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THE FUTURE OF RISK COMMUNICATION: TECHNOLOGY-BASED WARNING SYSTEMS

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ABSTRACT

Technology will transform conventional methods of risk communication by enabling delivery of dynamic warnings in situations when and where they are needed. Future warnings will involve computer control, flat-panel displays, electronic paper, wireless transmission, multiple sensors, and connection with the Internet, among other methods. This chapter describes issues supporting the use of technology in the control and display of warnings. One benefit is the potential of personalized perceptual and cognitive support tailored to fit individual needs. Challenges, such as barriers to technological implementation, are described. Implications, examples, and future prospects of warnings are presented.

INTRODUCTION

Warnings are usually considered to be signs or product labels made of paper, metal, or plastic. They are usually static and passive. People are less attuned to stimuli that do not change. Adding changing or dynamic qualities makes them more noticeable and can potentially provide more information. Some forms of dynamic warnings have been in existence for many years. Consider common auditory warnings, such as fire alarms, which are active and to some extent variable. Technology has provided new ways in which warnings can be presented and controlled in both auditory and visual modalities. They can compensate for sensori-perceptual and cognitive limitations. Not only can technology make warnings better able to capture attention but also to aid in comprehension and motivation.

Recent articles have described how new or very recent technology can produce better warnings (Mayhorn & Wogalter, 2003; Smith-Jackson & Wogalter, 2004; Wogalter & Conzola, 2002; Wogalter & Mayhorn, 2005). This chapter describes some of the ways that technology can be incorporated into warnings. First, the general characteristics of dynamic warnings are described to distinguish them from common static warnings. Second, aspects of displaying warnings using computer technology are discussed. Third, hazard detection through the use of sensors is considered. Fourth, the implications for tailoring warnings to fit the needs of individual users are explored. Finally, potential barriers to technological implementation are discussed.

Some of the methods described involve existing technology, and some are based on trends of how technology will likely progress in providing new ways to deliver warnings in the future. Most of the methods discussed concern the visual modality; however, implications for future directions regarding the auditory modality are also described.

DYNAMIC WARNING CHARACTERISTICS

One reason dynamic warnings can be better than static warnings is that they are generally more noticeable. Human sensory and perceptual systems are built to detect change. When something does not change or is no longer novel, it is less likely to attract attention. The reason is habituation. Exposure over time has resulted in some memory (although not necessarily complete memory) of the stimulus, and the stimulus becomes less salient relative to other stimuli or tasks. The problem is that adequate attention may be have been given before all of the relevant

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content has been extracted. Dynamic warnings are less likely to induce habituation as rapidly as static signs and thus are more likely to attract attention over time.

However, even dynamic warnings are not immune to habituation, as exposure to any stimuli over lengthy and frequent periods of time can result in habituation. The process of habituation is generally slower for dynamic than for static warnings. One of the reasons auditory warnings may be more attention-getting than visual warnings is that the former tends to have more stimulus change over time than the latter. But even auditory stimuli over time will eventually habituate. However, incorporating additional dynamic qualities can slow the rate of habituation. For example, one can enhance a relatively simple fire alarm by adding more dynamic qualities, such as by varying the frequency and temporal aspects of the auditory signal (Hass & Edworthy, chap. 14, this volume; Edworthy & Hellier, chap. 15, this volume). In general, warnings with more dynamic qualities will tend to be more attention-getting and delay habituation over time compared with stimuli with less dynamic qualities. Thus, dynamic warnings tend to slow the habituation process to a greater extent than static warnings; however, adding further variability to the dynamic warning will delay habituation even further.

The dynamic aspects need to be salient (prominent or conspicuous) to maintain their ability to attract attention. A simple example is the traffic signs shown in Fig. 63.1. Consider the conventional sign on the left. In this case, the school zone sign is intended to signal a lower speed limit for specific times within a designated area of roads around a school. Specifically, it is intended to warn drivers to decrease their speed during the time students may be in the area. The print size of those time periods is relatively small and is probably difficult for drivers to read in moving traffic. Moreover, the reduced speed limit is not applicable most of the time. Thus, drivers may inadvertently violate the speed limit because they are unable to read the time posting at all or before it is too late. Also, inadvertent violations may be simply a product of past experience of the sign's irrelevance and consequent habituation of a static stimulus. The right side of the Fig. 63.1 illustrates a version of the sign with two lights programmed to flash only during school hours. The right sign will likely have fewer violators and provide greater safety to children than the left sign, as the flashing light calls attention to the sign at the appropriate times. When not flashing, the sign can be disregarded. Habituation could still occur, however, if the sign was allowed to flash all of the time. Assuming that it is appropriately maintained and programmed, the sign on the right will slow drivers better than the conventional static one on the left. With the flashing sign, violators will also find that it is more difficult to convince a police officer or judge that they did not notice the sign.

