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DESIGNING FOR STRESS

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The proposal must be postmarked no later than 5 p.m., but as the copying is being done frantically an hour before the deadline, the machine ceases to function, displaying a series of confusing error messages on its computer-driven display. With panic gripping the unfortunate victim, he finds himself unable to decipher the complex and confusing instructions. Meanwhile, in another building on campus, the job candidate giving a talk has fielded a few difficult (some might say nasty) questions, and now turns to the video demo that should answer the questions. Nervous and already upset, she now finds that the VCR will not function, and as she fiddles with the various buttons, no one lifts a hand to assist her. Finally, in the sky above the city, the pilot of the advanced commercial airliner is descending toward a landing, having programmed the flight management system to proceed according to ATC clearances. Suddenly, the message arrives from ATC that the plane has dangerously descended in conflict with another airline. The system must be reprogrammed to an alternative heading and level.

Difficulties in a human-system interface, like those described here, characterizing stressful performance with a complex system, are typically addressed by three generic means: training, selection, and design (Huey & Wickens, 1993). Design issues themselves may be categorized into those that focus on task design, (e.g., workload reduction through task sharing) and on interface design. Many of the chapters in this book have discussed training issues, whereas Hogan and Lesser (chap. 6, this volume) have considered the implications for selection. In the present chapter we consider

the implications for design.

It is obvious that design changes, intended to lessen the unfortunate consequences of stress on human-system performance, must be based on an accurate (and therefore valid) model of stress effects on performance. Unfortunately, however, we find that there are several factors that stand in the way of creation of such a model. We discuss these factors first, before describing the most important (validated) components of the model, and then discussing some of its implications for design.

A VALID STRESS MODEL

There are a variety of sources of information that can be used to derive a model of human performance under stress: accident analysis, incident analysis, operator protocols, and laboratory experiments. Unfortunately, all of these suffer certain limitations, as I have discussed elsewhere (Wickens, 1995). Accident analysis suffers from the problems of low sample size and small *N*. For example, the case study of the USS Vincennes (Klein, chap. 2, this volume) has received tremendous scrutiny in its analysis, but, without the benefit of hindsight, it is very difficult to draw conclusions on the critical causal factors in the incident, and to attribute the manner in which stress may or may not have been a responsible agent. A single accident case study is simply incapable of revealing which of several causal factors might have been most responsible.

Incidents and case studies have the advantage of occurring more frequently (than accidents) and therefore providing a larger, and more stable data base on which to draw conclusions. Nevertheless, many inferences must be made in order to establish the degree of stress that may have been present at the time of the

incident, and most incidents may have multiple causes as well. However, the advantages of large numbers is that, through statistical amalgamation, true causal factors tend to remain, whereas random, noncausal, or "noise" factors diminish in their influence. In this manner, for example, McKinney (1993) inferred that inflight emergencies of solo combat pilots would be a source of stress, and, through analysis of a large number of such incidents, he was able to generalize some characteristics of problem solving degradation in these stressful conditions.

Protocol analysis of users performing an operational system, a useful tool in many instances, is less than fully satisfactory for several aspects of stress research, because it is unlikely that analyses will be taken while stressful conditions are present. (However, this is not invariably the case. For example, it is known that the student pilot's initial check ride is quite stressful, and these could be favorable conditions for passive, nonverbal protocols to be collected.)

The fourth, best controlled technique for the analysis of stress effects is through laboratory experiments. These may be done in relatively realistic surroundings, such as the Army combat training arena (Berkun, 1964) or the real-mission flight simulator (Ruffle-Smith, 1979), or the environment may be somewhat more simplified (and, therefore, often more controlled; Keinan & Friedland, chap. 8, this volume; Wickens, Stokes, Barnett, & Hyman, 1993).

However, two statistical factors often limit the generalizability of conclusions from such studies. First, the actual effect size (in terms of variance accounted for) may be quite small, despite its statistical reliability. For example, a change in decision strategy of .08 probability units, or a change in response time of 150 msec may be observed as a statistically significant effect, given a sufficiently large N experiment. However, great caution must be exercised before assuming that this effect would be manifest in the single operator that operates a complex system without benefit of experimental control over all of the extraneous variables. If such effects are not likely to be shown, it hardly seems wise to base extensive

and expensive design changes on them.

