual warnings, their success in switching attention depends largely on salience. Auditory warnings should be louder and distinctively different from expected background noise. Auditory warnings are sometimes used in conjunction with visual warnings. A common method is where a sound (tone, chime, etc.) is used as an alert to prompt an examination in the visual modality having more specific information (Sanders & McCormick, 1993; Sorkin, 1987).

4.6 Attention Maintenance

Individuals may notice that a warning is present but not stop to examine it. A warning that is noticed but fails to maintain attention long enough for its content to be encoded is of little direct value. Attention must be maintained on the message to extract meaning from the material (Wogalter & Leonard, 1999). During this process, the information is encoded or assimilated with existing knowledge in memory.

With short, brief warnings the message information may be acquired very quickly, sometimes at a glance. For lengthier warnings to maintain attention, they need to have qualities that generate interest and do not require considerable effort. Some of the same design features that facilitate the attention switch stage also help to maintain attention. An example is legibility, which is discussed below.

4.6.1 Legibility

If a warning contains very small print, it may not be legible, making it difficult to read. Older adults with age-related vision problems are a particular concern (Wogalter & Vigilante, 2003). If it requires extra time and effort to read nearly-illegible print, then some may not do it. Distance and environmental conditions such as fog, smoke, and glare can negatively affect legibility (Collins & Lerner, 1982).

Sanders and McCormick (1993) give data on the legibility of fonts developed for military applications. Legibility of type can be affected by numerous factors, including choice of font, stroke width, letter compression and distance between them, letter case, resolution, and justification. There is not much research to support a clear preference for certain fonts over others; the general recommendation is to use relatively plain, familiar fonts. It is sometimes recommended that a serif font, with embellishments in the lettering, such as Times Roman be used for smaller print containing message text and sans serif font (plain fonts without embellishments) such as Helvetica be used in applications requiring larger headline style print. The American National Standards Institute's (ANSI, 2011) Z535.2 and Z535.4 warning sign and label standard include a chart of print size and expected reading distances in good and degraded conditions.

Contrast and color of print affect legibility. Black on white or the reverse has the highest contrast, but legibility can be adequate with other combinations such as black print on a yellow background and white print on a saturated red background. Color selection should also be governed by the context where the warning is presented (Young, 1991). A red warning in a mostly red context should be avoided.

4.6.2 Formatting

Visual warnings formatted to be aesthetically pleasing are more likely to hold attention than a single chunk of very dense text (Wogalter & Vigilante, 2003). Also formatting can show the material's conceptual organization, making it easier to assimilate the material into memory. In general, the use of generous white space and bold bulleted lists are preferred to long, dense prose text (e.g., Taylor & Wogalter, 2011). Full justification (straight alignment at both margins) can be more difficult to read than "ragged right" justification because the spacing between letters and words is consistent, thereby aiding saccadic eye transitions during reading.

4.6.3 Pictorial Symbols

Interest is also facilitated by the presence of well-designed pictorial symbols. People prefer warnings that have a pictorial symbol to warnings without one (Kalsher et al., 1996; Mayhorn & Goldsworthy, 2009). Well-designed symbols do not need to hold attention for long if the message it depicts is comprehended at a glance as described in the next section.

4.7 Comprehension and Memory

This stage of the C-HIP model concerns processes involved in understanding and memory. Discussed in the sections below are two aspects of this stage: comprehension derived from subjective hazard connotation and semantics from the specific wording and symbols used. These processes involve people's existing memory and knowledge together with the warning and context.

4.7.1 Hazard Connotation

Certain aspects of a warning may convey some subjective level or degree of hazard such as overall danger (Wogalter et al., 1997).

Visual In the United States, standards such as ANSI (2011) Z535 and guidelines (e.g., FMC Corporation, 1985) recommend that warning signs and labels contain a signal word panel that includes one of the terms DANGER, WARNING, or CAUTION. According to ANSI Z535, these terms denote decreasing levels of hazard, respectively. Figure 3 shows two ANSI-type warning signal word panels. According to ANSI Z535, the DANGER panel should be used for hazards where serious injury or death *will* occur if the directed compliance behavior is not followed, such as around high-voltage electrical circuits. The WARNING panel (not pictured) is used when serious injury *might* occur, such as severe chemical burns or exposure to highly flammable gases. The CAUTION panel is used when less severe personal injuries (e.g., cuts, bruises) or property damage might occur. Research shows that laypersons often fail to differentiate between CAUTION and WARNING, although both are interpreted as connoting lower levels of hazard than DANGER (e.g., Wogalter & Silver, 1995). The term NOTICE is intended for messages that are important but do not relate to injuries. The term DEADLY, which has been shown to connote hazard significantly above DANGER, has not been adopted by the ANSI, yet it might be considered for hazards that are significantly above those connoted by the term DANGER (Wogalter, Kalsher, Frederick, Magurno, & Brewster, 1998).

Figure 3 Examples of two signal word panels including alert symbol and color. Note that the DANGER panel is white print on red background and the CAUTION is black print on yellow background. Not shown is the WARNING panel, which is black print on orange background.

Color Color is often used as a cue for hazard with red being generally the highest in hazard connotation with other colors having less or no hazard connotation (Zielinska, Mayhorn, & Wogalter, 2017). In the ANSI signal word panel, the words are paired with colors (red, orange, and yellow, for DANGER, WARNING, and CAUTION, respectively). This assignment is a method of redundancy that is useful if one cannot read or perceive the color. However, like the associated words, the colors orange and yellow are not readily distinguished with regard to hazard connotation. However, red is consistently judged as having a higher hazard connotation than the other colors (e.g., Chapanis, 1994; Mayhorn, Wogalter, & Shaver, 2004).

Auditory Different characteristics of sounds can lead to different hazard connotations. Sounds with higher frequency (higher pitch), greater amplitude (louder), and faster repetitions are perceived as more urgent (Edworthy, Loxley, & Dennis, 1991). Similar effects have been shown with voiced warnings (Hellier et al., 2002).

4.7.2 Competence

Three areas of competence that are important in warning design are technical knowledge, language knowledge, and reading skill. Some hazards are complex and understand of them requires some level of expertise that laypersons may not have such as the hazards associated with medications, chemicals, and electronic devices. If the receiver does not have the relevant technical competence needed to interpret the information, a warning concerning hazards containing technical is likely to be unsuccessful. The level of knowledge and understanding of the target audience should be considered in developing warnings.

The issue of language competence is straightforward, and it is increasingly important. Subgroups in the United States speak and read languages other than English, most predominantly Spanish. As trade is increasingly international, multiple languages and pictorials can be used (Lim & Wogalter, 2003).

Reading skills and capabilities in the population vary from illiteracy to graduate-level skill. Yet, high levels of reading skill are commonly needed to understand warnings that are directed to individuals who have lower-level skills. In general, reading levels should be as low as feasible. For the general public, the reading level might need to be in the fourth- to sixth-grade levels (general education of children 10–12-years old). However, warnings specifically directed to technically trained individuals such as licensed health care professionals who by training have some expected level of expertise can be more technical and complex (Mayhorn & Wogalter, 2017). The reading levels should be matched with the intended target audience. There are readability formulas based on word frequency in printed language, length of words, and number of words in statements that are used to estimate reading grade level (Duffy, 1985). These formulae have limitations and are notorious for giving inaccurate estimates on comprehensibility. However, they could be useful in preliminary analyses of text. A discussion of reading level measures and their application to the design of instructions and warnings can be found in Duffy (1985).

An additional point on reading ability concerns illiteracy. Even in the richest countries of the world there are a substantial number of functional illiterates. There are estimates that over 16 million functionally illiterate adults exist in the U.S. population. Therefore, successfully communicating warnings may require more than keeping reading levels to a minimum. While simple solutions to this problem do not exist, well-designed pictorial symbols, speech warnings, special training programs, and greater use of technology may be necessary to accommodate these groups. Testing with the samples of the target audience can confirm whether the proposed warning is understandable.

