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Operator Stress & Display Design

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Operator Stress and Display Design

These design guidelines, based on knowledge of how operators perform under time and task pressure, can lead to better decision making in emergencies.

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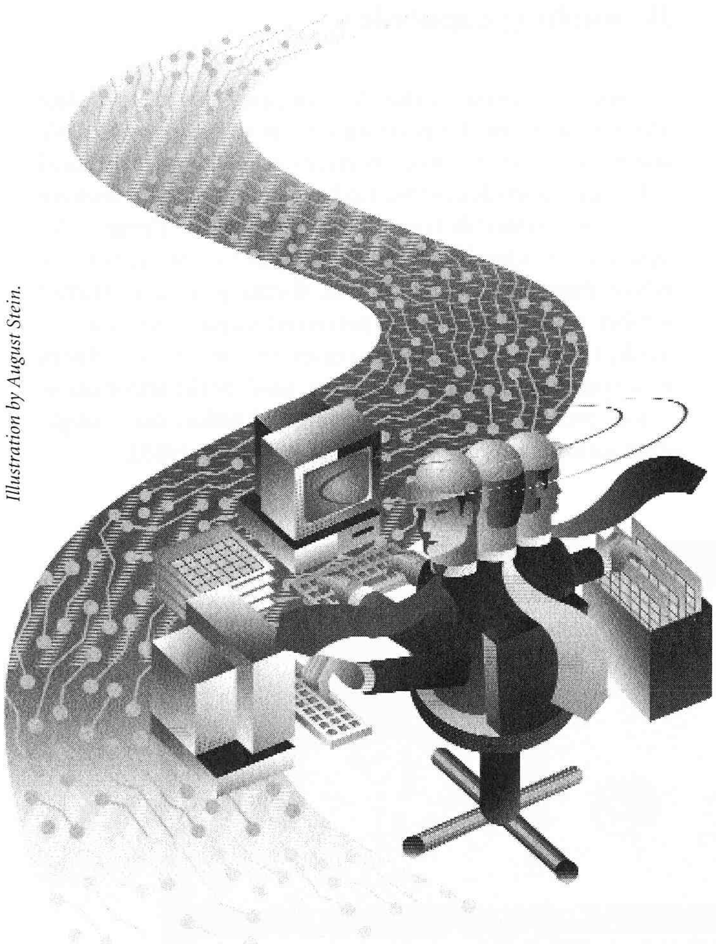

Illustration by August Stein.

It is near the end of a long shift, some hours past midnight, and the combined effects of caffeine, nicotine, and sugared snacks are no longer sufficient to sustain the alertness of tired and weary operators. Circadian rhythms are at their lowest ebb while oppressive, routine operations have so long persisted that chronic boredom reigns supreme. Suddenly a warning sounds, then another, then another – the systems displays are producing a cascade of flashing lights and tone alarms.

Operators rush to workstations, where information begins to overflow like a virtual Niagara of bytes. The apprehension in the air is tangible. It is evident to everyone that a coherent response must be made soon if the situation is to be recovered. As a result, time pressure is now added to anxiety and information overload and rapidly shifts the situation from boredom to terror (Hancock, 1997a). The answers to the problem are somewhere in the system, but a massive noise-to-signal problem is building by the minute. Unfortunately, the resolution is spread across a tapestry of displays. Like pieces of a dynamic jigsaw puzzle, the solution resides in separate parts distributed across many minds, but team communication and team cohesion are rapidly failing, overwhelmed by the demands of information overload and the destructive effects of situational stress. If someone doesn't do something soon . . .

The foregoing account is fictitious, but it might well represent any number of real-world emergency experiences in circumstances as diverse as a nuclear power station control room, a military command and control facility, or the nerve center of a large urban emergency response team. Operators across many application domains are required to perform under situational stresses. However, the problem of information overload is not restricted to emergency circumstances alone but is the common experience of most computer users. Time pressure is also a ubiquitous imposition and not restricted to critical situations.

Observations such as these confirm the growing consensus that the dynamic context of performance is a crucial arbiter of design (Flach, Hancock, Caird, & Vicente, 1995). The premise that many jobs have to be performed in the presence of high task workload and situational stress is our focus in this article. A number of observations about humans performing under workload and stress permit the derivation of some general principles or guidelines for display design for these conditions. Here we enumerate some of these guidelines.