According to Sanders and McCormick (1993), the optimal flash rate is in the range of four flashes per second, with equal intervals of on and off time. The flash should be at least twice as bright as the background to be seen easily in the ambient context; however, it should not be so bright that it causes people to look away from the glare (Wogalter, Kalsher, & Racicot, 1993).

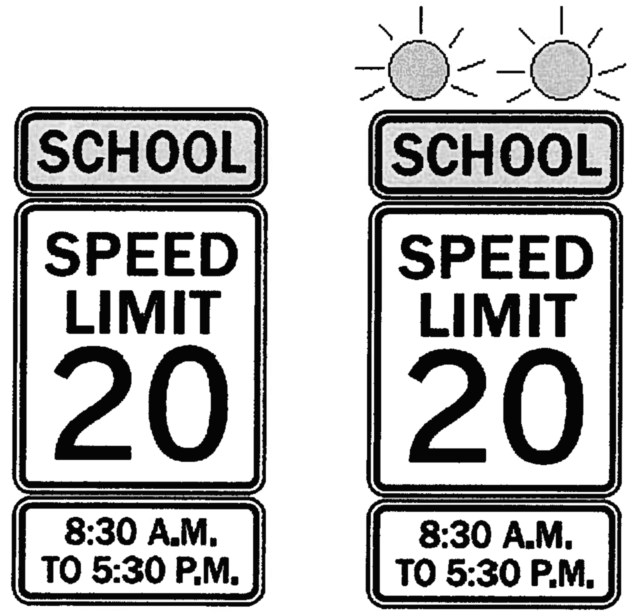

FIGURE 63.1. Two school zone signs. The left sign is a conventional sign; the right is enhanced with two lights that flash during the times children may be in the area.

Learning

Although habituation is generally considered a bad consequence of exposure over time, it is an indication that some learning has occurred with at least some memory having been formed. Of course, learning is a positive consequence of warning exposure if adequate hazard information has been extracted before habituation set in. If a warning's information is already part of a person's knowledge base, it is less important that the person needs to attend to the warning. Habituation is generally not a problem in such instances (excepting in certain cases when a reminder is needed). Habituation is a problem when a person no longer attends without having incorporated into memory all of the necessary hazard information.

Spacing Effect

The number of exposures and the duration of those exposures influence the learning process. Learning is benefited by certain schedules of presentation. This is sometimes called the spacing effect. Distributed exposure of material of any sort (including warnings) produces greater memory than massed exposure (Underwood, 1961). In other words, for a total time of exposure to a given warning of, say, 100 seconds, 10 distributed exposures each of a 10-second duration will be better than a single exposure of 100 seconds. This is similar to cramming for an exam the night before (massed) versus studying the same amount of total study time but distributed in short sessions across several evenings (distributed). The latter will usually result in better performance on a test than the former. Research also indicates that distributed learning is more resistant to forgetting compared with massed learning. Once learned, the warning needs to be presented occasionally as a reminder to activate and reinstate the memory to better enable access to that knowledge. This re-exposure primes or activates the associated memory, enabling easier access to that memory later.

Hazard Level

Potentially, technology-based warnings could dynamically display the degree to which a hazard exists. In other words, the warning could change when the severity and likelihood of a hazard changes. Edworthy (e.g., Edworthy & Adams, 1996; Edworthy & Hellier, chap. 15, this volume) has made the point that warnings should reflect the extent of the hazard. In this way, the warning should look or sound more urgent when conditions warrant an immediate response and less so when the condition is less urgent. Research investigating the communication of message urgency has examined a number of variables, such as the use of signal words, color, pictorial symbols, and sound complexity. These findings are described in the following sections.

Signal Words. Visually presented warnings often contain specific terms, such as "DANGER," "WARNING," and "CAUTION" to communicate high to low levels of hazard, respectively (ANSI, 2001). Electronic displays of warnings might change the signal word to reflect the current hazard level. It should be acknowledged that research shows that laypeople do not distinguish between certain convention signal words (WARNING and CAUTION). However, other easily distinguishable terms (e.g., DEADLY) and terms for a larger range of hazard connotation are available in (e.g., Wogalter & Silver, 1990, 1995).