4.7.3 Message Content

The content of the warning message should include information about the hazard, the consequences of the hazard, and instructions on how to avoid the hazard.

Hazard Information Providing hazard information tells the target audience about potential safety problems. Example hazard statements are (1) toxic vapors; (2) slippery floor; and (3) high voltage (7200 volts).

A hazard should be spelled out clearly in a warning. Three exceptions are when the hazard is (1) generally known by the population; (2) known from previous experience; or (3) "open and obvious." (The latter two concepts will be described in more detail in Sections 4.7.8 and 4.7.10.) Other than these exceptions, information on the nature of the hazard is an important component of most warnings (Wogalter et al., 1987).

Consequences Consequence information conveys the nature of the injury or property damage that could result from the hazard. Hazard and consequence information are usually closely linked in the sense that one leads to the other. Statements regarding these two elements are sometimes purposely sequenced in this way such as in "Toxic Vapor, Severe Lung Damage."

Sometimes, consequences information can be placed near the beginning of the warning to get and hold the receiver's attention (Young et al., 1995). This is particularly true for severe consequences such as death, paralysis, and severe lung damage. So, another appropriate statement sequence is the opposite of that mentioned above, as in "Severe Lung Damage, Toxic Vapor."

There are also situations when it might not be necessary to state the consequences in the warning. This point is related to the open and obvious aspects of hazards. For example, a sign indicating "Wet Floor" probably does not need to include a consequence statement "You Could Fall." It is reasonable to assume that people will correctly infer the appropriate consequence. Nevertheless, the hazard statement could be improved by including "Slippery" as a substitution for "Wet" to include consequences with the statement. Although this is a simple example, it shows how consequence information can be combined with a hazard statement.

An important reason why consequence information is needed is that warning recipients could make incorrect inferences regarding injury or property damage outcomes with complex hazards. Previous research with older adults indicates that people aged 65+ years often have difficulty comprehending warning content when inferences are required (Hancock et al., 2005). Thus, it is important in designing warnings to assess whether the consequences can be inferred correctly and, if not, then to reword or redesign the warning.

The lack of specificity is a shortcoming in many warnings. Warnings commonly fail to provide important details. The statement "May be hazardous to your health" in the context of a toxic vapor hazard does not tell the receiver whether she may develop a relatively minor throat irritation and cough or suffer severe lung damage. Also providing only general information is deficient if warnings are expected to provide "informed consent" about risks. As will be discussed later, knowledge about severe consequences can motivate attention to and compliance with warnings (see Section 4.9 on Motivation).

Pictorial symbols can also be used to communicate consequence information (Goldsworthy, Schwartz, & Mayhorn, 2008a; Mayhorn & Goldsworthy, 2007, 2009). Some symbols (e.g., for a slippery floor hazard) convey both hazard and consequence information without it being depicted separately. Figure 4 contains some example industrial safety symbols that convey both hazard and consequence information.

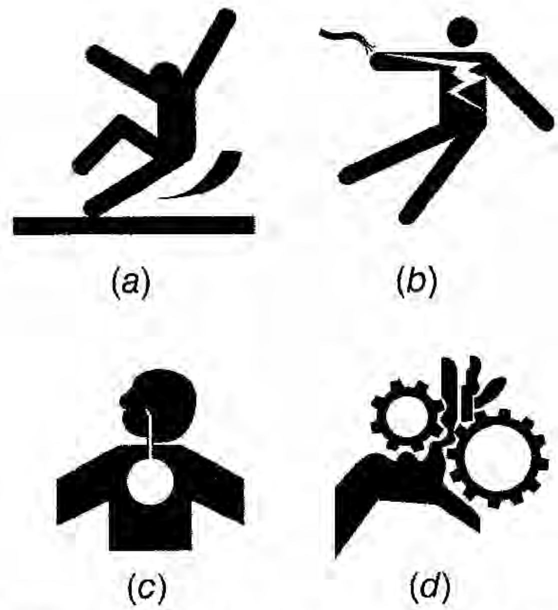


Figure 4 Examples of pictorials conveying hazard information: (a) slippery floor; (b) electrical shock; (c) toxic gas; (d) pinch point.

4.7.4 Instructions

In addition to getting people's attention and telling them about the hazard and potential consequences, warnings should also instruct people about what to do or not do to stay safe (directions on how to avoid the hazard). Typically, instructions are given following hazard and consequence information. An example of an instructional statement is "Must Use Respirator Type 1234, that can be included in the context of hazard and consequence statements, as in "Severe Lung Damage, Toxic Vapors, Must Use Respirator Type 1234." The instruction assumes, of course, that the receiver will know what a type 1234 respirator is and have access to one.

Figure 5 shows examples of symbols used in warnings to convey instructional information (directions to avoid the hazard). Note that some incorporate a prohibition symbol, a circle with an internal slash through it, meaning not to do what

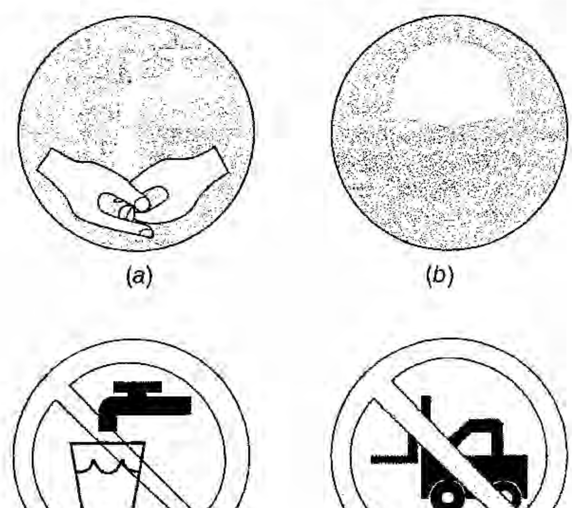


Figure 5 Examples of pictorial symbols conveying instructions/directions information: (a) wash hands; (b) wear hard hat; (c) do not drink water; (d) no forklifts in area.

is depicted within the circle (Ribar, Wogalter, & Mayhorn, 2007). Prohibition symbols are usually red or black.

Sometimes a distinction is made between warnings and instructions. Warnings are communications about safety, while instructions may or may not concern safety. Warnings include instructions on how to avoid the hazard, but not all instructions are or a part of warnings. "Keep off the grass" is an instruction that generally has nothing to do with safety.

4.7.5 Explicitness

Specificity is generally preferred over generality. An important design principle relevant to warning comprehension is explicitness (Laughery, Vaubel, et al., 1993; Laughery & Paige-Smith, 2006). Explicit messages contain information that is sufficiently clear and detailed to permit the receiver to understand the nature of the hazard, the consequences, and the instructions. Consider the unclear statement "Use with adequate ventilation." Does this mean open a window, use a fan, or something much more technical in terms of volume of airflow per unit time? Warnings are frequently not detailed or specific enough. However, sometimes technical details are not necessary and could be detrimental in certain instances. Two examples of warnings illustrate a lack of explicitness, despite having hazard, consequence, and instructional statements: (1) "Dangerous Environment, Health Hazard, Use Adequate Precautions" and (2) "Mechanical Hazard, Injury Possible, Exercise Care." Explicit alternatives might be (1) "Severe Lung Damage, Toxic Chlorine Vapor, Must Use Respirator-Type 123" and (2) "Pinch Point Hazard—Moving Rollers, Your Hand/Arm May Be Severely Crushed or Amputated, Do Not Operate without Guard X89 in Place."