The Stressed Operator

What is the best approach to attack the problem of designing for stressed operators? If consistent and informative principles already existed, one might be able to answer this question at an overall systems design level. However, the present state of affairs debars this high level of analysis because the basic knowledge is not yet well articulated. In this case, one needs first to consider how individual operators react to high-stress and high-workload conditions. Fortunately, there is some useful information regarding these forms of behavioral response (see Hancock & Desmond, 2001). It is known, for example, that extremes of stress affect sensory and perceptual capacities, which results first in a diminution and then a failure of information assimilation. Such degradation denies the subsequent opportunity to engage in the appropriate decision-making and response execution.

In essence, when anticipating high-stress situations, designers need to be aware that they are dealing with selective and diminishing capacities.

Figure 1 represents the changing capacity to assimilate information from the environment as stress increases. We base these observations on an extensive review of theoretical and empirical evidence that we have documented elsewhere (Hancock, Szalma, & Weaver, 2002). Primarily through the depletion of attentional capacity, operators systematically reduce their information intake, focusing on a restricted number of cues of greatest perceived importance (Easterbrook, 1959). As the stress increases, the individual reduces the number of information sources, until, at the termination of this process, there is an apparent fixation on a single informational source (see Hancock & Dirkin, 1983).

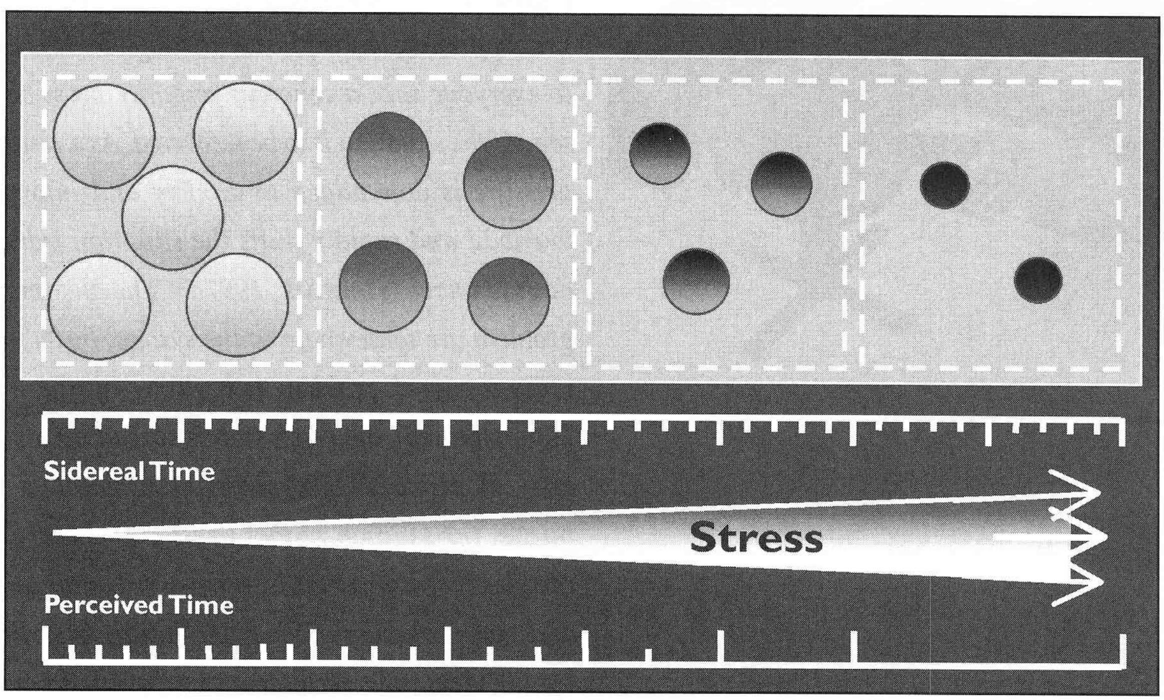

Figure 1: Systematic distortion of perceptual space-time with increase in stress. The upper panel shows a reduction in scan range together with greater focus on each fixation. The lower panel (bracketing the stress level) shows that temporal perception is affected in a similar manner to the spatial distortion.

A little-recognized correlate of this activity is the reduction of time sampling. In addition to variation in spatial sampling, individuals experience significant distortions of time as their restricted attention is diverted away from temporal cues. This distortion is especially important when timing is a critical facet of the task at hand (see also Hancock & Weaver, 2003). This process is a perceptual form of narrowing, which we suggest is replicated at a macro level in strategic task shedding. It has been a source of contention whether the narrowing phenomenon is largely perceptual or sensory in nature. Evidence suggests that operators are able to narrow to salient cues that appear in any part of the visual field (Dirkin & Hancock, 1985; Hancock & Dirkin, 1983; Hockey, 1970, 1983). Narrowing, having been replicated in other sensory capacities (Bacon, 1974), can be taken as an attentional strategy engaged by higher centers of the brain. We have recently proposed that the distortions of both space and time result from a common attentional mechanism (see Hancock et al., 2002).