Color. Like signal words, color has been shown to affect perceived hazard (e.g., Smith-Jackson & Wogalter, 2000; Wogalter, Kalsher, Frederick, Magurno, & Brewster, 1998). The color red has been shown to express greater hazard than yellow or orange, which between them are not substantially different from each other. Other colors, such as blue and green, generally express less or no hazard (Braun & Silver, 1995; Chapanis, 1994; Rashid & Wogalter, 1997). Thus, dynamic warnings designed to reflect the current status of the situation could change: from yellow or orange for lower hazards to red for higher hazards.

Quantitative Information. An electronic sign could also give quantitative information. For example, consider a sign posted before a bridge crossing a body of water, where it is known that severe wind gusts could blow large trucks out of their lanes (and perhaps off the bridge). A dynamic sign could display not only qualitative information, such as signal word color to signal the hazard level, but it could also show a measure of the wind speed combined with an informative pictorial symbol. Of course, drivers would need to know what wind speeds are hazardous, and the sign could include that information as well. An example is the following:

Signal word (and color):	DANGER (red)
Hazard severity:	Extremely Strong Wind Gusts
Wind speed (quantitative):	48 mph (or equivalent km/hour)
Instructions:	Trucks Don't Use Bridge
Alternative route:	Reroute to Highway 42 North or Wait in Rest Area Ahead

When conditions are less severe, the displayed wind speed would be lower and would use lower-level terms and colors corresponding to the degree of hazard, such as WARNING and yellow.

Pictorial Symbols. Symbols are increasingly being used in warnings. The benefits include increased likelihood of attention being directed to the warning and potentially improved message comprehension. The latter benefit is important for persons not skilled in a particular language to read and understand warning text (e.g., low literates and foreigners; Wogalter & Leonard, 1999). Research suggests that pictures are sometimes easier to remember than words, sometimes called the picture superiority effect (Nelson, 1979). Like the signal words and colors described earlier, symbols could be added or changed in electronically displayed warnings at different points in time to communicate varying levels of hazard or different hazards. For example, an electronic sign could replace numerous printed signs alerting factory workers to noise, hazardous airborne particles, and respiratory hazards. However, designers of these warning systems should be cautious in using symbols because they may not communicate as well as intended. It is therefore recommended (see ANSI, 2002) that symbols be evaluated to determine their comprehensibility (Deppa, chap. 37, this volume). In particular, abstract concepts are often not amenable to a well-understood symbol without accompanying text or training (Hicks, Bell, & Wogalter, 2003; Mayhorn, Wogalter, & Bell, 2004; Wogalter, Sojourner, & Brelsford, 1997).

Sound and Speech. Variations in sound can convey different levels of urgency (e.g., Edworthy & Hellier, chap. 15, this volume; Edworthy et al., 2004; Haas & Edworthy, chap. 14, this volume). Likewise, speech can be altered to convey different levels of urgency. Louder, higher-pitched speech presented at a somewhat faster rate produces higher ratings of perceived hazard than the same words presented at a less loud, lower pitch and at a slower rate (e.g., Hollander & Wogalter, 2000). Emotionally emitted speech is perceived as more urgent than monotone speech (Barzegar & Wogalter, 1998a, 1998b). Results also show that the perceived hazard of the content of auditorily presented signal words and phrases is similar to those of the same material presented visually (Lim & Wogalter, 2004). Thus, like the visual displays described in the preceding sections, speech displays can be altered in sound quality and content to reflect the hazard level involved.

DISPLAYS

In the previous section, electronic displays were mentioned but not described explicitly. In this section, nonconventional

FIGURE 63.2. A traffic signal countdown sign. (See Color Plate 22).

methods of displaying warnings made possible by new technology are described. Their purpose is to facilitate warning delivery.

Flat-Panel Technology

One relatively recent technological innovation is the availability of flat-panel displays. High-resolution liquid crystal displays (LCDs) are now commonly purchased for use as computer monitors and high-definition televisions. Large versions of flat-panel displays (using somewhat different technologies) are also being used in sports stadiums and as advertisement billboards in big cities. Although still relatively expensive, the price associated with flat-panel displays will undoubtedly drop over time, and new uses can be considered for warning applications. One such use is in highway signs. Changeable message signs using lower-resolution technology already exist on highways in some places. Examples are shown in Figs. 63.2 and 63.3. Eventually, warning signs on highways and smaller signs in other applications will use high-resolution technologies such as those used in flat-screen LCD monitors. One benefit of these displays is that they are backlit, bright, and have high contrast, and thus are more likely to attract attention in most ambient light conditions compared with conventional signs. Most important, a major benefit of these devices is that the information content displayed on them can be changed as needed. Figure 63.4 shows a high-resolution display in a hotel elevator. Such a display could provide warning information (such as an urgent instruction to exit the elevator immediately in case of a fire in the building) or other pertinent instructions. The same kind of device, but somewhat larger, could be mounted elsewhere in a building (e.g., on walls, posts, etc.) to display warning information as appropriate. It could be displayed in remote places, powered by solar cells. Of course, these devices would need to be protected so that vandalism and the elements do not threaten their operation.

