Wogalter, M. S. (2006). Future technology-based warning systems. *Proceedings of ABERGO 2006. 14o Congresso Brasileiro de Ergonomia.* In M. M. Soares & L. B. Martin (Orgs.) ISBN: 85-89211-06-1. Curitiba, Parana, Brasil.

Future technology-based warning systems

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ABSTRACT

Warning signs and label are sometimes used to control hazards. They are intended to convey information about products, equipment and environment dangers to protect people and property from injury and loss. Their actual implementation is usually through the use of ink on paper or paint on metal to produce static stickers and signs. However, new and emerging technologies will likely revolutionize risk communication in the future. Technology will enable delivery of dynamic warnings in situations where and when they are needed rather than less discriminately as done now. Future warnings will involve computer control, flat-panel displays, wireless transmission, multiple sensors, and connection with the Internet, among other methods. This paper describes issues supporting the use of technology in the dynamic control and display of warnings. The potential benefit of personalized warnings tailored to support and fit individual perceptual and cognitive needs will be described. Potential barriers to implementation will also be described. Implications, examples, and future prospects of warnings will be presented.

INTRODUCTION

Warning signs and labels for environments and products are commonly thought to be made of paper, metal, or plastic. They are usually static and passive. Having these characteristics do not correspond well to one of the roles that is needed to benefit warning effectiveness, and that is, attention capture. People are less attuned to stimuli that do not change. Adding changing or dynamic qualities makes them more noticeable. Some forms of dynamic warnings have been available for decades. Consider common auditory warnings such as fire alarms, which are active, and to some extent variable. Technology has provided new ways that warnings can be presented and controlled to both the 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 provide information to aid 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, 2006). This paper will describe some of the ways that technology can be incorporated to make warnings better . First, characteristics of dynamic warnings are described relative to static warnings. Second, the use of computer display technology is discussed. Third, hazard detection using sensors is considered. Fourth, implications for tailoring warnings to fit the needs of different users are explored. Finally, potential barriers to technological implementation are discussed.

Most methods described involve existing technology but some are based on trends on how technology will likely progress in providing future delivery of warnings. Most concern the visual modality; however, implications pertaining to the auditory modality are also described.

DYNAMIC WARNING CHARACTERISTICS

One reason why dynamic warnings are usually better than static warnings is that they tend to be 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 to any given stimulus over time usually results in the production of some memory of the stimulus (although not necessarily complete memory of it) and as a result of that memory, the stimulus becomes less salient and less attention-getting relative to other things that may be available to consider. Some types of important information such as one's own name or a person's hobby are shower to extinguish by habituation. Also, dynamic warnings are less likely to induce habituation as rapidly as static signs, and thus are more likely to continue to attract attention over time.

Even dynamic warnings are not immune to habituation as exposure to any stimuli over lengthy and frequent periods of time can result in decreased salience. However, the process of habituation is generally slower for dynamic than static warnings, and may be slowed even further by incorporating additional dynamic qualities. For example, a relatively simple fire alarm can enhanced by adding more dynamic qualities such as by varying the frequency and temporal aspects of the auditory signal (Hass & Edworthy, 2006; Edworthy & Hellier, 2006). In general, adding variable and salient characteristics to a dynamic warning will delay habituation even further.

A common method to make warnings salient through the visual modality is to use a flashing light. According to one text (Sanders & McCormick, 1993), the optimal flash rate is approximately 4 flashes per second with equal intervals of on and off time. Also, the light of the flash should be at least twice as bright as the background so as 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).

Spacing Effect

Information acquisition is benefited by certain schedules of presentation based on the timing, frequency and duration of exposures. Distributed exposure of material of any sort (including warnings) across time produces greater memory than massed exposure (Underwood, 1961). This is sometimes called the spacing effect. In other words, holding constant the total time of exposure to a given warning, of say 20 seconds, ten distributed exposures each of 2-second duration will be better than a single exposure of 20 seconds. This is like "cramming" for an exam the night before (massed) versus studying the same amount of total study time but distributed in shorter 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 to massed learning. The implication here is that once learned, a warning might only need to be presented occasionally thereafter as a reminder cue to activate and reinstate the memory, and also to enable better access to that knowledge. Re-exposure primes or activates the associated memory and enabling easier retrieval to that memory later.