Reflecting the other side of the statistical coin, the second concern is with insufficient sample size that is sometimes a deficiency of experimental design (particularly experiments carried out in complex environments). Here, the low N can so reduce the power of an experiment as to make finding an effect very unlikely, even if the effect is substantial, so long as the "traditional" .05 criterion is accepted for effect reporting. As Harris (1991) has eloquently pointed out, in doing experiments with design implications (i.e., human factors research), it is incumbent on the researcher to consider the potential costs of type-2 statistical errors (reporting no effect when there really is one), as well as the standard guarding against type-1 errors (the traditional .05 significance test). Sometimes the cost of rejecting an effect when there is one there may be large, particularly if a low power design (i.e., with small subject sample size), makes the probability of such an error fairly high.

These two statistical concerns lead logically to the importance of meta-analysis, (Rosenthal, 1991) for pooling what data are available from multiple experiments that have provided common manipulations. Some of the chapters in this book have provided valuable contributions in this direction (see also Cannon-Bowers, Salas, & Converse, 1990; Hockey, 1986). The data base of research on which to draw, however, remains woefully inadequate - the result, in part, of the difficult roadblocks that confront the investigator of stress research. These roadblocks of course have to do with the legitimate concerns for the health and safety of human subjects. Whether or not the need for the human factors community to better understand human performance under stress is sufficiently balanced against the limited availability of data is a judgment that protocol review committees must decide.

A SIMPLIFIED STRESS MODEL

As a consequence of the limitations of all methodologies, and

the small experimental data base available, it is prudent to provide a stress model with design implications that only considers well-documented and relatively robust effects. It is also prudent to restrict the operational definition of stress in the current writing to what I term *emergency stress*. These are the circumstances in which the operator believes that external conditions create a potential for serious damage, either in bodily harm or psychological state, and are normally coupled by some degree of time pressure (Svenson & Maule, 1993). Given the assumption of correlation with time pressure, which will indeed be experienced in most emergency situations, it is possible to state with some confidence that the effect; discussed in the next sections will often be observed.

Attentional Tunneling

The idea that the scope or "breadth" of an attentional spotlight will narrow under stress has been documented by a number of studies (Hockey, 1986). For example, Weltman, Smith, and Egstrom (1971) compared the performance of two groups of divers on a central and peripheral signal-detection task. One group was led to believe that it was under conditions of a 60-foot dive in a pressure chamber; the other was not. In fact, there was no change in pressure for either group. Both groups showed similar performance on the central task, but performance on the peripheral task was significantly degraded for the pressure group. This group also showed greater anxiety-related increases in heart rate, substantiating the increased level of stress. Stress may also cause a focusing of attention on one particular task or cognitive activity, as well as on a particular perceptual channel. In the analysis of cockpit voice recordings at times of high stress prior to accidents, Helmreich (1984) found evidence of severe breakdowns in the pilots' ability to handle multiple tasks or multiple concerns.

Although perceptual or cognitive tunneling produced by stress usually degrades performance, it is also possible to envision cir-

cumstances in which this tunneling may actually facilitate performance, in which focused attention on critical task aspects is desired. Indeed, this positive effect was observed in a study by Houston (1969), who found that noise stress improved the focus of attention on the relevant aspect of a stimulus and reduced the distracting effect of irrelevant aspects.

Data provided by Houston's experiment and others suggest that the attentional or cognitive tunneling resulting from stress is defined in terms of subjective importance or priority. That is, performance of those tasks or processing of that information thought to be most important remains unaffected or perhaps is enhanced (through arousal), whereas processing information with lower perceived priority is filtered (Bacon, 1974; Broadbent, 1971). In one sense, this kind of tunneling is optimal, but it will produce undesirable effects if the subjective importance that defines the attended channel proves to be unwarranted. Such was the case, for example, in the incident of the Three Mile Island nuclear power plant (Rubinstein & Mason, 1979). Immediately after the crisis in the plant developed and under the high stress caused by the initial failure, the operators appeared to be fixated on a single faulty indicator, supporting an incorrect belief that the water level in the reactor was too high, thereby preventing their attention from focusing on more reliable indicators that supported the opposite (and correct) hypothesis. As suggested by this example and elaborated later, this narrowing effect can be directly related to biases in decision making. For the operator who has a well-structured and accurate model of task demands and a well developed skill in discriminating sources of useful (versus trivial) information, however, it can be expected that stress should lead to little degradation of performance. This buffering of stress effects was demonstrated by the flight crew of United Airlines flight 232, which suffered a life threatening total failure of the hydraulics system on approach to Sioux City Airport, yet was able to focus attention effectively on implement-

ing a solution to the problem at hand, (Predmore, 1991).