FIGURE 63.3. A changeable-message highway sign in Rio de Janeiro, Brazil. (See Color Plate 23).

FIGURE 63.4. A high-resolution LCD display in a hotel elevator.

Video

The flat-panel displays described previously can also be used to present video warnings. Many video media exist today (e.g., DVD, flash memory, cable and DSL, and wireless methods, such as WiFi, RF, and Bluetooth). Moreover, video production capabilities have been brought to the consumer market, including camcorders and computer software, that allow editing. Now individuals and small employers can develop informative yet relatively inexpensive safety and warning videos. These videos can be made available on the Web and played using one of several free video players or can be provided on videotape, compact disk, or DVD with the purchase of a product along with the manual. Are warning videos useful? Some initial research in this area was conducted by Racicot and Wogalter (1995). In this study, participants were asked to mix several chemicals, but before starting, they were assigned to one of three conditions. They either (a) watched a video of a model demonstrating the proper safe behavior of putting on protective equipment (e.g., face mask and gloves), (b) watched a static warning sign displaying the same warning instructions on the video monitor, or (c) saw nothing relevant to safety on the video monitor. More people wore the protective equipment in the video model condition than the other two conditions. These results and those

FIGURE 63.5. An in-vehicle navigation system display showing a warning.

of Chy-Dejoras (1992) suggested that video displays can be an effective means of conveying safety information.

In-Vehicle Displays

Dynamic warnings have been used in vehicle systems for many years. Most contain rather simple dynamic systems, such as a flashing light on the dashboard or an intermittent tone as a reminder to wear seatbelts. Although they are more noticeable than static stimuli, they often become habituated over time. A better reminder for the seatbelts would be a sound that changes to maintain the noticeability of the signal.

Many newer vehicles are being installed with navigation systems with touch-screen LCD displays that have map software on DVDs. Figures 63.5 and 63.6 show an in-vehicle navigation display. Although some systems have additional information stored in the navigation software, such as points of interest, restaurants, and so forth, in the future, they could also provide additional information. One major problem with the conventional owner's manuals is that people do not read them or do so incompletely (Mehlenbacher, Wogalter, & Laughery, 2002). A potential alternative or supplement is to communicate safety information and warnings through the navigation system display. For example, an owner who cannot contact a repair service when the vehicle has a flat tire might access procedures for tire repair from the navigation system. The display could provide information textually and graphically, and perhaps also give voice directions and a video. Other warnings that could be conveyed to drivers include directions on how to properly attach child seats and whether and how much one can recline the passenger seat when the vehicle is in motion. Of course, only limited use of the navigation system should be allowed while the vehicle is moving. Many current navigation systems warn about using them while driving, and many of them lock out functioning when the vehicle is moving.

In complex warning systems, in which there may be multiple hazards simultaneously, prioritization of warning messages is needed. The most important messages should be given priority over less important ones. Hazard analysis should be conducted to determine the ordering of messages (Vigilante & Wogalter, 1997). Some messages (e.g., very low tire pressure) may be given higher priority than others (e.g., time for an oil change) so that the driver is not distracted unnecessarily. Future systems would be sensitive to context so that only warnings relevant to the situation would be presented, e.g., warning about initially unscrewing lug nuts before jacking up the car when accessing information about how to change a flat tire.

World Wide Web and Internet

Eventually, motor vehicle systems will have wireless connections to the World Wide Web (WWW) and the Internet. With this access, the electronic database need not be stored in the vehicle. Other road-related information could also be made available, such as current reported dangerous conditions along the way to the intended destination (e.g., a flooded street). Likewise, it will be easier for manufacturers to provide updated information to users of previously sold products, such as a revised section of an owner's manual or new warnings via the Internet.

The Internet can also provide up-to-date information and warnings for nonvehicular products. A growing number of manufacturers are placing product manuals online in PDF files that retain all necessary formatting. In this way, replacement manuals for ones that have been lost or misplaced can be accessed.