Level of Danger

Dynamic warnings could display the degree of hazard as it changes over time and conditions. In other words, the warning could vary as the severity and likelihood of a hazard changes. Edworthy (e.g., Edworthy & Adams, 1996; Edworthy & Hellier, 2006) has argued that warnings should reflect the extent of the hazard. The warning should look or sound more urgent when conditions warrant an immediate response, and the warning should connote less urgency when the hazard is not so great. Research on the topic of connoted hazard has involved the use of signal words, color, pictorial symbols, and sound complexity. Some relevant research findings are described below.

Signal words. In the U.S., visual product warning labels and signs usually contain prominently-displayed terms such as “DANGER,” “WARNING,” and “CAUTION” to quickly communicate high to low levels of hazard (see ANSI Z534, 2002). Dynamic displays could change the signal word to reflect the current hazard level. Terms for signaling different levels of hazard could be tested to determine the sets of words (Wogalter & Silver, 1990, 1995).

Color. Like signal words, color has been shown to affect perceived hazard (e.g., Chapanis, 1994; Rashid & Wogalter, 1997; Smith-Jackson & Wogalter, 2000; Wogalter, Kalsher, Frederick, Magurno, & Brewster, 1998). The color red has been found to express greater hazard than yellow or orange, which are not substantially different from each other. Blue and green generally express less or no hazard. Thus, as the hazard level changes so could the colors on the dynamic warning.

Quantitative information. A dynamic warning could also give quantitative information. The speed of wind gusts crossing a bridge could be given numerically in mph or km. To be sure that people know what speeds of winds are dangerous, the sign should also translate its meaning e.g., 5 km as15 km as Mild Wind; and 80 km as Extremely Strong Wind Gusts.

Pictorial symbols. Potentially, pictorial symbols increase the warning's noticeability and people's understanding of the message. In the latter, persons not skilled in a particular language of the warning text (e.g., low literates and other-language users) might be able to comprehend at least part of the warning's meaning (Wogalter & Leonard, 1999). In other word, if they cannot read the words, they can potentially understand a well-designed (comprehended) pictorial. Symbols could be added or changed in electronically-displayed warnings at different points in time to communicate varying levels hazard or different 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 that symbols be evaluated to determine their comprehensibility (ANSI, 2002; Deppa, 2006). 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).

Message text. Most warnings contain words so warnings could be dynamic in telling the hazard, consequences and the instructions (ANSI, 1991; Wogalter et al., 1987) as the hazard situation changes. Text could be combined with several combinations of the above mentioned features such as signal words, color, numbers, and pictorial symbols to quickly convey the degree of hazard.

Sound. Variations in speech and non-verbal sound can convey different levels of urgency (e.g., Edworthy & Hellier, 2006; Edworthy, Hellier, Morley, Grey, Aldrich, & Lee, 2004; Haas & Edworthy, 2006). Louder, higher-pitched speech presented at a somewhat faster rate produces higher levels of perceived hazard than the same words presented at a lower amplitude, lower pitch, and slower rate (e.g., Barzegar & Wogalter, 1998a, 1998b; Hollander & Wogalter, 2000). Thus, speech displays can be altered in sound quality and content to reflect the hazard level involved.

DISPLAYS

In this section, methods of displaying warnings made possible by new technology are described.

Flat-Panel Screens

One relatively recent technological innovation is availability of flat-panel displays for televisions, computers and small consumer electronics. Generally as technology matures prices are reduced and there is a concurrent increase of quality. Thus, in the future it is reasonable to expect that resolution will be higher than today and much reduced cost. Large versions of flat-panel displays are used in sports stadiums and as advertisement billboards in big cities. New uses can be considered for warning applications. One is in highway signs. Changeable message signs using lower-resolution technology already exist on some roadways. Eventually, warning signs both on highways and in other applications will use high-resolution technologies such as those in flat-screen LCD monitors. A major benefit of these devices is that the information content displayed on them can be changed as needed. Panels could be mounted outside or inside (e.g., on walls, posts, etc.) to display warning information as appropriate. In remote placements, the displays could be powered by solar cells, but will also need protection from weather and vandalism.