4.7.6 Pictorial Symbols

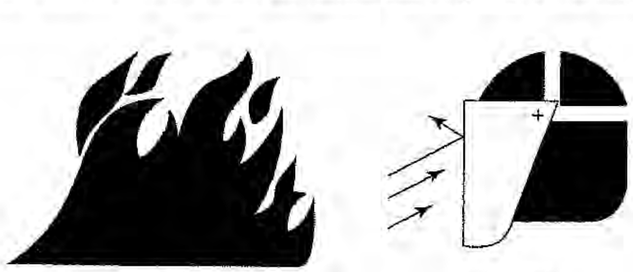
Pictorial symbols are used in warnings that communicate hazard-related information, often in conjunction with a printed text message. Guidelines such as ANSI (2006) Z535.3 and FMC Corporation (1985) encourage the use of safety symbols if they aid warning comprehension (Boersema & Zwaga, 1989; Lerner & Collins, 1980; Wolff & Wogalter, 1993, 1998; Zwaga & Easterby, 1984). The symbols can depict one or more warning message components. Well-designed symbols can potentially cue large amounts of knowledge at a glance. They can benefit low literates as well as persons who do not use the regional language (Mayhorn & Goldsworthy, 2007, 2009). Some results suggest that a person's affective state can affect pictorial comprehension (Jiamsanguanwong & Umemuro, 2014).

Clearly comprehension is a primary concern of symbols. In some pictorials, the depiction directly depicts and represents the information or object intended to communicate. Figure 6 shows two examples of direct representation. One shows both a hazard and consequences by depicting a raging fire, and the other shows both the hazard and the instructions, depicting the need for an eye shield. Other symbols are identifiable only after some form of training/learning has taken place. People may identify the particular objects represented in a skull and crossbones symbol, but the fact that it represents a poison hazard needs to be learned. In a classic example, Casey (1998) describes an instance where hundreds of Kurdish farmers in Northern Iraq died when they consumed grain treated with alkyl mercury fungicide because they did not realize the skull and crossbones symbol was intended to indicate poison. Likewise, participants from Tanzania and the United States displayed different observed comprehension of "universal medical icons" presumably due to cultural differences (Zender & Cassedy, 2014).

Other symbols are completely abstract, such as symbols intended to convey "do not enter" (an example is shown in Figure 7) and biohazard concepts. They are unique and arbitrary. These symbols would not be identifiable without training/learning. As a general principle, pictorials that directly and specifically illustrate the hazard, consequences and/or instructions are identified at a higher rate than those that are abstract (Hicks, Bell, & Wogalter, 2003).

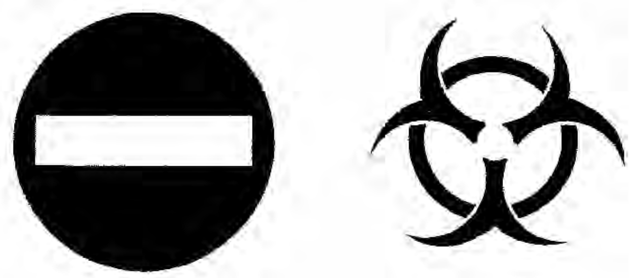
Comprehension of safety symbols is often lower than might be expected (e.g., Caffaro & Cavallo, 2015) without iterative testing and redesign (Wolff & Wogalter, 1998) and training (e.g., Lesch, 2008). What is an acceptable level of comprehension for pictorials? This question has been addressed in the ANSI (2011) Z535.3 standard, which suggests a goal of 85% comprehension by the target audience. One criterion indicates that safety symbols should be designed to accomplish the highest level of comprehension attainable. If 85% cannot be achieved, the symbol may still be useful if it is better than alternative designs. A second criterion is that the symbol should not be misinterpreted. According to the ANSI (2011) Z535.3 standard, an acceptable symbol must have less than 5% critical confusions (opposite meaning or a meaning that would produce unsafe behavior). Research by Mayhorn and Goldsworthy (2007) illustrates an example of a misinterpretation of a pictorial that was part of a warning for a medication used for severe acne but causes birth defects in babies of women taking the drug during pregnancy. The pictorial shows a side-view outline shape of a pregnant woman within a circle-slash prohibition symbol. The intended meaning is that women should not take the drug if they are pregnant or plan to become pregnant. However, some women incorrectly interpreted the symbol to mean that the drug might help in preventing pregnancy, a severe critical confusion.

There are techniques to prototype symbols and do iterative redesigns in attempts to attain greater levels of comprehension (e.g., Banares, Caballes, Serdan, Liggayu, & Bongo, 2018). Research also suggests that sometimes more than one symbol may be needed to convey difficult concepts (Adams, Boersema, & Mijksenaar, 2010). For some concepts it might not be possible to attain high levels of comprehension by symbolic means without some form of training (Hicks, Bell, & Wogalter, 2003).



(a) (b)

Figure 6 Examples of pictorials showing a direct representation: (a) raging fire and (b) wear eye shield.



(a) (b)

Figure 7 Examples of pictorial symbols that can be recognized only after learning: (a) do not enter and (b) biohazard.

4.7.7 Habituation

Repeated exposure to a warning over time will reduce its ability to attract attention. Even well-designed warnings will eventually become habituated if repeated or from continuous exposure. While there are no easy solutions to the habituation problem, one approach is to use the attention-getting features described in this chapter to slow the progress of habituation or to cause dishabituation (attentional recovery) compared to warnings without the features (Kim & Wogalter, 2009).

4.7.8 Memory and Experience

There are several ways to enhance safety knowledge. Training given to employees is one method. Experience is another way that people acquire safety knowledge during their life experience. Some experiences are fairly common, but every individual's experiences are unique and as a result each person has a knowledge base that is somewhat different. "Learning the hard way" by doing something that leads to an injury (or knowing someone who did) usually increases perceived hazard (Wogalter, Brems, & Martin, 1993). Older adults commonly cite personal experience as a source of knowledge regarding hazards associated with household products such as cleaners and appliances (Mayhorn, Nichols, et al., 2004). However, such experiences are not good experiences to have, and having raised hazard perceptions does not necessarily mean the perceptions of risk are accurate (Wogalter et al., 1993).

4.7.9 Warnings as Reminders

The process of comprehension is tied to the person's knowledge base stored within memory. Although individuals may have knowledge about a hazard, they may not be aware of it at the time they are at risk. In short, this is a distinction between awareness and knowledge. This is analogous to the short-term and long-term memory distinction in cognition. Short-term, or working, memory is sometimes thought of as conscious awareness and is known to have processing capacity limitations. Long-term memory contains the contents of one's worldly knowledge. People may have information or experience in their overall knowledge base, but at a given time, it is not in their current awareness—or what they are thinking about. It is not enough to say that people know something. Rather, it is important that people be aware of the relevant information at the critical time. No one knew better than the three-fingered punch press operators of the 1920s that their hand should not be under the piston when it stroked, but such incidents continued to occur, despite knowledge. Here warnings are an insufficient solution. A better solution was a procedural guard that required positioning each of two hands at control locations away from the danger area to engage the press to punch. The distinction between knowledge and awareness has implications for the role of warnings as reminders. Potentially warnings could serve to cue information in long-term memory to bring forth related and previously dormant knowledge into conscious awareness (Smith & Wogalter, 2010). Another example is the personal digital assistant that can assist users in adhering to medication regimens by sounding an auditory signal when it is time to take a particular medication (Mayhorn et al., 2005).

4.7.10 "Open and Obvious"

A source of information about dangers is the situation or product itself. In U.S. law there is a concept of "open and obvious." This concept means that the appearance of a situation or product or the manner in which it functions may communicate the nature of the safety problem. That a knife can cut is apparent to all people except young children. Many hazardous situations are not open and obvious. Some are associated with chemical hazards where labeling and warnings are necessary because the chemical itself (by visual appearance or cues from other modalities such as olfaction) does not make the hazard known. Another issue is attentional where one hazard attracts more attention than another. Hidden hazards have been documented in the agricultural context. Farmers working to repair tractors may actively work to avoid the dangers of moving parts but may fall prey to a lesser apparent hazard such as carbon monoxide (McLaughlin & Mayhorn, 2011).