Some companies have live customer service personnel that work over e-mail or instant messaging, and this might be broadened to include safety information. In addition, some companies maintain automatic or expert-like systems that can parse word phrases to show potential related information to answer consumers' questions. Some of this information could include relevant warnings. Thus, people could get access to information when they need it. Combined with wireless Web, they also can get information wherever they need it.

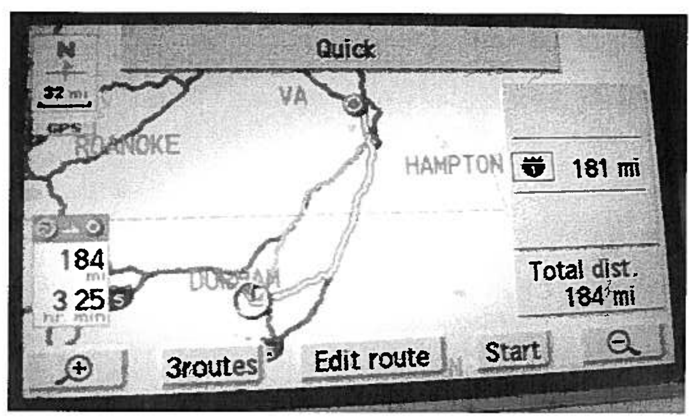

FIGURE 63.6. An in-vehicle navigation system showing route information.

Electronic Paper

Another technology that has potential for displaying dynamic warning content is electronic paper. Electronic paper is a very thin, flexible, high-resolution, low-power, display technology that shares many of the physical characteristics of paper but the information it displays is controlled by a computer chip. Its light weight and flexibility make it useful for applications in which the cost, size, weight, or power requirements of computer displays would otherwise preclude their use. Although not yet rugged enough for use in outdoor applications, electronic paper could be used in certain commercial and industrial environments or even in the home. For example, a label on a product powered by a miniaturized special-use battery and controlled by a transistor chip could display different information, such as multilingual messages or additional warning information, that would not otherwise fit on a conventional paper label.

Voice Warnings

The auditory modality can also be a potentially useful means of providing dynamic warning information. Recent technology has allowed the use of digitized voice in many applications. The technology is relatively inexpensive. It is now in many answering machines and even in some greeting cards. Progress in voice recognition systems is making this technology more viable it becomes better at parsing continuous speech.

Voice warnings have been found to be a relatively powerful method of conveying warnings and promoting compliance (Wogalter & Young, 1991). In a study by Conzola and Wogalter (1999), participants performed a disk drive installation task. When they opened the cardboard box containing the drive, a warning was presented in large print or by voice, or no warning was given. In both the print and voice conditions, the warning conveyed information on how to avoid damaging equipment during the installation procedure (such as touching the terminals to release excess static electricity). Whether participants correctly complied with the steps in the warning was recorded. The results showed that people more frequently complied with the voice warning than with the print warning. This and other research (e.g., Wogalter & Young, 1991) suggests that technology involving voice presentation can be useful in facilitating warning compliance. In the Conzola and Wogalter study, the electronics used to present the voice warning were taken from relatively inexpensive greeting cards that had a recordable, miniaturized voice chip, battery, and speaker. As described earlier, the characteristics of the voice can be manipulated to give different degrees of urgency to the message.

DETECTORS AND SENSING DEVICES

To this point, discussion has been limited to the types of displays that receivers may encounter. In this section, the focus will shift to how technology may benefit warning effectiveness by means of detection and sensing. A fundamental principle of warnings is that they should be presented when and where they are necessary. If the warning is presented too distantly from the hazard, people may not recognize the connection between the sign and the hazard or may not remember the hazard. But the warning should not be so close to a hazard that the individual at risk has little time to react. In addition, if the warning is always present, there may be habituation. Thus, it is desirable to present the warning at a location and time that depends on the foreseeable tasks or behaviors of the user. Besides memory-related issues, selective presentation would reduce undesirable distraction from an inappropriate warning. Sophisticated technology can be used in making decisions on whether to present a warning or not and, if so, when to present it and what to present.