Video

The flat-panel displays described above can also be used to present video warnings. Many video media exist today, including DVD, flash memory, cable and DSL, wireless reception 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 be provided on videotape, CD, or DVD with the purchase of a product in addition to the manual. Research by Racicot and Wogalter (1995) suggests video warnings benefit compliance. Participants were assigned to one of three conditions before mixing and measuring a set of chemicals. 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 after having viewed the video model than in the other two conditions. These results and those of Chy-Dejoras (1992) suggest that video displays can be an effective of conveying safety information.

In-vehicle displays

Dynamic warnings have been used in vehicle for many years. Most contain rather simple dynamic systems such as a icon light on the dashboard or an auditory alert as a reminder to wear seat belts. These simple warnings often become habituated over time. A better reminder for the seatbelts would be a light or sound that changes in displayed characteristics.

Automotive and portable navigation systems with touch screen panel displays with map software are becoming an increasingly common accessory. Some systems have additional information stored in the navigation software such as “points of interest,” restaurants, etc. In the future, they will likely provide additional information. One major problem with conventional paper-based 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. While the vehicle is moving only part of the navigation system might be allowed to be used by a driver (to avoid distraction from the driving task); indeed, some current systems lock out some functions when the vehicle is moving.

In cases of multiple hazards, the prioritization of warning messages is needed. The most important messages should be given priority over less important ones (Vigilante & Wogalter, 1997). Future systems will be sensitive to context where only the warnings most relevant to the situation are presented.

Internet

Eventually, just about everyone and every motor vehicle will have wireless connections to the Internet. With this access, information could be made available, such as real-time reporting of dangerous conditions along the roadway to an intended destination (e.g., a flooded street). In some cases, manufacturers may be able to provide updated information to users of previously-sold products. A growing number of manufacturers are placing product manuals on-line in .PDF files that retain all necessary formatting. In this way, replacement manuals for ones that have been lost or misplaced can be accessed. Moreover, a revised section of an owner’s manual or new warnings via the internet could be transmitted to users.

With wireless web access, consumers could get information when and wherever they need it. This fits with a fundamental principle of warnings: that warnings should be presented when and where they are necessary. If the warning is presented too distantly (both temporally and physically) from the hazard, people may not recognize the connection between the sign and the hazard or may not remember the hazard. The warning should not be so close to the hazard that the individual at risk has insufficient time to react appropriately to avoid the hazard.

Many companies employ or contract live customer service personnel that work over email or instant messaging, and this might be broadened to include safety information. Also, some companies maintain automatic or expert-like systems that can parse word phrases to show potentially-related information to the consumers' query. This information could include relevant warnings.

Electronic paper

Another technology with the potential for displaying dynamic warning content is electronic paper. Electronic paper is a thin, flexible, high resolution, low power, information display with many of the physical characteristics of paper. For example, a label on a product powered by a miniature battery and controlled by an inexpensive transistor chip could display information such as multilingual messages or additional warning information that would not otherwise fit on a conventional paper label.

Voice warnings

Recent technology has allowed the use of digitized voice in many applications not previously considered. The technology is now relatively inexpensive. It is now in many answering machines, toys, and even in some greeting cards. Voice recognition systems are being more viable as they become better at parsing continuous speech of different users.

Voice is a relatively powerful method of conveying warnings and promoting compliance (Wogalter & Young, 1991). For example, research 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). The results showed that participants more often complied with the voice warning than to the print warning. As described earlier, voice characteristics can be manipulated to give different degrees of urgency.

SENSORS

Technology will benefit warning effectiveness through detection and sensing. As mentioned earlier, it is desirable to present the warning at a location and time that it is needed to avoid the hazard. This will also depends on the foreseeable tasks or behaviors of the user. Besides memory-related issues, selective presentation of the warning 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. Part of this system involves sensors.