Working Memory Loss

Mandler (1979) has discussed the degrading effects of anxiety on working memory. Correspondingly, Berkun (1964) performed a study in which U.S. Army personnel were placed under very realistically simulated combat stress conditions in which they believed that their life was at risk. Much of the degraded performance in procedures that Berkun observed can be attributed to reduced working memory capacity. Logie and Baddeley (1983) and Lewis and Baddeley (1981) have noted similar working memory decrements of divers performing at depth. Idzikowski and Baddeley (1983a, 1983b) observed an anxiety-related working memory loss in speakers waiting in the wings to give their first public speech. Noise, as well as danger and anxiety, has also produced consistent effects on working memory (Hockey, 1986). Although it is intuitively evident that the presence of noise would disrupt the ability to rehearse verbal information in working memory (Poulton, 1976), it also appears that the combined stress effects of noise and anxiety may disrupt spatial working memory systems as well (Stokes, Belger, & Zhang, 1990; Stokes & Raby, 1989). Indeed, in a simulation study of pilot decision making, Wickens, Stokes, Barnett, and Hyman (1988) observed that the effects of noise stress were greatest on decision problems that relied on spatial visualization for their successful resolution.

Long-Term Memory

Although stress appears to disrupt working memory, it appears to have less of an effect on the retrieval of information from long-term memory to the extent that information is well rehearsed and memorized. For example, in their study of pilot judgment, Wickens et al. (1988) found that those judgments requiring direct retrieval of facts from long-term memory were relatively unimpaired by stress.

In Berkun's study of Army soldiers under stress, he found a difference between more- and less-skilled soldiers in the extent to which performance degraded. The more experienced soldiers were less disrupted, a finding which is also consistent with this view assuming that the more skilled soldiers had better learned procedures stored in long-term memory. Stokes et al. (1990) found that the decision-making performance of novice pilots deteriorated under stress, whereas performance of a group of highly trained pilots in the same circumstances was not affected. Presumably, the latter group was more able to rely on direct retrieval of information from long-term memory in making their decisions.

Similar to the narrowing effect that stress exerts on perception and selective attention, however, stress appears to restrict the information retrieved from long-term memory more specifically to those habits that are well learned or over-learned (Eysenck, 1976). Although there do not appear to be much experimental data supporting this claim, at least one study shows that increased stress actually eliminates some of the benefits of expertise and training in decision making (Ben Zur & Breznitz, 1981). Studies by Fitts and Seeger (1953) and Fuchs (1962) and analyses of aircraft accidents carried out by Allnutt (1987) have all suggested that stress will lead to a regression to earlier learned and more compatible response patterns when these patterns may conflict with incompatible (but appropriate) ones. Collectively, these findings suggest the importance of extensive training in procedures and actions that may need to be taken in emergency situations. They further emphasize that

such procedures should require only actions of high compatibility. The findings, however, emphasize the extent to which creative innovative problem solving may be degraded under stress because, by definition, such problem solving will not have been accomplished in the same way in the past and hence repetitive practice of the same steps cannot be achieved.

Strategic Shifts

There is some evidence from behavioral studies that stress leads to consistent shifts in processing strategy. In a study of the anxiety brought on by the first parachute jump, for example, Simonov, Frolov, Evtushenko, and Sviridov (1977) observed a shift in performance of a signal detection task that can be characterized by a riskier criterion setting. The paratroopers were simply more likely to respond "yes" and hence made more hits and more false alarms. Hockey (1986) concluded that there is a general effect of noise, and/or anxiety stress on the speed-accuracy tradeoff, shifting performance to a less accurate but not slower level. In their study of pilot judgment, Wickens et al. (1988) found that judgments were less accurate but not necessarily slower under the combined stress effects of noise, time pressure, and threat of loss of income.