4.7.11 Technical Information

Many warnings require an appreciation of technical information for complete understanding of the material. Examples include the chemical content of a toxic substance, the maximum safe level of a substance in the atmosphere in parts per million (ppm), and the biological reaction to exposure to a substance. This information is included in safety data sheets (SDS) required by the U.S. Occupational Safety and Health Administration that employers make available to employees who may be exposed to the chemicals (usually provided by a distributor, supplier, or manufacturer). SDS contain highly technical information. While there are circumstances where it is appropriate to communicate such information (e.g., to an industrial hygienist or a toxicologist on the staff of a chemical plant, or firefighters arriving on the scene of a factory fire), as a general rule it is neither necessary nor useful to communicate such information to a general target audience. Indeed, it may be counterproductive in the sense that encountering such information may result in the receiver not attending to the remainder of the message and thereby missing useful information. Rather, users need to be informed that the substance is toxic, the injury or illness it can cause, and how to use it safely. Different components of the warning system can and often should be used to communicate to the different audience groups.

4.7.12 Auditory

Auditory warnings can be complex in form. Different ones can be used to convey distinct levels of urgency and meanings (Edworthy & Hellier, 2006). These auditory warnings may be nonverbal sounds (with different waveform characteristics) or voice also with different waveforms (Edworthy & Hellier, 2000; Taylor & Wogalter, 2019). Complex nonverbal signals are composed of sounds differing (sometimes dynamically) in amplitude, frequency, and temporal pattern. Their intended purpose is to communicate different types and levels of hazards. These signals have the potential to transmit more information than simple auditory warnings, but the receiving person must know what the signal means. Some form of education and training is necessary. Only a limited number of different nonverbal auditory signals should be used to avoid problems in discriminating and cuing their associated meaning (Banks & Boone, 1981). Also there needs to be concern with false positives and negatives and their effect on credibility (Bliss & Fallon, 2006).

It is common for voice (speech) to be used in transmitting warnings. Voice chips and digitized sound processors have been developed, making voice warnings feasible for a wide range of applications. Under certain circumstances, voice warnings can be more effective in transmitting information than printed signs (Wogalter, Kalsher, et al., 1993; Wogalter & Young, 1991). Additionally, voice modifications and manipulations can produce different levels of perceived urgency similar to connoted hazard mentioned earlier for signal words and color (Edworthy & Hellier, 2000; Hollander & Wogalter, 2000). Voice warnings will likely be used increasingly in future applications. However, there are some inherent problems to consider. Transmitting speech messages requires longer durations than simple auditory warnings or reading an equivalent message. Comprehension can also be a problem with complex voice messages. To be effective, voice messages should be intelligible and brief. With noise that may mask, headphones and earphones that cover or compete with outside sounds, and different degrees of deafness, the warning designer should probably consider using loud sounds or present warning information in other modalities for backup and redundancy.

One example of previous research that has successfully demonstrated the utility of voice warnings is Conzola and Wogalter's (1999) "talking box" study. When participants opened the box, a miniaturized voice system delivered a sequence of precautionary steps to be performed before installing a computer disk drive in the box. With safety instructions that require numerous complex steps, working memory could be overloaded if the sequence is provided in one continuous presentation. A system that provides support by giving carefully timed or user-prompted instructions might be effective in reducing the likelihood of overloading cognitive resources.

4.8 Beliefs and Attitudes

If a warning successfully captures and maintains attention and is understood, it might fail to be processed further due to discrepant beliefs and attitudes held by the receiver. Beliefs refer to an individual's knowledge of a topic that is accepted as true. Attitudes are similar to beliefs but have greater emotional involvement (DeJoy, 1999). According to the C-HIP model, a warning will be successfully processed if the information concurs with the receiver's current beliefs and attitudes. The warning message is easily processed if it matches and concurrently reinforces what is already known. In the process, their reinstatement will make those beliefs and attitudes stronger and more resistant to change. If, however, the warning information does not agree with the receiver's existing beliefs, then for the warning to be effective, the receiver's beliefs and attitudes must be altered to an extent necessary to benefit safety. To do so, the message must be persuasive to change preexisting beliefs and attitudes and motivate compliance, such as using strong emphasis terms (Kim & Wogalter, 2015).

Beliefs can be wrong (cf. Wogalter & Taylor, 2015). Mentioned earlier was the idea of elevated perceived hazard by persons who have been directly injured or know persons who have been injured. Hazard perceptions can be over- or underestimated. For example, people's benign experiences with a product can result in them believing it is safer than it actually is. It can also be a problem when people believe that their own abilities will enable them to overcome the hazard, such as drivers believing their driving skills will not suffer when they divide their attention by using cellular telephones (Strayer et al., 2003; Wogalter & Mayhorn, 2005b).

4.8.1 Hazard Perception

One of the factors to determine whether people read and comply with warnings is their perception of the level of hazard and consequences. The greater the perceived level of hazard and consequences, the more responsive people will be to warnings (Wogalter et al., 1991; Wogalter, Brems, et al., 1993). Warnings on products perceived as low hazard will be less likely to be noticed or read (Wogalter, Brems, et al., 1993). Perceived hazard is closely related to the severity of injury that is anticipated. The greater the perceived level of potential injury, the more hazardous the product is perceived (Wogalter et al., 1991). People largely believe that consumer products sold in the U.S. are reasonably safe (Kim & Wogalter, 2011).

4.8.2 Familiarity

Familiarity beliefs are formed from past similar experience where at least some relevant information has been acquired and stored in memory. Familiarity can lead to a belief that everything that is necessary to know about a product or situation is already known (Wogalter et al., 1991; Wogalter, Brems, et al., 1993a). A person who is familiar with a piece of equipment might assume that a new piece of equipment operates in the same way. This may not be true, but due to their belief, the person does not read the product manual and as a result could be seriously injured. Numerous studies have explored the effects of people's familiarity/experience with a product on how they respond to warnings. With greater perceived familiarity, people are less likely to look for, notice, or read a warning (Godfrey & Laughery, 1984; LaRue & Cohen, 1987; Otsubo, 1988; Wogalter et al., 1991). Greater familiarity is associated with reduced compliance likelihood (Goldhaber & deTurck, 1988). This notion of "familiarity breeds contempt," however, should not be overemphasized for at least two reasons. First, people more familiar with a situation or product may have more knowledge about the hazards and consequences as well as an understanding about how to avoid them. Second, with increased use of a product, people are exposed more frequently to the on-product warnings. Of course, warnings in tiny dense print may never be read even over many cycles of exposure.

Prior experience can be influential in other ways. As mentioned earlier, having experienced injury or having personal knowledge of someone else being injured can lead to an overestimation of danger (Mayhorn et al., 2004a). Usually this is less of a problem compared to the potential for underestimation by non-experienced persons (Wogalter et al., 1991; Wogalter, Brems, et al., 1993a).

Experts in a domain may be so facile with their knowledge that they fail to realize that non-experts do not have similar skills and knowledge. To the extent it is incorrectly assumed that people already know the hazards, there may be a tendency for manufacturers to produce inadequate warnings for non-expert users (Laughery, 1993).

4.9 Motivation

Even if people see, understand, and believe a warning, they may not comply with it. Motivation is closely tied to behavior. Motivation can energize individuals to carry out activities that they might not otherwise do. Among the most influential factors for motivation in relation to warnings are the following: cost of compliance, severity of consequences, social influence, and stress.