Humans have sensori-perceptual and cognitive limitations. Habituation was one example presented earlier in which unchanging stimuli results in less attention after repeated exposures. People also have other limitations that technology can be used to augment or compensate for. Warning systems that include detectors (sensing) devices can do some of the noticing for the person (Wogalter & Mayhorn, 2006). Numerous kinds of sensors are currently available to detect temperature, 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 U.S. that states "Bridge Ices Before Road." Some of these signs are permanently placed and displayed. It would be better if they were only displayed when there are freezing conditions, in part to avoid habituation to the sign's presence. Some have a hinge that allows them to be folded up during the times of the year when consistently hot temperatures yields little chance that there will be freezing weather. Rather than use a static sign that may or may not be manually folded up, a better method would be to use a temperature sensor and in conditions of freezing or near freezing presents the bridge icing warning.

Inexpensive motion detectors have been available for many years. They could also be used to initiate a warning when someone enters a hazardous area (Wogalter et al., 1993). Likewise, there are smoke detectors, gas vapor detectors, that could be employed.

Multiple sensors

To display a warning in highly specific situations, multiple detectors could be used. Combinations of several detectors could "recognize" particular patterns based on physical characteristics, behavioral movements, and other inputs. Many detectors, both in number and in kind, can provide greater accuracy and specificity for determining more precisely when and what to warn about. Some newer vehicles have newer generation air bag systems with multiple sensors to detect characteristics and positioning of occupants in the front passenger seat. The systems can differentiate 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 the deployment. A system could also be used to detect bodily motion. 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. An important limiting factor of multiple-detector systems is the hardware/software programming. It requires predictive data regarding risk conditions that would be derived from task analysis. Many influences and conditions will need to be anticipated and planned for.

Perceptual and cognitive support

Another benefit of sensor systems is that they can supplement peoples' sensory and cognitive systems. Some of our systems are limited in processing capability and capacity. Sensors can compensate for peoples' limitations by doing the sensing for them. Humans do not have a natural capability to detect radiation and carbon monoxide (CO), but there are devices to do that job (Geiger counters and CO detectors). Both involve hazardous emissions in the environment that are beyond the sensori-perceptual capabilities of humans. For example, CO is an odorless, tasteless, non-irritating gas. Currently, there are public security systems under development to detect small amounts of residue from explosive material on people and their luggage.

The sensor need not directly detect a hazard. Hazard detection 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 poisonous gas may be present. The dead bird serves to indicate, somewhat indirectly, that a hazard may exist. Likewise in health and medical settings, people's symptoms are often the byproduct of many causes of illness but the presence of certain combinations of symptoms can be used to diagnose certain illnesses. For example, tests indicating that a person is HIV positive do not necessarily mean the person has AIDS. The HIV test provides an indirect indication that a relevant virus is present.

Technology-based warning systems could also be used to compensate for age-related declines in sensory and cognitive capabilities. Personal Digital Assistants (PDAs) could be used to provide medication reminders to older adults (Lanzolla & Mayhorn, 2004). Wireless PDA systems could connect with a pharmacy's computer and upload information about warnings. This could help track pill-taking schedules and assist with the development of customized regimens.

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 Global Positioning Satellite (GPS) system combined with a database of laid cables, could assist in determining whether the location in which they 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 and sales to prevent shoplifting, could be used to transmit information to a display about associated warning information.

Identification

Technology such as ExxonMobil's Smart Pass, where an individual's account is identified by passing an electronic key/tag near gas pump, suggest future warning systems. An extension of this technology 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 areas of an industrial facility or a hospital or other locale with hazardous areas where only certain authorized persons are allowed 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 let through 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 be permitted into a limited set of areas), the cards themselves might have database information and/or a wireless connect made to a database located elsewhere to provide the authorization-related information. Thus, databases combined with detectors could tailor warning messages about persons with particular backgrounds.

TAILORING

As mentioned above, warnings could be tailored for certain in individuals and groups of individuals such as tailoring for older adults and their medication schedules. Older users with as presbyopia, an age-related loss of visual acuity could benefit in other ways. The system could identify an individual as an older adult and then provide larger print messages on a PDA, electronic paper or tablet.