Domer and Pfeifer (1993) observed systematic shifts in strategic thinking in operators of a video firefighting game that result from unpredictable bursts of noise stress. On the one hand stresses subjects respond more rapidly and give more tactical commands to the simulated firefighting units under their control; on the other hand, however, these commands are simpler, somewhat less effective, and lead to more tactical errors than the commands issued by nonstressed subjects, hence illustrating a form of speed-accuracy tradeoff that may be described as "adaptive" in the sense of minimizing the disruptive effects of the noise bursts.

The tendency of those under the stress of an emergency to shift performance from accurate to fast (but error-prone) responding has been cited as a concern in operator response to complex failures in nuclear power control rooms. The operator often has a desire to do something rapidly, when in fact this impatience is often counterproductive until the nature of the failure is well understood. In the Three Mile Island incident the hasty action of the control room operators was to shut down an automated device that had in fact been properly doing its job. Fischer, Orasanu, and Montalvo (1993) noted that good performing crews under the time stress of a simulated inflight emergency were actually slower, but more careful in the selection of emergency procedures, than poorer performing crews.

Decision Making

Understanding the effects of stress on decision making has always been of great interest to the human factors profession. The importance of this knowledge has been enhanced by the analysis of the faulty decisions made in the Three Mile Island incident and, more recently, by concerns over the decisions made in the U.S.S. Vincennes incident (U.S. Navy, 1988; Klein, chapter 2, this volume). The concern that decisions degrade under stress is reinforced by anecdotes, and case studies of poor pilot judgments that have occurred under stressful conditions of bad weather, spatial disorientation, or aircraft failure (Jensen, 1982; Nagel, 1988; Simmel, Cerkovnik, & McCarthy, 1987). However, it is often difficult to tell whether stress was itself a causal factor in the poor decision or whether the conditions that produced the stress were also those that, for example, degraded the information available in such a way

that the poorer decision became more likely.

To predict, the effects of stress on decision making, one approach is to adopt a componential approach (Wickens & Flach, 1988; see also Orasanu, chap. 3, this volume). Because different decisions may involve varying dependence on such components as working memory, attention, and long-term memory retrieval, each decision may be affected differently by stress as a function of the components on which it depends and of the differential effects of stress on those components as described earlier (Wickens et al., 1988).

An alternative approach is to examine the results of experiments that impose stress on decision making, diagnosis, and problem-solving tasks. Although few studies exist, their results are consistent with the picture of a stress-sensitive decision-making process. Such studies have not only shown that decisions of various sorts degrade under stress but have also concluded that this degradation takes specific forms. Thus, for example, Cowen (1952) found that subjects perseverated longer with inappropriate or rigid problem solutions under the stress produced by threat of shock, a sort of action tunneling that is consistent with the idea of attentional tunneling. Keinan, Friedlan, and Benporat (1987) found that the allocation of attention to a word problem became increasingly nonoptimal and unsystematic as stress was imposed by the threat of an electrical shock. The investigators also observed that this stressor produced a premature closure: Subjects terminated their decision before all alternatives had been considered. Ben Zur and Breznitz (1981) found that stress, although leading to some filtering of information, also led subjects to give more weight to negative task dimensions and, as a consequence, make less risky decisions.

Driskell and Salas (1991) observed that stress actually increased the receptivity of members of a dyad to judgments provided by the other member in reaching a problem solution. They

imposed stress on U.S. Navy personnel who believed they were one component of a cooperative decision-making dyad. In fact, unknown to the subjects, the other component of the dyad was always the same source of computer-generated information for all subjects. The investigators were interested in the extent to which perceived stress influenced the receptivity to information received from a team member when that member was perceived to be either above or below them in the military chain of command. Not surprisingly, greater receptivity to information was shown when the member was perceived of higher rank. Whether the rank was higher or lower, however, both groups were more willing to accept the information under the conditions of perceived stress.

As we have discussed earlier, Wickens et al. (1988) observed that the combined stress of noise, time pressure, risk, and task loading produced a general degradation of pilot judgments on a computer-based flight simulation. The stress effect, however, was selectively observed only on decision problems that were difficult in terms of their spatial memory demand. As noted previously, their data indicated that decisions did not degrade under stress when long-term memory retrieval was the primary mechanism. These conclusions are related to those drawn by Klein (1989; see also chap. 2, this volume), who argued that expert firefighters use direct long-term memory retrieval to make their decisions. Given this characteristic, experts making decisions about familiar courses of action should be less likely to suffer degrading effects of stress.