4.9.1 Cost of Compliance

The cost associated with compliance can be a strong motivator (or inhibitor). Generally, compliance with a warning requires that people take some action (or no action). Cost of complying may include time, effort, or money to carry out the behavior instructed by the warning. When people perceive the cost to comply as greater than the benefits, they are less likely to perform the safety behavior. This problem is commonly encountered in warning analyses, when the instruction statement requires an inconvenient, difficult, or occasionally impossible behavior. "Always have two or more persons to lift [box or object]" cannot be done if no one else is around. "Wear rubber gloves when handling this product" is inconvenient to do if the user does not have easy access to appropriate gloves.

Thus, the requirement to expend extra time or effort can reduce motivation to comply with a warning (Dingus, Hathaway, & Hunn, 1991; Wogalter et al., 1987; Wogalter et al., 1989). A method to reduce the cost of compliance is to make the directed behavior easier to perform. For example, if hand protection is required when using a product, gloves might accompany the product. Safe use of a product should be as simple, easy, and convenient as possible.

Also, the costs of noncompliance can affect compliance motivation and behavior especially when the potential consequences are severe. When severe consequences are likely, people are more motivated to carry out safety behavior. Thus, to benefit motivation, injury associated with noncompliance should be explicitly stated in the warning (Laughery, Vaubel, et al., 1993). Explicit injury–outcome statements such as "Can cause liver disease—a condition that almost always leads to death" provide reasons for complying and are preferred to general, non-explicit statements such as "Can lead to serious illness." In a sense, compliance decisions can be viewed in part as a trade-off between the perceived costs of compliance and noncompliance.

4.9.2 Severity of Consequences

A related issue to the costs of noncompliance is the severity of consequences. Perceived severity of injury is intimately tied to risk perception, as discussed in Section 4.8. Severity of injury is a factor in people's reported willingness to comply with warnings. People's notions of product hazardousness are substantially based on the perceived potential injury severity (Wogalter et al., 1991; Wogalter, Brems, et al., 1993). Likelihood of injury, however, is not as strongly tied to people's hazard-related judgments (Wogalter & Barlow, 1990; Young et al., 1990). These findings support the importance of clear, explicit consequence information in warnings. Such information can be critical to people's risk perception and their evaluation of trade-offs.

4.9.3 Social Influence and Stress

Another motivator of warning compliance is social influence. Research (Wogalter et al., 1989) has shown that if people see others complying with a warning they are more likely to comply themselves. Similarly, seeing that others do not comply lessens the likelihood of compliance. Social influence is an external factor because it is not part of the warning design. An example of a risky behavior that is strongly influenced by social interaction is the "sharing" of prescription medications by teenagers (Goldsworthy & Mayhorn, 2009; Goldsworthy, Schwartz, & Mayhorn, 2008b). Explicit warnings are needed to counteract misconceptions associated with social factors.

Other factors that influence motivation to comply with a warning are time stress (Wogalter, Magurno, et al., 1998) and mental workload (Wogalter & Usher, 1999). In high-stress and high-workload situations, competing activities absorb some of the cognitive resources available for processing warning information and carrying out compliance behavior and thus reduce their effectiveness.

4.10 Behavior

The last stage of the sequential process of the C-HIP model is to carry out the safe behavior. Determining what people will do in the context of a warning is a desirable measure of its effectiveness. Behavioral compliance research shows that warnings can change behavior (e.g., Cox et al., 1997; Laughery et al., 1994; Wogalter et al., 2001). The main issue in contemporary research is not whether warnings can or cannot be effective but rather it is directed at determining the factors and conditions that influence whether a warning is effective in producing compliance. Silver and Braun (1999) and Kalsher and Williams (2006) have reviewed published research that has measured compliance with warnings under various conditions.

Behavioral compliance is usually considered the gold standard of warning effectiveness. In a behavioral compliance study, one can see in an overt empirical way whether the warning was effective. In one example of this, Burt, Henningsen, and Consedine (1999) found that certain symbols were more effective than others in producing a targeted correct posture by participants lifting a box.

Relative to all of the studies concerning warnings, behavioral compliance metrics are reported in research studies at a less frequent rate than might be expected. It is challenging to set up a proper behavioral compliance experiment. There are ethical constraints in exposing people to hazards to measure warning effectiveness. Thus oftentimes in the general behavioral compliance study an attempt is made to have the scenario appear to have some level of risk when it actually does not have any (or minimal). The methodology is important when a reasonably realistic risk situation is staged. Participants are led to believe they are doing one or more other tasks for reasons not related to the warning aspects of the situation. In some sense, the warning aspects are peripheral and incidental to the main reason of the study (i.e., the participant is not told of the purpose of the study until debriefing afterwards). The benefit of a behavioral study is that the effects of warnings can be seen and measured from overt compliance.

Three additional points about methodology are worth mentioning. Sometimes compliance can be measured indirectly (e.g., whether a pair of protective gloves have been used in private settings as evidenced by its stretch marks, see Wogalter & Dingus, 1999).

As a proxy, researchers sometimes use subjective judgments of willingness to comply as an alternate measure. However, such studies while useful to compare conditions relative to one another rarely produce results that match absolute levels of compliance.

As will be discussed later (Section 6) at least some of the future of warning research is probably in Virtual or Augmented Reality because people can be placed in risky-appearing situations without the actual risk. For example, Duarte et al. (2010) used virtual reality to measure behavioral compliance in a building fire scenario involving emergency egress without placing users at risk from physical harm. Additional studies on this topic are mentioned later.

4.11 External and Environmental Factors

The receiver's processing of a warning is affected by its environmental context. This includes non-warning information on the product label, characteristics of the product itself, other people, other tasks the receiver might be doing at the time, other aspects of the environment, including illumination and background noise (Vredenburgh & Helmick-Rich, 2006). These non-warning sources of information provide the context and they compete with the warning for attention and other stages of processing.

4.12 C-HIP's Utility

This review of factors influencing warning effectiveness was organized around the C-HIP model. Besides its usefulness in organizing a large body of research, it is useful in identifying and predicting potential processing bottlenecks and indicating specific deficiencies in the warning system. Suppose a manufacturer finds that a critical warning on their product label is not working to prevent injury. One reaction might be to increase the size of the font so more people are likely to see it. But noticing the warning label (the attention switch stage) might not be the problem affecting compliance. Additionally, users might report having seen (attention switch stage), read (attention maintenance stage), understood (comprehension and memory stage), and believed the warning message (the beliefs and attitudes stage). The problem with the manufacturer's warning could be at the motivation stage—users are not complying because they believe the cost of complying to be too high (e.g., wearing uncomfortable personal protection equipment) and that did not outweigh their perceptions of risk. In other cases, earlier bottlenecked stages could be causes of failure. Thus, one could use the model to pinpoint the reasons for a warning not working and allowing targeted remedies. By using the model as an investigative tool, one can determine the specific causes of a warning's failure and not waste resources fixing the wrong aspects.

For the practitioner, the model has utility in determining the potential effectiveness of a warning. To the extent that a warning fails to meet various design criteria, the model can be a basis for judging adequacy (a form of heuristic testing). The lack of signal words, color, and pictorials or placement in a poor location can be a basis for judging adequacy regarding attention. A high reading level, the use of technical terminology, or the omission of critical information may be the basis of a warning's comprehension inadequacy. The failure to give persuasive statements could insufficiently affect beliefs. The lack of explicit consequences information when the outcome of noncompliance is catastrophic is inconsistent with warning adequacy criteria regarding motivation. Considerations such as these can be useful in formulating opinions and addressing issues on warning success.

5 DESIGNING FOR APPLICATION

Warning systems should be designed to maximize their effectiveness. This section describes some basic guidelines and principles to assist in the design and production of warnings.