Earlier, it was noted that humans have sensori-perceptual and cognitive limitations. Habituation was one example presented in which exposure to unchanging stimuli results in less attention after repeated exposures. People also have other limitations, and technology can be used to supplement their abilities. Warning systems that include detectors (sensing devices) can take on the burden of noticing (Wogalter & Mayhorn, 2005). Numerous kinds of sensors are currently available to detect heat, cold, moisture, gas vapors, motion, weight, and so forth. One simple example of a warning sign that could use technology with a sensing system is the roadway caution sign in the United States that states "Bridge Ices Before Road." Some of these signs are permanently placed and displayed. Some have a hinge that allows them to be folded up during the times of the year when there is little chance that there will be freezing weather. An example is shown in Fig. 63.7. The fact that some of these signs can be folded up acknowledges the problem of habituation. If it is always in view, people may not pay attention to the sign, even when the conditions make hazard occurrence likely. Unfortunately, these signs are infrequently folded up or taken down during warm, balmy conditions, when they are irrelevant. The photograph in Fig. 63.7 was taken in the middle of summer during a blistering heat wave in Raleigh, North Carolina. A better method would be to use a detector that measures the temperature and then presents the message when conditions are

FIGURE 63.7. A sign concerning icing on a bridge displayed on a hot summer day.

conducive for the hazard. When the temperature is near or below freezing, the message would be displayed and, when above freezing, the message would not be.

Inexpensive motion detectors have been sold in hardware stores for many years (e.g., for outdoor security lighting). They could also be used to initiate warnings when an individual is in a specific hazardous area. In a study by Wogalter et al. (1993), participants entering a risk area (where they were to mix various chemicals) broke an infrared beam, which elicited the display of a warning on a light-emitting diode (LED) screen advising users to don a mask and gloves because of potential chemical irritation. The results showed that participants more frequently wore the protective equipment when a dynamic warning was present than when it was absent.

Multiple Detectors

To ensure that the warning is only displayed in highly specific situations, multiple detectors could be used. Combinations of several detectors could recognize particular behaviors and task performance based on physical movements and other inputs. Multiple detectors, both in number and in kind, can provide greater accuracy and specificity to enable the system to decide when to warn and what to warn about. A preliminary example was shown in a study by Boyette, Lloyd, Manuel, Boyette and Echt (2001). They monitored several vital signs during a patient's performance of rehabilitation exercises. When the detectors received certain types of "out of range" input, a warning was used to discontinue the exercise. In addition, many late-model vehicles have newer generation air bag systems with multiple sensors to detect occupants in the front passenger seat. The systems can differentiate between the presence of a small child as opposed to an adult or a package on the seat. In the case of a crash, decisions are made on whether to deploy an airbag or not and, if so, what kind of deployment is to be initiated (e.g., fast or slow, large or small). A general system of this type could be employed in issuing warnings, both in vehicular and nonvehicular circumstances. Given input to multiple detectors, decisions are made (based on preprogrammed criteria) whether to warn or not and, if so, what to warn. For example, such a system could be used to detect the extent to which users might be at risk for acquiring a cumulative trauma disease. Multiple sensors could detect whether a person is performing a task incorrectly or for too long and then warn the individual to perform the task correctly or to take a break. Clearly, an important aspect of multiple-detector systems is the hardware and software programming and the data entered into the system. Hence, this type of sophisticated system is dependent on the availability of predictive data regarding foreseeable conditions that would be derived from a prior task analysis.

Perceptual and Cognitive Support

In general, the benefit of using detectors and sensing systems is that they can supplement peoples' sensori-perceptual and cognitive limitations. Humans do not have a natural capability to detect radiation and carbon monoxide, but there are devices to do that job (Geiger counters and carbon monoxide detectors). Both involve hazardous emissions into the environment that are beyond the sensori-perceptual capabilities of humans (e.g., carbon monoxide is an odorless, tasteless, nonirritating gas). These and other kinds of detection equipment can compensate for peoples' limitations by doing the sensing for them. Currently, there are systems under development to detect small amounts of residue from explosive material on people and baggage. Additionally, newer kinds of in-wheel tire pressure monitors can detect less perceptible and unacceptable air inflations and signal that information to drivers.

Sometimes, not even technology can readily or directly detect a hazard. In these cases, the detection of the hazard may be accomplished through a correlated surrogate. Surrogate detection involves the use of other aspects related to the hazard, but not the hazard itself. A dead bird lying on the ground in a mineshaft is an indication that methane gas may be present. The dead bird is not the hazard—the hazard is the gas—but the dead bird is an indication that a hazard may exist. Likewise, in medicine, symptoms are often the by-product of some biochemical causative agent. The presence of certain combinations of symptoms is used to diagnosis illness. For example, tests indicating that a person is HIV-positive do not necessarily mean the person has AIDS. The HIV test only provides an indirect indication that a particular family of virus strain is present.