The conclusion drawn by Klein (1989), however, is partially contradicted by a study carried out by Koehler and McKinney (1991), who evaluated the decision-making performance of Air Force pilots in 195 aircraft malfunction mishaps. Their analysis of decision quality revealed that experts (long-time pilots) did not necessarily perform better than relatively new pilots under the high-stress conditions of an inflight malfunction. Although this conclusion must be tempered by the fact that experts were more

often flying a lead aircraft in formation, thereby adding to their attention demands, a second finding is consistent with the picture presented here; that is, expert performance was particularly disrupted when the malfunctions were novel and unique, more so than the performance of the novices. This is consistent with the view that experts had well-learned solutions available in long-term memory for the routine problems that were not available for the unique ones. The novices had fewer such solutions available for either problem type, and the loss in their performance from routine to unique would therefore be less.

Of course a finding that is, by now, very well documented is that different people adapt very differently to stressors. Fischer, Orasanu, and Montalvo (1993) and Orasanu and Strauch (1994) reported a finding for a full-mission flight simulation of how aircrews responded to the stressful time pressured circumstances of inflight emergencies. Although some crews behaved "optimally," others clearly made some poor choices on their handling of the emergency. In contrast to the more effective crews, those who were less effective and harmed more by stress (a) tended to make certain key decisions more rapidly, without careful considerations of the complexity of the options (a form of speed-accuracy tradeoff), and (b) tended to be reactive, and procrastinating rather than proactive and foresightful in scheduling subtasks that needed to be done in advance of the simulated landing.

A FEW DESIGN PRINCIPLES

The previous section has documented several relatively well validated "stress effects." Many of these, of course, have direct implications for training. This includes not only training of the skill itself, but training on strategies to deal with stress (see chaps. 7 and 8, this volume), such as avoiding the tendency to perform premature actions. The direct implications for design are perhaps somewhat less clear cut. To some extent it is evident from the simplified stress model presented earlier that design decisions to simplify operations under normal procedures will also better support performance under stress, and here we discuss three such principles:

Reduction of working memory load. Working memory is a vulnerable bottleneck for routine as well as stressed performance. Hence, design decisions made to allow continuous visual display of information that may need to be entered or computed will surely benefit performance of both kinds of tasks. An example here would be the visual display of computer-coded digital data link messages from controller to pilot (Kerns, 1991). Such visual digital coding should be able to augment (rather than replace) auditory channels, and would seemingly offer a substantial advantage for a stressed pilot disoriented in bad weather.

Principle of pictorial realism and ecological interface design. Much can be said about the potential "intuitive" advantages of presenting information about physical systems, as a "picture" that mimics many aspects of the system in question. Roscoe (1968) has described this as the principle of pictorial realism (PPR). Indeed, to the extent that the operator is familiar with the underlying structure of the information presented, presenting this information as a picture would appear to support more "natural" and "automatic" processing, and would thereby capitalize on and exploit the well-learned habits that are stress resistant.

In an aircraft, this might involve representing guidance for flight path control as a forward-looking "highway in the sky" (Haskell & Wickens, 1993). A derivative of the PPR is the principle of ecological interface design (Bennett, Toms, & Woods, 1993; Rasmussen & Vicente, 1989), in which pictorial graphic displays attempt to mimic or display prominently the physical constraints and variables relations necessary for control that are inherent in the operator's mental model of complex processes, even as these variables may not be embodied in a true visible "picture." Applications of this principle have primarily been in the area of nuclear and energy conversion processes (Bennett, et al., 1993, Moray, et al., 1994). At an even simpler level, the PPR advises the depiction of continuously changing quantities as pictures (analog), rather than as symbols (digital), and the advantages of analog over digital displays in high-stress environments is well documented (Sanders & McCormick, 1993; Wickens, 1992). Indeed, one of the clear design deficiencies that could have been responsible for the misclassification of the Iranian Airlines jet as a hostile fighter in the USS Vincennes incident was the depiction of the aircraft's altitude by a digital readout (see Klein, this volume).

Nevertheless, the PPR can be oversold as a design improvement. There are clearly times, for example, when symbolic depictions or distortions of the true "picture" might actually improve the user's performance. For example, in a number of investigations, we have found that depiction of 3-D space is more effective by a set of planar displays, than by "pictorially real" 3-D displays (Wickens, Liang, Prevett, and Olmos, in press), because of inherent perceptual ambiguities caused by the latter.