5.1 Standards

A starting point in designing warnings is to consider existing guidelines such as the ANSI (2011) Z535, FMC Corporation (1985), or Westinghouse Electric Corporation (1981). ANSI Z535 is currently a six-part standard that includes descriptions of safety colors, signs, symbols, labels, tags, and ancillary materials. ANSI standards are voluntary standards; that is, they are recommendations (not requirements or law) and are generally considered "minimums." We believe that blindly following the ANSI standard will not necessarily lead to adequate warnings. There is a need for some human factors judgment and testing to "fine tune" the warning for the particular product or situation.

In the ANSI Z535 standard, there is an emphasis on a standardized way to format signs (Z535.2) and product labels (Z535.4). According to these standards, warning signs and labels should possess the following components: (1) a signal word panel such as DANGER, WARNING, or CAUTION (with corresponding red, orange, or yellow color) and an alert symbol to attract attention and connote levels of hazard; (2) a hazard statement that describes the nature of the hazard; (3) a description of the possible consequences associated with noncompliance; and (4) instructions for how to avoid the hazard. Research indicates that each of these four components can provide benefit to warning efficacy, however, recent evidence also indicates that experimental design and analytical methods must be carefully considered when assessing compliance with ANSI Z535 because they can influence results (see Kalsher, Obernauer, & Weiss, 2019). Moreover, when one (or more) of the message components is redundant with other statements (Wogalter et al., 1987; Young et al., 1995), pictorial symbols can be used in lieu of some of the component text, assuming understandable symbols are used. Safety symbols should meet certain comprehension criteria to be acceptable for use by itself (without words). Both the ANSI (2011) Z535.3 and the International Organization for Standardization (ISO, 2001) 9186 symbol standards provide guidelines and methods to assess symbol comprehension.

5.2 Checklist of Potential Warning Components

Use of only standards and guidelines may not always produce an effective warning. Table 2 presents a checklist of factors that should be considered in designing warnings. These factors are based not only on standards and guidelines but also on empirical research. While not an exhaustive list, Table 2 contains a basic set of factors that the warning literature indicates should be considered in warning design. Thus, one method of assessing warning quality is simply to decide whether a design meets appropriate criteria such as those in Table 2. For attention, warning effectiveness might be questioned if no signal word is used, color is not adequately employed, the print is small, in high density, or embedded in other types of information. Likewise, if the reading level is high, technical language is used, or it is vague and not explicit, then the warning may not be comprehended as intended. Similar considerations can be applied with respect to the criteria for the other stages. See also Lenorovitz, Leonard, and Karnes (2012) for a somewhat different checklist of warning features.

Implementation of specific factors may also depend on the specific hazard, other characteristics of the product, anticipated environments, and level of knowledge in the target audience. For example, some warning components may not be necessary if the target audience consists of trained experts or if the information is apparent from the context and other aspects.

5.3 Principles

In addition to Table 2, the rules for judging efficacy can be expressed as principles that should be considered when designing warning systems. Some basic principles are described below.

5.3.1 Principle 1: Brief and Complete

As a general rule, warnings should be as brief as possible. Two separate statements should not be included if one will do. Longer warnings or those with nonessential information are less likely to be read, and they may be more difficult to understand. Thus, the brevity criterion conflicts to some extent with the explicitness criterion. Being explicit about every hazard could result in very long warnings, which is not desirable. However, the brevity criterion should not be interpreted as a license to omit important information. A compromise between brevity and completeness is discussed in the next section on prioritization.

A concept related to completeness is over-warning. The term over-warning is sometimes used to describe how our world is filled with warnings. The notion is that if warnings were to be placed on everything, people would simply ignore them. While this notion has face validity, there has been little empirical data on warning excess. Nevertheless, over-warning may be a valid concern, and unnecessary warnings should be avoided. A related issue arises when there is an absence of certain warning information, as part of a failure to warn or inadequate warning claim. Defendant manufacturers through their attorney may argue that information being left off of a warning was a good thing because its inclusion could hurt the likelihood of other important information being read. However, this argument does not comport with the "right to know" purpose of warnings. Warnings should provide the opportunity to know about hazards as part of deciding whether to take the risk. Indeed, research indicates that people want to know about hazards even if definitive risk information is not available (Freeman & Wogalter, 2002).

Table 2 Warning Design Guidelines

Warning components	Design guidelines
Signal words	DANGER—Indicates immediately hazardous situation that will result in death or serious injury if not avoided; use only in extreme situations. Use white print on a red background (ANSI Z535). WARNING—Indicates a potentially hazardous situation that may result in death or serious injury if not avoided. Use black print on an orange background. CAUTION—Indicates a potentially hazardous situation that may result in minor or moderate injury. Use black print on a yellow background. NOTICE—Indicates important non-hazard information. Use white print on a blue background. To the left of the signal word is the alert symbol
Format	Text should be high contrast, e.g., black print on white or yellow background Use left justification (ragged right). Headings and short statements may be centered Use list or outline format Each statement starts on its own line Use white space or bullet points to separate individual or sets of conceptually-related statements Most important warning statements should receive priority, e.g., positioned early in a list
Wording	Use as little text as necessary to convey the message. Use short, familiar words. Use short statements rather than long, complicated prose Give information about the hazard, instructions on how to avoid hazard, and consequences of failing to comply Be clear. Avoid using words or statements that might have multiple interpretations, particularly critical confusions that could lead to injury. Be explicit and concrete. Tell specifically what the hazard is, what the consequences (extent and type of serious injury), and what to do or not do to avoid the hazard/consequences. Use active rather than passive voice Remove unnecessary connector words (such as prepositions, articles) particularly in headings Avoid using abbreviations unless their designations are widely known by the target population Use multiple languages to reach at-risk groups who do not use main local language
Pictorial symbols	When used alone, acceptable symbols should have at least 85% comprehension scores, with no more than 5% critical confusions, according to ANSI Z535.3 Comprehension test—use open-ended test with relevant context Safety symbols that do not pass a comprehension test can sometimes be used if accompanied by words, if critical confusions are low Use bold shapes. Avoid including irrelevant details. Complicated illustrations may need color highlighting to draw viewers to critical elements. Prohibition (circle slash should not obscure critical elements of symbol) Should be legible under degraded conditions, e.g., distance, size, abrasion
Font	Text should be legible enough to be seen by the intended audience at the expected viewing distance and angle Use mixed-case letters. Avoid using all caps except for signal words or for specific emphasis Use san serif fonts (Arial, Helvetica, etc.) for signal words and larger text Use serif (Times New Roman, etc.) fonts for smaller sized text Use plain, familiar, non-decorative font Avoid horizontally compacted text, lettering should not touch or be too close.
Other	Located/positioned so presentation is where it will be seen or heard Test to assure message satisfies the C-HIP stages in Table 1

5.3.2 Principle 2: Prioritization

Prioritization concerns how warnings should be positioned for products and environments with multiple hazards. It includes deciding what statements to include or exclude from a label, how to sequence items, and how much relative emphasis to give them. According to Vigilante and Wogalter (1997a, 1997b), prioritization considerations are:

1. *Likelihood.* The more frequently an undesirable event occurs, the greater priority it should be given.
2. *Severity.* The more severe the potential consequences of a hazard, the greater priority it should be warned. If a chemical product poses a skin contact hazard, a higher priority would be given to a severe chemical burn consequence than if it were a minor rash.
3. *Known (or not known) to target population.* If the hazard is already known and understood or if it is open and obvious, warnings may not be needed, except for use as a reminder.
4. *Importance.* Is it important for individuals to know the hazard? Give people the opportunity to know about

aspects that could injure them. Some hazards may be more important to know than others, particularly if the hazards are not obvious or there is an accumulating history of injury.

5. *Practicality.* There are occasions when limited space (a small label on a small container) or limited time (a television commercial) does not permit all hazards to be addressed in a single component of the warning system. However, labels should direct users to additional information in easily available ways.