Technology-based warning systems might also be used to support age-related changes in sensory and cognitive capabilities, such as in older adults. Personal digital assistants (PDAs) could be used to provide medication reminders, that is, cognitive support (Lanzolla & Mayhorn, 2004). Future PDA systems could communicate via a wireless connection with a pharmacy's computer and upload information about warnings. Such an arrangement would allow the pharmacist to track a patient's pill-taking schedule, as well as assist with regimen customization.

Wireless

With the advent of personal wireless communications (e.g., through cellular phone technology, Bluetooth, RF, etc.), information can be delivered when needed. Suppose that water and sewer pipes are being rebuilt in an area. Wireless communication to a PDA with a global positioning satellite system combined with a database of laid cables, could assist in determining whether the location in which workers are about to dig might result in cable damage.

Furthermore, electronic tags (an electronic form of bar coding) similar to those being placed on consumer products for tracking inventory, sales, and to prevent shoplifting could be used to transmit information to a display about associated warning information.

Identification

Technology, such as ExxonMobil's Smart Pass, in which an individual's account is identified by passing an electronic key or tag near a gas pump, is suggestive of future warning systems. An extension is a method of short-range detection and identification of persons carrying an electronic "key." Such systems could be capable of detecting and identifying visitors entering restricted, hazardous areas of an industrial facility, hospital, or other locale. Who were not authorized to enter. A visitor's tag given at the entrance of a facility could be used to detect attempts to enter a prohibited area or even track the visitor throughout the facility. Conversely, an electronic tag could directly deny access to unauthorized personnel or issue a warning not to enter the area.

Even more sophisticated tags or smart cards can be connected to a database with background information. Authorized persons would be allowed to enter the area, but unauthorized persons would be warned or prevented from entering. As there may be several levels of authorization (e.g., a plant manager may have access to all areas, but a custodian might not have that permission), the cards themselves might have database information or a wireless connection made to a database located elsewhere to provide the authorization-related information. Thus, databases combined with detectors could tailor warning messages for persons with particular backgrounds.

FIGURE 63.8. A personalized warning sign with an individual's name inserted. Reprinted with permission from "The Role of Perceived Relevance in Behavioural Compliance in Personalized Warning Sign" by M. S. Wogalter, B. M. Racicot, M. J. Kalsher, and S. N. Simpson, 1994, *International Journal of Industrial Ergonomics, 14*, 238.

TAILORING

Some forms of tailoring have already been described in earlier sections of this chapter, including tailoring for older adults and their medication schedules. In this section, additional examples are described. The idea of tailoring is that people have different needs and, as a result, different warnings should be issued. Sometimes, this is necessitated by differences in individual capabilities, but warnings might also be tailored to the situation. The role of the system is compensatory when addressing differences in capability, such as in the older-adult example given earlier, where memory for pill taking is being supplemented. Another instance might include systems that monitor users with sensory deficits, such as presbyopia, an age-related loss of visual acuity. Such a system could identify an individual as an older adult and then provide larger print messages on a PDA, electronic paper, or a tablet.

Warnings could also be personalized. Research by Wogalter, Racicot, Kalsher, and Simpson (1994) suggested that personal relevance is associated with warning compliance. Relevance is a belief that the warning is applicable to the individual. In the Wogalter et al. (1994) study, when a participant's individual name was placed within an electronically presented warning, compliance was greater than with a generic warning. An illustration of the sign is shown in Fig. 63.8. Information from smart cards, such as in the Smart Pass example given earlier, can provide such identifying information and subsequently produce more effective warnings by embedding the name of the targeted individual in the warning. Here, the insertion of personalized information provides a shortcut for individuals deciding on whether the warning is intended for them because it clearly is.

A highly sophisticated extension of tailoring is to modify the warning based on the person's experience and skill level. An expert may not need a warning, or if a warning is to be given, it can be more technical and contain abbreviated information to inform and remind. For the novice, the information may need to be simple and limited in scope to avoid overloading limited attention resources and memory capacity. Use of a prioritization strategy would limit the presentation of certain information, so that only the most critical is given. However, the system could also make available additional information linked to the basic warning information if more detailed descriptions are needed.

One example where information should be tailored to the user is in material safety data sheets (MSDSs). These sheets usually contain detailed, comprehensive information about chemicals and are supposed to be made available to employees working with the chemicals according to the U.S. Occupational Safety and Health Administration's HazCom Right-to-Know laws. However, these sheets are highly technical and lengthy and are usually beyond the reading levels of most workers exposed to the chemicals (Lehto, 1998). Also, the critical information that these workers need (e.g., protective equipment required) is usually embedded within the text and consequently may not be read by the workers needing that information. Smith-Jackson and Wogalter (1998, in press) found that different users prefer different ordering of the information in MSDSs. Firemen want fire-related information as a priority, and others tend to want protective equipment and health risks as a priority. Systems like those described in this chapter could present the most critical information tailored to the individual.

