TECHNOLOGY WILL REVOLUTIONIZE WARNINGS

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ABSTRACT

Warning signs and labels are commonly used to convey information about equipment and environmental dangers for the purpose of protecting people and property from injury and loss. Most current warnings consist of ink on paper or paint on metal as static sticker labels and signs. New and existing technology are transforming conventional static warnings to dynamic warnings in which information can be presented when and where needed. Future warnings will use computer-controlled, flat-panel displays connected to sensors, among other methods. The benefits of and barriers to the control and display of high-tech warnings are considered.

INTRODUCTION

Most warning signs and labels are made of paper, metal, or plastic. The static nature of these warnings do not correspond well to one of main roles needed of warnings, and that is, to capture. People are less attuned to stimuli that do not change. Changing, dynamic qualities increases noticeability. Some forms of dynamic warnings have been available for decades, such as fire alarms. Technology has provided new ways that warnings can be controlled and presented in both the auditory and visual modalities. Technology-enhance warnings can compensate for sensori-perceptual and cognitive limitations. Not only can technology make attention capture more likely, but also it can provide information to aid comprehension and motivation to comply.

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 article will describe some of the ways that technology can be incorporated to make warnings better. First, characteristics of dynamic warnings are described. Second, the use of computer display technology is discussed. Third, the use of sensors is considered. Fourth, implications for tailoring warnings to fit the needs of different users are explored. Finally, potential barriers to the implementation of high-tech warnings are discussed.

***Proceedings of the Solutions in Safety through Technology Symposium*, 2006, American Society of Safety Engineers (ASSE). Scottsdale, AZ.**

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, there are many implications pertaining to the auditory modality.

DYNAMIC WARNINGS

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 memory being developed of the stimulus (although not always comprehensive memory) 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 because exposure to any stimulus over time results in decreased salience. But 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.

With respect to the visual modality, a common method to enhance warning salience is to use a flashing light. According to one source (Sanders & McCormick, 1993), a flash rate of approximately 4 flashes per second with equal intervals of on and off time is beneficial. Also, the light should be at least twice as bright as the background to enable it to be seen easily in the ambient context; however, it should not be so bright to cause people to look away due to 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. Once learned, a warning might need only to be presented occasionally thereafter as a reminder cue to activate and reinstate memory, and also to enable access to that knowledge. Re-exposure primes or activates the associated memory and enabling easier retrieval later.

Hazard Level

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 mirror the extent of the hazard. The warning should look or sound more urgent when conditions warrant an immediate response, and it should connote less urgency when the hazard is not so great. Research on the topic of hazard perception has involved the use of signal words, color, pictorial symbols, and sound complexity. A few of the major research findings are described below.

Signal words. In the U.S., visual warnings 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 are available (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, but these latter words are not substantially different from each other. Blue and green generally connote little or no hazard. As the hazard level changes so could the colors on the dynamic warning.

Quantitative information. A dynamic warning could give quantitative information. For example, prior to crossing a bridge, motorists could be given wind speed numerically in mph (or km). The sign should also translate the speed given, e.g., 15 mph as Mild, and 30 or more as Extremely Strong.

Pictorial symbols. Potentially, pictorial symbols increase the warning's noticeability and comprehension. People 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) symbol. Symbols could be added or changed in electronically-displayed warnings at different points in time to communicate varying levels hazard or different hazards. However, there should be some caution 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 symbolic representation (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 and pitch, and at slower rate (e.g., Barzegar & Wogalter, 1998a, 1998b; Hollander & Wogalter, 2000). Speech can be altered in quality and content to reflect the hazard level involved.

DISPLAYS

In this section, methods of displaying warnings using newer technologies are described.

Flat-Panel Screens

One relatively recent innovation is flat-panel displays for televisions, computers and small consumer electronics. Additionally, as technology matures, prices decrease while quality increases. Thus, in the future it is reasonable to expect higher display resolution at costs lower than those today. 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 in some places. Eventually, warning signs both on highways and in other applications will use high-resolution technologies. 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

Many video media exist today, including DVD, flash memory, cable and DSL, wireless reception such as WiFi, RF, and Bluetooth. Video production capabilities have been brought into 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 method of conveying safety information.