Proximity compatibility principle (PCP). A fundamental part of our stress model is the assertion that information access, through visual search or other retrieval mechanisms, is disrupted and sometimes curtailed in times of stress (particularly when that stress has a time component). The major bias of perceptual or cognitive tunneling certainly represents one important aspect of this disruption. Therefore, it may be expected that performance of tasks which require accessing two sources of information to be integrated or compared might be more disrupted by the degrading effects of stress (Pamperin & Wickens, 1987). Good design will thereby present in close display proximity those sources of information that must be processing in close "mental proximity" (Wickens & Carswell, 1995). For example, it is useful to have the error codes explaining a malfunction available to be viewed right next to the computer-driven display that annunciates a particular error symbol. Here again, the Vincennes incident was potentially illustrative. The altitude reading of the target aircraft was displayed quite separately from the radar depiction of its ground track, making it more difficult for operators to integrate the lateral and vertical trend information of the single aircraft (and therefore understand, it as climbing and not descending).

The PCP naturally has a number of derivative, implications for design (Wickens & Carswell, 1995). All have in common the design principle to make it easier to compare and relate sources of information that must be used together in the service of a single task. By so doing, the stress-related damage to cue sampling can be lessened (because the travel of atten-

tion between samples is reduced). Furthermore, the implications of stress damage to working memory will be attenuated, because working memory is often involved in the comparison of displayed information sources.

The principles listed here are all generally helpful for design and, for the most part, have more "upsides" than downsides. Applying them for design in normal use should also facilitate performance under stressful conditions in emergencies.

However, design for stress is also characterized by a certain number of trade-offs: What is good in one situation (i.e., stress) is not necessarily good for normal operation, and it is to these trade-offs we shall now turn.

DESIGN TRADE-OFFS

Guidance Versus Awareness. A characteristic of routine operation is that it is just that - it is routine and predictable. Therefore, the need to make the operator aware of a broad set of alternative actions, or a wide range of the information space in which performance takes place, is less important than the need to provide continuous feedback that the actions performed are correct and correctly carried out by the system. These generic information requirements transcend quite different system types: In aviation navigation during routine flight, for example, the pilot primarily needs to know if the aircraft flight parameters are maintained near the target values, and that other systems are normal; in process control operation, the operator needs to know that the system is responding to control inputs, and, again, that other system components are normal; in routine computer usage, the operator simply needs feedback that commands have been registered from keystrokes. As Landeweerd (1979) has noted in the context of process control in normal operation, primary awareness must be given to the forward causal flow of events: Do the operator's operations CAUSE the appropriate system response to occur? Using a term borrowed from the domain of assessment, this is *convergent thinking*.

In marked contrast, the emergencies and abnormalities that often trigger stress have a very different set of information requirements - now reasoning must often work backward, from effect to possible cause (diagnostic reasoning), and the operator may need to be aware of a much broader range of task domain information in order to support divergent thinking and problem solving. Two examples illustrate the difference. First, unlike the pilot on routine flight, the pilot who suddenly finds himself lost or spatially disoriented can no longer afford to consider only what is directly in front of the aircraft (the information for routine local guidance), but now must be aware of the full terrain surrounding the aircraft in a 360° sphere because the - desired flight path could now be anywhere, and any number of hazards could intervene between current location and heading and the desired levels of these parameters (Wickens, Liang, Pevett, & Olmos, in press; Wickens & Pevett, 1995). Second, the process control operator confronting a malfunction must now try to make sense of a myriad of confusing lights and warning signals, tracing these back to the cause through a combination of symptomatic interpretations and trouble-shooting tests. It is clear that neither narrowly focused information displays nor routine procedural actions are appropriate for either of these situations. Roth and Woods (1988), for example, have explicitly pointed out the problems with "brittle" procedural checklists to be rigidly followed in times of failure and fault. Each fault may be so unique that subtle departures from a proceduralized action

sequence may need to be taken based on the symptoms and consequences emerging from previous actions.

In sum, the challenge to the designer is how to support the very different information needs in the stressful times of failure recovery, and in the nonstressful times of routine operation, without overwhelming the operator at the moment of emergency. A key design concept here seems to be the development of ecological displays that can efficiently provide a single context within which both routine and nonroutine information can be depicted in integrated functional terms that match the operator's mental model of the process under supervision. These design efforts for single display frameworks have been examined in both process control (Bennett et al., 1993) and Aviation (Wickens et al. in press; Wickens & Pevett, 1995) contexts.