More sophisticated systems could provide different warnings as experience and skill levels progress. With these systems, the warnings change as the individual progresses in a particular task. The system senses the level of user experience through that person's task performance to give the applicable warning. This kind of system has interactivity, in which ongoing detection affects what warning information may be given.

POTENTIAL BARRIERS TO IMPLEMENTATION

Although the promise of future technology-based warning systems is great, a number of potential barriers exist that might delay implementation. Some of the systems described in this chapter are rather simple and some are more complex; in some cases, the systems are seemingly expensive. However, the cost will go undoubtedly down, and the sophistication will go up.

Examples of previously expensive technology are quite numerous (transistor radios, color televisions, and cellular phones), and this trend will likely continue with current and future technology. Prospectively, technology's involvement with warnings will be ubiquitous.

However, appropriate implementation of technology with warnings must also be concerned with intrusiveness and annoyance, as well as issues of maintenance. Inappropriate or false presentation of warnings should be avoided. Likewise, a failure to present a necessary warning could be disastrous. Moreover, the alerting nature of warning presentation should not detract from performance on an important concurrent task. As the sophistication of electronic warning systems improves, the control of presentations that are in error such as false alarms and misses, should also decrease. The chapters by Bliss and Fallow (chap. 17), Meyer (chap. 16), and Lehto (chaps. 6 & 7) in this volume describe some of the difficulties associated with dynamic warnings. Their feasibility also involves system maintenance once they are in place. Besides misfiring being clearly a problem, people may come to rely on the system to provide the correct warning information, and thus persons who are responsible for making sure these systems always work should take steps to ensure that they do.

FIGURE 63.9. A sign indicating that video surveillance is being conducted.

Security and Privacy Concerns

Some of the sophisticated systems described earlier may include within them or be able to collect personal information that could generate privacy concerns among individuals. Such information needs to be kept secured and not released for purposes that the individual does not want. There are many issues about the ethical use of electronic databases containing personal information that are being discussed by numerous groups in academia, government, and industry. The issues are very complex and probably will be debated for many years. It is important that people be given explicit information about what information is being collected and how it will be used so that individuals can make informed decisions (Spunar, Racicot, & Kalsher, 1995). There are already increasingly massive databases (e.g., video surveillance) concerning personal and behavioral information, and it is likely that the data gathering trend will continue. Figure 63.9 shows a sign indicating that video surveillance is being conducted. There needs to be a balance between maintaining privacy and promoting personal safety. What could happen if such systems are prevented from using personal information, which in turn might prevent the proper warnings from being issued? Consider the seriousness of injury to individuals and the pain and suffering that could otherwise result. Notably, perceptions of this privacy–safety tradeoff appear to differ by context. In the workplace, employers may be able to monitor employees' computer and phone usage. In contrast, the use of surveillance is much less acceptable in home environments, although it might be permitted in certain circumstances (criminals confined to their home) and where young children and very old adults are concerned.

CONCLUSIONS

Future warning systems will have properties different from and better than traditional static warnings. These improved capabilities will include dynamic modification of message content, compensation for human limitations, interactivity, and personalization via tailoring to meet the needs of particular users. The end result will be an increased capacity to warn users of potential or existing hazards. The key to building these enhanced warning systems lies in the effective integration of technology.

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

Although the promise of next generation, technology-enhanced warning systems in improving safety is tantalizing, discussion also focused on a number of potential barriers to implementation. The financial costs of upgrading and maintaining existing systems as well as designing new systems could be considerable, particularly for early purchasers of the system; however, these expenses are likely to decrease as the availability of the technological components and their integration increases.

Further challenges include the design of systems that are not annoying or intrusive, yet are still effective in terms of warning delivery. Perhaps the largest barrier that needs to be addressed is the delicate balance between privacy concerns stemming from system acquisition of user information and the ability to effectively warn users. Although a solution to this ethical consideration is beyond the scope of this chapter, warning designers and researchers should be aware of this issue when evaluating and implementing new system designs.

This chapter addressed how dynamic warning systems might be developed and enhanced using current and future technology. The chapter began by describing reasons why these systems would likely be more effective than common, static warnings. Future warnings can potentially benefit users by supplementing their individualized needs by compensating for various limitations. Clearly, the pursuit of advanced, technology-based warning systems is a promising area.

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