As a general rule, unknown and important hazards leading to more severe consequences that are more likely to occur should have higher priority than less severe or less likely hazards. Higher priority warnings should be placed on the product label. If it is not practical to place all of them on the label, then hazards with lower priority should be given in a prominent and complete way elsewhere in the warning system such as package inserts, manuals, packaging, and other media.

5.3.3 Principle 3: Know the Receiver

Gather information about relevant receiver characteristics. To illustrate one way to collect and use that information, Goldsworthy et al. (2010) used receiver-centered testing to present complex risk-related scenarios involving dangerous sharing of prescription medications among young adults. An analytic technique known as latent class analysis (LCA) was used to select warning content appropriate for this target audience.

Thus, a way to meet the needs of receivers is to purposely tailor the warning as appropriate to the person, product, and situation. Another approach to tailoring warnings can be accomplished through the use of technology as will be described in Section 6 on Future Warnings. As will be seen in that section, this tailoring method involves the use of sensors, computers, software, and displays (Wogalter & Mayhorn, 2005a).

5.3.4 Principle 4: Design for Low-End Receiver

When there is variability in the target population, the warning should be designed for the low-end extreme. Safety communications should not be written at the level of the average or median percentile person in the target audience. Such warnings will present comprehension problems for people at lower competence, experience, and knowledge levels. Likewise, formatting and presentation should take into consideration those who are older, with perceptual, cognitive, and physical declines. Warning directives should be able to be carried out by persons who are differently-abled when practical and feasible. An added benefit of designing warning systems for the low-end user is the realization that these solutions typically result in more user-friendly products and environments that benefit all consumers regardless of ability and demographic differences (Vanderheiden, 1997).

5.3.5 Principle 5: Warning System

When the target audience consists of subgroups that differ on relevant dimensions or when they may be involved under different conditions, consider employing a warning system that includes different components for the different subgroups. Do not assume that all necessary communications will be accomplished with a single warning method. For example, exterior packaging (e.g., the box) is useful for point-of-purchase decisions but it may be discarded and unavailable after the first use of the product (Cheatham & Wogalter, 2003). However, the on-product label or its container (e.g., a pill bottle) is more likely to be available for consultation at future uses. Other components of a warning system that might be used include inserts, manuals, and websites.

5.3.6 Principle 6: Durability

Warnings should be designed to last as long as needed. There are circumstances where durability is typically not a problem. A product purchased off a store shelf for immediate consumption is an example. On the other hand, products with a long lifespan, such as lawn mowers and tools can present a challenge (Glasscock & Dorris, 2006). Aspects that negatively affect durability over time include exposure to outside weather conditions or involve extensive handling or abrasion forces (Shorr et al., 2009). Some product manuals include a list of all on-product labels together with part numbers to enable ordering replacements when missing or degraded. But the evaluation of degradation and ordering is probably rarely done. This suggests that the original labels should be as durable as possible to last the product's expected lifespan.

Related to durability concerns is the availability of warning information after the product has been put into use. Some ancillary materials may not be available at later uses of the product (Cheatham & Wogalter, 2003; Wogalter, Vigilante, et al., 1998; Wogalter & Laughery, 2015) or never transferred to subsequent owners or users (Wogalter, Vigilante, et al.,1998). This is why careful consideration of what warnings ought to be placed directly on a product is critical because these warnings may be the only ones available at later points in time.

5.3.7 Principle 7: Test the Warning

In addition to considering design criteria, it is frequently necessary to carry out some sort of testing to evaluate a warning or a prototype of a warning. This approach may entail asking people to generate ideas for improvement and/or formal assessments involving larger numbers of people giving independent evaluations. Of course, the sample should be representative of the target audience while also considering practicality and feasibility.

To assess attention, a warning could be placed on a product while people carry out a relevant task to determine if they look at it or notice it. To assess comprehension, studies can determine to what extent a hazard conveyed by a warning is understood. This process probably has the best cost–benefit ratio of any procedure in the warnings design process. Relative to behavioral studies, comprehension can be assessed easily, quickly, and inexpensively. Well-established methodologies include memory tests, open-ended response tests, and cognitive interviews (e.g., Brantley & Wogalter, 1999; Wolff & Wogalter, 1993). The qualitative data that result from open-ended and interview methodologies can sometimes be difficult to interpret but can be exceptionally valuable in determining what information in the warning was or was not understood. Feedback from users might offer suggestions for what might be done to redesign the warning to increase understanding.

Studies can also determine whether members of the target audience accept the warning information as true, applicable, and relevant to them. Negative results on these dimensions may be indicative of a lack of sufficient persuasiveness. Motivation can be assessed by obtaining participants' subjective judgments on intent or willingness to comply. Lastly, behavior can be tested with empirical compliance measures.

Studies intended to measure warning effectiveness must incorporate appropriate principles of research design. Some of the salient factors to consider are the selection of participants to be representative of the target population, avoiding confounding by extraneous variables, guarding against contamination by expected outcomes, and determining the best coding rubric when using qualitative data. For additional discussion about different approaches to evaluating warning effectiveness, see e.g., Frantz et al. (1999), Wogalter, Conzola, et al. (1999), Wogalter and Dingus (1999), and Young and Lovvoll (1999).

6 FUTURE WARNINGS

Technology has provided new and better methods to present hazard information (Laughery & Wogalter, 2006). In the following sections, potential approaches to apply technology to warnings are discussed.

6.1 Dynamic Warnings

As described earlier, most visual warnings are static signs or labels. Their presentation is passive and unchanging. These "static" displays will be enhanced and perhaps replaced by dynamic displays.

Static warnings usually need feature enhancements to make them salient to facilitate attention switch. Perceptual and cognitive systems are less "attuned" to unchanging stimuli. When something does not change over time, it is less likely to attract attention due to low salience. Adding dynamic qualities enhances their likelihood to attract and maintain attention. Research shows that, in general, dynamic warnings are more effective than static warnings (Duarte, Rebelo, Teles, & Wogalter, 2014a; Smith-Jackson & Wogalter, 2004; Vilar, Rebelo, Noriega, Teles, & Mayhorn, 2015; Wogalter & Mayhorn, 2005a, 2006a).

A static school sign might not be attended to by drivers who then fail to slow down if most of their driving in the area occurs outside school hours when children are not around. But adding something to make them more conspicuous such as lights that flash during appropriate times will more likely alert drivers to slow down (Duarte, Rebelo, Teles, & Wogalter, 2014a).

In the above example, the *dynamic school warning sign* also had additional information that the static sign lacked. The flashing lights are activated at appropriate times, i.e., during periods before and after the children enter and leave the school campus. When the lights are not flashing, drivers do not have to slow down because children are less likely to be present. The warning is given where and when it is needed, and reduces false positive errors (Wogalter & Mayhorn, 2006a).

Presentation of alarms in the auditory modality is analogous. A continuous tone is static and will lose impact over time. The urgency of a relatively simple fire alarm can be enhanced by adding dynamic qualities, as in varying the frequency and temporal aspects of the auditory signal (Edworthy & Hellier, 2006). Dynamic auditory alarms may be present in cockpits, control rooms, and hospital settings. By contrast, most vehicles contain simple warnings, such as a flashing light or a recurring tone or chime (e.g., seat belt buzzers). Likewise, medical devices commonly activate some form of alarm buzzers when sensors indicate life-threatening conditions.

Dynamic warnings can be given in video form and it is usually a combination of both visual and auditory information (Racicot & Wogalter, 1995). Research indicates that warnings presented via video using both the visual and auditory modalities (Barlow & Wogalter, 1993; Wogalter, Shaver, & Kalsher, 2014) are more effective than presentation in one modality (or not at all). A wide range of dynamic enhancements can be given within each modality.