Command Versus Status Displays. A related trade-off is inherent in the choice between displaying what is (a status display) and displaying what to do (a command display). There is a certain irony in this choice. When life is routine, the operator is not under stress and there is ample time to absorb and interpret a great deal of information; then presentation of status information makes a great deal of sense. The operator can take the time to fully understand the status of the system under his or her purview, and choose actions appropriately. However, under the crisis of an emergency, the operator may have neither the time nor the resources available to figure out what to do, and hence may need a command display that instructs the most appropriate action. This is certainly the philosophy of the TCAS display for pilots that under the crisis of a potential midair conflict, commands the pilot to perform certain maneuvers (turn, climb, etc.; Chappell, 1990).

The potential problem with this situation is that effective command displays depend critically on a certain amount of computer intelligence to forecast the future system states, and to make assumptions about how different elements in the system will respond. TCAS logic, for example, must make assumptions about the future flight path of the aircraft and about the likelihood that both aircraft involved in a potential conflict will or will not perform evasive maneuvers in the timely and accurate fashion recommended. Where such intelligence may be imperfect, there may be occasions in which an operator should see the current status on which the computer's command recommendations are based. This double need for both status and command information requires design considerations of *foreground-background redundancy*. That is, redundant presentation of both command and status information is desirable; however it is CRITICAL that the nature of the two sources be clearly distinguished so that there can be no confusion regarding what is status information ("you are too far left") and what is command information ("turn right"). Display design should also make the command information more salient, because that is what may need to be processed in the times of stress when cognitive tunneling serves to filter out less important channels of information. Therefore, a viable approach would seem to be one that presents both command and status information within the same framework, but highlights the command information (presents in the foreground) while deemphasizing the background status information, allowing it to be plainly visible, but not the primary source of attention capture as the display is quickly viewed.

Flexibility Versus Consistency. With increasing sophistication of automation and artificial intelligence, it is progressively more feasible to structure "intelligent interfaces" (Hancock & Chignell,

1989) that assume configurations which are most appropriate for a given operation, phase, or set of user requirements. For example, "tailored logic" in a multifunction display would yield those displays that are appropriate for a current phase of flight most easily through a menu system (e.g., takeoff, cruise, landing; Reising & Curry, 1987). Within the context described in the previous section, status displays could appear in routine circumstances and command displays could be made to appear during emergencies. A corresponding adaptive presentation could contingently present local guidance versus global awareness information. Such flexibility has the advantage of saving the operator the time of engaging in information search, allowing the maximum amount of display space devoted to the most valuable information for a given function, or both.

However, flexible display (or control) design is purchased at the cost of inconsistency, and there are severe dangers of inconsistently configured interfaces, particularly in times of stress (Braune, 1989). Consider, for example, the dangers inherent when a given digital symbol has a very different meaning, depending on the setting of another mode switch. Such confusion was thought to underlie a recent crash of an Airbus A320, when accident investigators inferred that the pilots might have confused a setting of 3.3° flight path angle (what they thought it meant) with 3.3 x 1000 vertical feet/minute descent rate (what the automation had actually commanded and was therefore depicted on the display). The digital indicator read "3.3" in both cases, and only a relatively subtle indicator suggested the critical differences in modes. The inconsistent meaning of similarly appearing displays or controls appears to be a particularly lethal invitation for stress-induced confusion, and is a force that should temper a designer's enthusiasm for overly flexible, changeable, and modifiable interfaces. Design for stress, in short, should strive for the creation of consistency.

CONCLUSION

In conclusion, we have tried to offer some advice, although it was not often very concrete, on how to address these trade-offs between what is best suited for normal nonemergency situations, and what is best suited for the stressful operation during emergency. In many cases these recommendations are based on extrapolations from models of stress in simpler situations, rather than concrete scientific evaluations of emergency response in real-world tasks. However, given the importance of both efficient stress management in crisis and appropriate display-control interfaces in preventing human error, it would appear to be of some urgency to proceed with research evaluations of the suggestions made. As other chapters in this book have noted, training can be an important and necessary remediation for stress, but it is far from sufficient (Huey & Wickens, 1993).

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