In-vehicle displays

Dynamic warnings have been used in vehicles for many years. Most contain rather simple dynamic systems such as a icon on the dashboard or an auditory signal to indicate the wearing of 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 increasingly common. Some also include “points of interest,” restaurants, etc, and in the future, will likely provide other useful information. Since many drivers do not completely read the owner's manuals to the vehicle they drive (Mehlenbacher, Wogalter, & Laughery, 2002). A potential alternative or supplement to owner's manuals is to communicate safety information and warnings through the navigation system display. A potential disadvantage is distraction from the driving task, but some current systems lock out some functions when the vehicle is moving.

In cases of multiple hazards, 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 and a decision system dynamically suggests the most relevant warnings to present.

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 owner's 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. Revised sections of owner’s manuals or new warnings for older products could be made available to users.

With wireless web access, consumers could get information when and wherever they need it. As mentioned earlier, 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 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

Electronic paper is a thin, flexible, high resolution, low power, information display. It is not wood based but has 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 basic labeling information together with additional information that would not otherwise fit on a conventional paper label (e.g., additional language translations).

Speech warnings

Inexpensive sound transducer chips are being used in applications not previously considered. Now in many answering machines, children's toys, and some greeting cards. Voice recognition systems are becoming better at parsing continuous speech of different users.

Speech 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 static electricity). The results showed that participants more often complied with the voice warning than to the print warning. As described earlier, speech sound characteristics can be digitally manipulated to give different degrees of urgency.

Detection Systems

Technology will benefit warning effectiveness through detection and sensing. It is desirable to present warnings at locations and times needed for hazard avoidance. Presentation positioning 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. More 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 sensory and cognitive limitations. Habituation was one example presented earlier in which unchanging stimuli results in less attentional response after repeated exposures. Technology can be used to augment or compensate for limitations. Warning systems that include sensors can do some or all of the noticing (Wogalter & Mayhorn, 2006).

A wide variety of sensors are currently available. Some examples include those that detect temperature, moisture, smoke and gas vapors, motion, weight, and so forth. A permanent sign that says “Bridge Ices Before Road” is not warranted in very hot weather. A better method would be to use a temperature sensor and in freezing or near freezing conditions presents the bridge icing warning. Inexpensive motion detectors could be used to initiate a warning when someone enters a hazardous area (Wogalter et al., 1993).

Multiple sensors

To present particular warnings in highly specific situations, multiple detectors could be employed. Combinations of detectors could "recognize" particular patterns based on physical characteristics, behavioral movements, and other inputs. Together they can provide greater precision in when and what to warn about. Newer generation air bag systems have multiple sensors. Some can 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, the system determines whether to deploy an airbag or not, and if so, what kind of the deployment.

Multiple sensors could potentially detect whether a task is being performed incorrectly and if so, then to give an appropriate warning. An important aspect of multiple-detector systems is hardware/software programming. It requires data predicting risk conditions from task analysis. A wide net of influences and conditions need to be anticipated and planned for.

Sensory and cognitive support

Sensor systems can supplement peoples’ sensory and cognitive systems. People are limited in sensory capability and processing capacity. Sensors can compensate for peoples’ limitations by doing the sensing for them. Humans do not have a natural ability to detect nuclear radiation and carbon monoxide (CO) when being harmfully exposed, but there are devices to do that job (Geiger counters and CO detectors). Both involve hazardous emissions in the environment that are beyond the sensory capabilities of humans. Detection of small amounts of residue from explosive material on people and their luggage has become important to public welfare.

The sensor need not detect the hazard directly. It could be accomplished with 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 the presence of methane gas. Likewise in health and medical settings, people's symptoms are often a byproduct of health conditions (i.e., indirect indications). Particular combinations or patterns of symptoms can be used to diagnose certain illnesses.

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 build customized regimens.

Wireless Identification

Information can now be delivered when needed with the advancement of wireless communications. 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 displays able to give warnings.

Technology such as ExxonMobil's Smart Pass, where identification is made by passing an electronic key/tag near gas pump, suggest future warning systems. An extension of this technology are other short-range detection and identification systems. 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 and issue a warning not to enter the area.

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. The cards themselves might have database of information (or a wireless connection is 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

Warnings could be tailored for certain individuals and groups of individuals such as older adults. The system could identify an individual as an older adult and then provide larger print messages on a PDA, electronic paper, or tablet.

