Applied Ergonomics 45 (2014) 1343–1352

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Coding warnings without interfering with dismounted soldiers' missions

Tal Oron-Gilad [a,*], P.A. Hancock [b], Jessica Helmick-Rich [b]

[a] Dept. of Industrial Engineering and Management, Ben-Gurion University of the Negev, P.O. Box 653, Beer-Sheva 84105, Israel
[b] Department of Psychology, University of Central Florida, USA

ARTICLE INFO

Article history:
Received 25 July 2012
Accepted 19 August 2013

Keywords:
Military
Warning
Retention
Task demand

ABSTRACT

Objectives: Warnings are an effective way to communicate hazard, yet they can also increase task demand when presented to operators involved in real-world tasks. Furthermore, in military-related tasks warnings are often given in codes to avoid counter-intelligence, which may foster additional working memory load.
Background: Adherence to warnings in the military domain is crucial to promote safety and reduce accidents and injuries. The empirical question arises as to how aspects of coding the warning may interfere with the primary task the individual is currently performing and vice versa.
Method: Six experimental conditions were designed to assess how warning-code storage format, response format, and increasing working memory demand (retention) affected both performance on the primary task and the rate of compliance to warnings, considered here as the secondary task.
Results: Results revealed that the combination of warning-code storage and response format affected compliance rate and the highest compliance occurred when warnings were presented as pictorials and responses were coded verbally. Contrary to the proposed hypotheses, warning storage format did not affect performance on the primary task, which was only affected by the level of working memory demand. Thus, the intra-modal warning storages did not interfere with the visual/spatial nature of the primary operational task. However, increase in working memory demand, by increasing the number of memorized warning codes, had an effect on both compliance rate and primary task performance.
Conclusions: Rather than warning code storage alone, it is the coupling of warning storage and response format that has the most significant effect on compliance.

1. Coding warnings without interfering

I have a strong memory from the "Yom-Kipur" war of the radio broadcaster repeating the code "viper-snake" "viper-snake". This combination of words indicated that an alarm was about to be heard and that we should head down to the bomb shelter in fear of an air raid (first author, personal memory from an early age).

Indeed, in military operations, warnings are often pre-coded and pre-memorized. Thus, it is not the warning itself but a code which represents it, that is given in real operational conditions. The use of codes is not a conventional way to use warnings. Commonly in workplaces, warnings are explicitly given and intentionally emphasized to promote safe behavior (e.g., Wogalter, 1994; Wogalter et al., 1992). Nevertheless, in operational settings, when the operator is outside, in various locations, oftentimes in hostile areas and with some degree of secrecy – implicit hints must be given instead of the traditionally known warning presentation. It is in this realm that we wish to examine how distribution of warnings is most efficiently conveyed.

Nowadays, field operators as dismounted soldiers are equipped with information technologies such as mobile phones and small scale computing devices, which makes it easier to convey to them short messages in more than one possible way (e.g., by voice, by text, or by pictorials). Under those circumstances, warnings are most likely to be given while the individual is engaged in performing an operational mission. In the military operation realm, the mission could be consisting of surveillance, recon or conflict-solving components. The dynamics of such missions may change rapidly and little is known to the distributer of the warning, who is remote from the field operator, about the particular state of the current task. Furthermore, since there is no direct contact between the receiver of the information and the transmitter, an acknowledgment of compliance may also be needed. In such cases, storage

* Corresponding author. Tel.: +972 8 6472227; fax: +972 8 6472958.
E-mail address: orontal@bgu.ac.il (T. Oron-Gilad).

0003-6870/$ – see front matter © 2013 Elsevier Ltd and The Ergonomics Society. All rights reserved.
http://dx.doi.org/10.1016/j.apergo.2013.08.011

and processing of pre coded warnings may generate conditions that become formally equivalent to dual-task performance. It is already known that distraction and disruption to operational tasks may occur when the operator experiences high cognitive load and task criticality (Woods, 1995). The question arises therefore, as how the storage and retention of coded warning, as well as their mode of acknowledgment, act to interfere with the primary mission that the individual is currently performing and vice versa, where the latter affects warning compliance rate.

It is known in the literature that coding pose more challenges for the operator than being given explicit instructions. To communicate information effectively one aims to create direct associations between the sign and its referent (Familant and Detweiler, 1993), which enables information in the signal to be directly mapped to a certain referent in the world. For example, the word "fire" shouted in a theater (signal), has the potential of being interpreted as a condition manifested by flames (referent). Direct associations are those involving one referent (e.g., a picture of protective glasses denotes that one should wear protective glasses). For those, the denotative referent is also the sign referent (i.e., the referent to which the signal directly refers). Indirect associations, in contrast, are those involving at least two referents. That is, a signal and a denotative referent may be linked via a chain of referent relations or via two or more parallel referent relations. Whether a warning is accurately identified is likely to depend on several factors describing the extent to which the signal resembles (i.e., shares features with) those that the operator has learned to associate with the referent.