The benefit of tailoring is that people have different needs that are addressed through the use of different warnings provided to them. Warnings can be personalized. Research by suggests that personal relevance of a warning increases compliance (Wogalter, Racicot, Kalsher, & Simpson, 1994) because people are more likely to believe that it is directed to them as opposed to being directed to other people. In the Wogalter et al. (1994) study, when a participant's name was placed within an electronically-presented warning compared to using a generic signal word, behavioral compliance was greater.

A further extension of this is to modify a warning based on the person's experience and skill level. An expert may not need a warning, or if a warning is 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 to avoid overloading limited attention and memory capacity. Prioritization should give only the most critical information. Additional information can be provided via links if more detailed descriptions are needed.

In the U.S., employers are supposed to make available Material Safety Data Sheets (MSDSs) for employees working with chemicals according to the U.S. Occupational Safety and Health Administration's HazCom Right-to-Know laws. These sheets usually contain detailed, comprehensive information. However, these sheets are highly technical and lengthy and are usually beyond the reading-levels of many workers (Lehto, 1998). Also the critical information is usually embedded within complex text, and consequently may not be read by the workers needing that information. Smith-Jackson and Wogalter (1998, in press) found that different user groups prefer different ordering of the information in MSDSs. Fire personnel wanted fire-related information as a priority on the sheets and other persons wanted protective equipment and health risks as a priority. Electronic systems could present the most important information tailored to individual needs.

Even more sophisticated systems could provide different warnings as experience and skill levels of the users progress. The system can sense the level of user's experience through that person's task performance to deliver applicable warnings.

IMPLEMENTATION BARRIERS

The promise of future technology-based warning systems is great, yet there are a number of potential barriers that exist that might delay implementation. Some of the systems described above are seemingly expensive. However, undoubtedly the cost will go down (while the sophistication will go up). Examples of previously expensive technology that was considered highly sophisticated are quite numerous (transistor radios, color televisions, cellular phones) and this trend will likely continue with current and future technology.

Implementation of technology with warnings must also consider their intrusiveness and annoyance as well as issues of durability and maintenance. Inappropriate or false presentation of warnings should be avoided. Likewise, a failure to present a necessary warning could be catastrophic. The alerting nature of a warning should not divert attention away from performing an important concurrent task. As systems improve, errors of presentation such as false alarms and misses should decrease. Also people may come to rely on the system to provide the correct warning information, and thus efforts should be taken to ensure that they always work. The systems need to be evaluated be sure they are effective.

Security/ Privacy Concerns

Some of the sophisticated systems described above may include within them or be able to collect personal information; this could generate personal security and privacy concerns. Such information needs to be kept secured and not be released for purposes not desired. These and related issues are being discussed by numerous groups in academia, government and industry. The issues are very complex, and probably will be argued for many years. People ought to be given information about what information is being collected and how it will be used so that individuals can make informed decisions (Spunar, Kalsher, & Racicot, 1995). Increasingly massive databases are being built with personal and behavioral information and it is likely the data gathering will continue. There needs to be a balance between maintaining privacy and promoting personal safety. If use of personal information is prevented, some kinds of warnings might not be delivered to the appropriate target populations. The warnings will be less tailored to fit the circumstances of the people involved. In the workplace, employers might be allowed to monitor employees' computer and phone usage, but this prospect is much less acceptable in home environments. Security and privacy concerns will be debated in the future and it is too early to know how this will turn out.

DISCUSSION

Future warning systems will have properties different from traditional static warnings. These improvements will include dynamic modification of message content, compensation for human limitations, 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.

A number of potential applications for technology to enhance warning effectiveness were presented. 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 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. It would free up attentional resources that might be used for hazard monitoring. 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.

While there is great promise of technology-enhanced warning systems in improving safety, there are also 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; however these costs are likely to decrease over time. Further challenges include the design and evolution of systems that are not annoying or intrusive, yet still effective in terms of warning delivery. Perhaps the most elusive barrier to be addressed is the balance between privacy concerns stemming from system acquisition of user information to better target users. Warning designers should be aware of ethical issues when evaluating and implementing new system designs.

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