People have different needs and different warnings could be provided to them. Research by suggests that personal relevance increases warning 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 abbreviated. For the novice, the information may need to be simple and limited in total quantity to avoid exceeding limited attention and memory capacities. Only the most critical information would be given but the highest priority information may depend on the individuals involved. Additional information can be provided via links if more detailed descriptions are needed.

In the U.S., employers are supposed to make available to employees working with chemicals Material Safety Data Sheets (MSDSs) according to the U.S. Occupational Safety and Health Administration's HazCom Right-to-Know laws. These sheets contain detailed, comprehensive information. However, these sheets are also highly technical and lengthy and are not easily comprehended by workers (Lehto, 1998). Also the critical information for workers (e.g., protective equipment) is usually embedded within complex text. Smith-Jackson and Wogalter (1998, in press) found that different user groups prefer different ordering of the sections of the MSDSs than is usually given. 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. Sophisticated systems could provide different warnings as experience and skill levels of users progress. The system senses task performance and delivers applicable warnings.

IMPLEMENTATION IMPEDIMENTS

The promise of future technology-based warning systems is substantial; yet there are a number of potential barriers that exist that might delay implementation. Some of the systems described above are now inexpensive, whereas some would undoubtedly be costly. However, the cost will go down (while sophistication simultaneously goes up). Examples of previously expensive technology are abundant and will likely continue in the future.

Considerations should also consider warning technology's intrusiveness and annoyance as well as issues of durability and maintenance. Inappropriate false alarming should be avoided. Likewise, a failure to present a necessary warning could sometimes be catastrophic. The alerting nature of a warning should not divert attention away an important, concurrently performed task. As systems improve, errors of presentation should decrease. Another concern is that people may come to rely on proper warnings being presented, and thus efforts should be taken to ensure that they always work. The systems need to be evaluated on their effectiveness.

Security/ Privacy Concerns

Some of the sophisticated systems described above may be able to collect or identify personal information; this could generate personal security and privacy concerns. The information should be kept secured and not be released for purposes not desired. These and related issues are complex and being debated by numerous groups in academia, government, and industry. In general, people ought to be told what information is being collected and how it will be used so that they can make informed decisions (Spunar, Kalsher, & Racicot, 1995). Increasingly massive databases are being built and the trend is likely to continue. There needs to be a balance between maintaining privacy and promoting personal safety. If the use of personal information is prevented, some kinds of warnings might not be delivered to the appropriate target populations. Warnings will be less tailored to fit the people involved.

SUMMARY AND DISCUSSION

Future warning systems will have properties different from traditional static warnings. These improvements will include dynamically modified message content, compensation for human limitations, and personalization via tailoring to meet the needs of particular users. The result will be an increased capacity to warn users of potential or existing hazards. The key to producing enhanced warning systems lies in the effective integration of technology.

A number of potential applications for technology to enhance warning effectiveness were presented, including the use of flat panel displays, video technology, and in-vehicle systems. These and other technologies will be used to improve warning delivery and presentation. Further inclusion of sensor technology in future generations of warning systems should facilitate detection and identification of potential hazards. Future warning systems will provide assistive support for sensory and cognitive limitations which are 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. Savings may also be realized from increased safety and reduction of personal injury and property damage. Further challenges include the design of systems that are not annoying or intrusive, yet are still effective in terms of warning delivery. Another barrier to implementation is finding an acceptable balance between privacy concerns stemming from system acquisition of user information in the process of tailoring warnings to users. Consideration of these issues are important when evaluating and implementing new technology-based warning systems.

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BIOGRAPHY

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University of Richmond (1986-1989) and Rensselaer Polytechnic Institute (1989-1992). He has a B.A. in Psychology from the University of Virginia (1978), an M.A. in Human Experimental Psychology from the University of South Florida (1982), and a Ph.D. in Human Factors Psychology from Rice University (1986). Most of his research focuses on warning effectiveness issues—about two-thirds of his 300 publications and 4 of his 6 books concern this topic. He is on the editorial boards of several scholarly scientific journals including *Applied Ergonomics*, *Ergonomics*, *Journal of Safety Research* and *Theoretical Issues in Ergonomics Science*. He is a Fellow of the Human Factors and Ergonomics Society and the International Ergonomics Society. He consults as an expert witness in various legal cases on issues associated with human factors/ergonomics, hazard perception, communication-human information processing, and warnings.