Unfortunately with military-based coding, the strength of the relationships between signs and referents are *intentionally* poor to avoid hostile forces from deciphering them. Studies that have looked at learning and retention of unrelated associations and their effect on recognizing auditory icons (Keller and Stevens, 2004) and their denotative referents (Stephan et al., 2006) have consistently shown that relative to direct and related associations, participants in unrelated conditions consistently demonstrated poor performance, made the most errors, and responded most slowly. Furthermore, Keller and Stevens (2004) found that random relations took over three times more exposure to learn than direct relations, and required over twice as much exposure to reach the same level of compliance. In military applied settings, where coding is frequent, such influences may have dramatic consequences.

Thus, aside from dual-task interference (e.g., Driskell and Olmstead, 1989; Kanki, 1996) between the appearance of a warning and the operational task, the use of coding may cause the compliance to the warning to be poor or erroneous, as deciphering the meaning of the message requires more processing. Furthermore, when codes are being used and the retention of warnings is necessary, additional load on working memory exists which may affect both mission performance and compliance. Thus, in addition to their specific form, the sheer number of retained warnings could affect performance by increasing the level of task demand imposed on the operator. Working memory capacity is limited and the amount of information that can be retained and recalled in real-world situations is similarly restricted (Miller, 1956; but see Ericsson and Staszewski, 1989). Thus, the number of remembered warnings might be reduced when working memory is divided between the operational task and the increasing spectrum of warning information. However, there are also reasons whereby the remembered warnings would not be reduced, when LTM schemata is used (e.g., if different warnings could be integrated in some way, or if cues were available to prompt the different warnings) but these may not necessarily be used the military context due to their increased notice ability by hostiles over time.

Previous research on warnings suggests that the mode of information presentation affects compliance (Lehto and Miller, 1986; Rogers et al., 2000; Wogalter and Usher, 1999; Ursic, 1984). For example, verbal information is remembered and recalled more often than written or pictorial information (Penney, 1975; Murdock, 1968; Watkins and Watkins, 1980) and verbal warnings have been found to communicate hazards better than pictorial or written formats (Jaynes and Boles, 1990; Wogalter and Young, 1991). Combined print and voice warnings have been shown to be more effective than either alone (e.g., Conzola and Wogalter, 1998). The visual presentation usually allows receivers to review a message for longer time or if it was not attended to or comprehended initially (Conzola and Wogalter, 2001). The auditory information may attune the operator toward the warning initially, but is not available for long duration (unless a repeat element is available). However, as noted by Conzola and Wogalter (2001) field experimentation on warnings in actual occupational settings is rather limited. Consequently, these results may well not apply in real-world circumstances where individuals most often receive warning information as a subsidiary form while focusing on their primary duties. Since the ability to expose real operators to hazards is limited, virtual reality is one promising direction (Duarte and Rebelo, 2007), to allow more realistic contextual setup of warnings.

Table 1
Overview of the experimental conditions.

Experimental condition	Compliance task storage and retention	Compliance task response mode	Operational task
1	Pictorial, Written and Verbal in all 6 conditions	Pictorial	Suspect detection
2		Written	Suspect detection
3		Verbal	Suspect detection
4		Pictorial	Navigation
5		Written	Navigation
6		Verbal	Navigation

Individual difference in WM can also affect the way warnings should be coded. Engle et al. (1999) proposed that WM capacity reflects one's ability to maintain information in the focus of attention in the face of distracting or interfering stimuli. "…*WM capacity is not about individual differences in how many items can be stored per se but about differences in the ability to control attention to maintain information in an active, quickly retrievable state*" (Engle, 2002, p.20). Furthermore, the relationship between working memory and cognitive abilities has been proposed to involve domain-specific resources (i.e., verbal and visuospatial; Baddeley, 1986). Consistently, Shah and Miyake (1996) have demonstrated the separability of spatial and verbal working memory resources using the spatial span test (recalling the orientation of a series of rotated letters presented sequentially). They showed that scores on the spatial span test correlate positively with spatial ability measures but not with verbal ability measures. Thus, individual difference in WM may have predictive power of the memory variables on situation awareness performance in complex task settings (see Sohn and Doane, 2003). This type of personality related information may be useful, with the flexibility of presentation format via personal mobile devices. However, very little is known about the impact of individual differences in complex operational task setups such as the one examined in the current study.

Therefore, the formal goal of the present study was to determine the effects of coding presentation and retention in a dual task paradigm with various task-induced levels of demand. Six experimental conditions were designed in order to investigate the effects of a) pairing storage formats with response modes (pictorial, written, and verbal storages with pictorial, written, verbal response modes); b) increasing the number of memorized coded warnings; c) altering the complexity and demand of the operational task; and d) evaluating the effect of individual differences in WM on compliance.