6.2 Expanded Use of Flat-Screen Displays

Technology has provided new ways of displaying warnings with the increased availability of flat-panel displays. They are used in high-definition computer and television monitors, as well as smartphone and pad/flat panel-type displays. Many vehicles provide information via one or more high-resolution screens, some capable of touch sensitivity. Newer vehicles can receive Internet signals directly or indirectly via smartphones. Extremely large flat panel displays are used in sports stadiums and as advertisement billboards. These electronic display technologies have potential for use in a variety of warning applications and if implemented well can give more and better warnings than traditional static displays. One such use is changeable information signs on highways. Bright, higher resolution, high-contrast versions of these signs can include graphics, mixed case font, etc. These electronic signs are more likely to attract attention than conventional static signs occupying the same space.

In addition to attracting attention, electronic display content can be changed to reflect the current or predicted hazard situation. Many primary highways have electronic signs that present timely, pertinent information about traffic and road conditions ahead and what to expect (e.g., delays, detour). Displays could be mounted inside or outside buildings. For example, electronic signs could alert factory workers in manufacturing facilities to current or developing hazardous conditions such as the presence of poisonous gas or electrical hazards in an area.

Some vehicles have display systems that can present safety information such as a searchable owner's manual, which can provide critical information when and where it is needed, such as what to do replace a blown tire. It could include video on how to properly install child safety seats and specific warnings to front seat passengers not to recline when the vehicle is in motion.

6.3 Detectors/Sensing Devices

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 make a connection between the warning and the hazard.

Sometimes warnings are not relevant in the situation such as a "Bridge Ices Before Road" sign seen in warm summer months. A better method might entail a temperature detector that presents the message when icy conditions are present such that it is only displayed when the temperature is near freezing.

Humans have sensory, perceptual, and cognitive limitations. Warning systems that include detector (sensing) devices can take on some of the burden of noticing and some of the processing for a warning (Wogalter & Mayhorn, 2005a, 2006b). Numerous kinds of sensor systems are available that detect temperature, moisture, gas vapor, motion, and weight. These sensors can provide input into systems that could, in turn, provide a perceptible and informative warning.

Another benefit of some kinds of sensors is that they can supplement people's limited abilities. Humans do not have sensory systems able detect radiation and carbon monoxide (CO), but fortunately there are devices that can do that job (e.g., Geiger counters and CO detectors; see Herring & Hallbeck, 2010). Another example is detection of a propane gas leak. Because people cannot detect the odor of the gas itself (and thus may not notice a leak), an odorant (e.g., ethyl mercaptan) is added to the gas before it is distributed to consumers' homes. The odor has been likened to the smell of rotten eggs. However, for a variety of reasons (Wogalter & Laughery, 2010, 2011), people may not smell the odorant and thus are at risk for fire and explosion from a gas leak. For more than two decades, hardware stores have been selling detectors that specifically "sense" the gas (not the odorant) and thus could serve as a first line sensor for leak detection.

Besides the sensor aspects of detectors, more advanced systems are likely in the future. This will be partly due to use of multiple sensors that provide patterns that can be interpreted by algorithms within computer systems to quickly determine the best course of action and provide guidance. Some systems will be designed to make automatic changes to the system itself for safety (as some building sprinkler systems do) but also to warn people in appropriate ways. For example, many large buildings have fire plans and often these plans and evacuation instructions are posted on doors, elevators, etc. However, people seldom read these materials. Future evacuation warning systems will detect specific problems (e.g., carbon monoxide) and then provide relevant warnings about the hazard, consequences and instruction (e.g., pointing out which set of stairs to use).

6.4 Individually Tailored Warnings

Tailoring warnings is the idea is that different people have different needs, and thus may need different warnings and instructions. Sometimes these differences are attributable to individual characteristics or capabilities, but the differences may also be based on varying situations where environmental factors play a part. Multiple detectors "sense" the position of a person doing tasks at a workstation, and when the pattern strays to some extent from a standard (good posture), a warning is given. Sensors combined with computer systems can be used to process information to enable warnings to be tailored to the hazard, the situation and the characteristics of the target user (Wogalter & Mayhorn, 2005a).

Warnings could also be personalized to enhance the degree of relevance to the targeted individual. Perceived relevance facilitates compliance (Wogalter, Racicot, Kalsher, & Simpson, 1994). One way to increase relevance is to present a warning that includes the targeted person's name. Compliance is higher with personalized warnings (Smith-Jackson & Wogalter, 2004; Wogalter & Mayhorn, 2005a, 2006a). Information from "smart" cards, fobs or phones could be used to present pertinent hazard information to a target individual. Face recognition systems are increasingly more common. Access to airports can be done by biometrics such as a retinal or fingerprint scan. Smart identification cards or smartphones can be used to provide information that could assist in determining what safety warnings to present based on qualifications, prior experience, etc. Use of these approaches shortens 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, job title, 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 as reminders. For the novice, the information may need to be simple and limited in scope to specific information that they need.

A prioritization strategy could inform what and how information should be provided to individuals (Wogalter, Conzola, & Vigilante, 2006). Prioritization would limit the presentation of certain information so that only the most critical is given initially but lower prioritization information is accessible if desired. Programmers would not know the content area or what warnings need priority, and thus involvement of a human factors expert would be beneficial. Although the potential for future technology-based warning systems is substantial, there are a number of barriers that could delay or prevent implementation. One example concerns the collection of personal information due to privacy concerns. The issue of privacy is complex so a balance will be needed between maintaining privacy and promoting safety.

Some of the systems described above are simple, and others more complex and expensive. But likely the cost of the latter systems will decrease. And the value must be weighed by the potential for increased safety. As a consequence of decreased cost and added safety, warnings will be increasingly involved in new technology. However, the methods of implementation as well as their appropriateness must also be considered. Some of the issues of concern are warning intrusiveness and annoyance as well as the potential of increased need for maintenance and repair. The systems also need to be "tuned" so that inappropriate or false warnings (false positives and misses) are avoided.

7 CONCLUSION

Warning design is comprised of many factors and considerations. In this chapter we have presented an overview of the current status of research, guidelines, and criteria for designing warnings.

Approaches to dealing with environmental or product hazards are generally prioritized such that first one tries to solve the problem by design, then by guarding, then by warning. Thus, in the domain of safety, warnings are viewed as a third but an important line of defense.

Warnings can be properly viewed as communications purposed to inform and influence the behavior of people. Warnings are not simply signs or labels. They can include a variety of media where various kinds of information get communicated to people. The use of various media or channels and an understanding of the characteristics of the receivers or target audiences to whom warnings are directed are important in the design of effective warnings. The concept of a warning system with multiple components or channels for communication to a variety of receivers is central.

The design of warnings can and should be viewed as an integral part of systems design. Too often it is carried out after the environment or product design is essentially completed. Importantly, warnings cannot and should not be expected to mitigate bad designs.

In this chapter, the C-HIP model with reference to warning processing was described. As part of this discussion, relevant factors influential at each stage of processing were presented. In addition, guidelines and principles for warning design in application were presented. Its potential use as an investigative tool was also discussed.

Determining whether or not a warning will influence behavior is often difficult. In addition to ethical problems of exposing people to hazards, actual field studies testing warnings are likely to be time-consuming and costly. Certainly, where feasible, such studies are desirable. Also, while laboratory or other controlled simulations of warning situations can be useful in assessing behavioral effects, such approaches leave open questions of generalizability.

The issue of assessing warning effectiveness has received a great deal of attention in recent years. Several criteria can be employed in assessing warnings, including whether they capture and maintain attention, are understood, are consistent with or capable of modifying beliefs and attitudes, motivate people to comply, and result in people behaving safely. Employing behavioral approaches can provide useful input toward the goal of providing effective warnings. Future use of technology will enable tailored warning presentations when and where the information is needed with relevance to individual characteristics, the task, and the environment involved.

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