Much of the narrowing effect is automatic and under only very limited voluntary control, although through adaptive behavior, the stressed operator can effectively accomplish a number of actions before dire effects prevail. Typically, one expects to see conscious load-shedding prior to this narrowing stage of stress response. Also not completely confined to conscious attention, shedding is the action of rejecting irrelevant or, at that moment, unwanted tasks or sources of information. In teams, shedding may take the form of task-sharing or task redistribution. In a single human-machine dyad, shedding might be embedded in the original task allocation design policy. In adaptive human-machine systems, task reallocation is designed to occur as either the human or the machine approaches close to his/its respective capacity limits (see Hancock, Chignell, & Lowenthal, 1985; Hancock & Chignell, 1988). Each of these forms of shedding requires some form of communication, often manifested in the observation that a particular task component is no longer being performed up to standard.

Task demand level can be changed by design, and so stress itself may actually come under the designer's control.

In essence, when anticipating high-stress situations, designers need to be aware that they are dealing with selective and diminishing capacities. Moreover, these capabilities diminish in a systematic fashion as more demanding tasks apparently drain resources at a faster rate than less demanding tasks. Similarly, tasks sharing common resource capabilities, such as two coincident tracking tasks, are more vulnerable to the effects of stress than are tasks that do not have significant overlap, such as a dichotic listening task combined with a tracking task (see Szalma & Hancock, 2003; Wickens, 1984). Expecting stressed operators to seek and distinguish novel sources of information is a fallacy that should be avoided by designers, as we indicate in our design recommendations at the end of this article.

Task Stress and Display Design

For many decades, stress was conceived overwhelmingly as a property of the surrounding environment. The stress literature is redolent with experiments investigating the effects of temperature, noise, vibration, and other factors on task performance (Broadbent, 1971; Poulton, 1970). Along with characteristics of the environment, operator states such as fatigue, lack of sleep, and drug levels also affect performance capacity in a similar, often deleterious manner (Hockey, 1983).

What has been emphasized in more recent theories of stress is that the task itself is the proximal form of stress (Hancock & Warm, 1989). That is, among the various sources of stress, the demands of the task at hand often place the highest level of stress on an individual. As with stress in general, these effects are most obvious at the extremes where the demand generates significant overload or underload on the resource-limited operator. Task demand level can be changed by design, and so stress itself may actually come under the designer's control.

One of the significant issues faced by the designer looking to support decision makers who act under stress concerns the problem of integrating new information. As noted earlier, stress acts to concentrate the individual's attention on a restricted number of sources with perceived high reliance. Further, stress exacerbates the dependence of the decision maker on scenario fulfillment derived from his or her previous experience and current mental model of the situation. Such influences mean that stressed individuals are very likely to discount new information or information that runs contrary to their expectations (Hancock & Mortimer, 2003). The challenge to the designer is how to bring such critical information to the immediate attention of the user.

As increasing levels of stress are encountered, the transmission of complex alphanumeric information is likely to become a further source of distraction, rendering displays uninformative and perhaps deleterious in their performance effects. In extremis, when the person is faced with a time-critical, life-or-death decision, it is important to frame information to address the lowest level of processing capacities. Such displays are likely to be graphic representations of material restricted to an extremely low baud rate with simple messages of affirmative command (e.g., a green arrow pointed toward safety, a red X to indicate danger). When at the very extremes of their tolerance, operators are likely to ignore complicated information regardless of the modality of presentation or even its task salience.

One can, however, take one step back from this edge of incipient failure to look at the process of information integration to the stressed but not terminally challenged user.

This is important because our recent experimental findings have shown that professional operators can be pushed almost to the edge of resilience without a significant decrease of operational capacity (Harris & Hancock, 2003). Our data on stress effects show the presence of this critical failure level in which individuals continuously employ their adaptive and resilient capacities up to the edge of resistance, after which rapid performance failure occurs (see the elbow of the extended–U description of Hancock & Warm, 1989).

Expecting stressed operators to seek and distinguish novel sources of information is a fallacy that should be avoided by designers.

The task of the designer is to support the individual in this phase before the point of incipient failure. Our recommendation for this support, derived from a number of experiments, is that designers should use integrated displays in which different facets of system information are brought into a coherent whole so that the operator's need to engage in information integration is dramatically reduced. Such displays can be beneficial to performance (see Bennett & Flach 1992; Sanderson, Flach, Buttigieg, & Casey, 1989) and, under certain conditions, can reduce mental workload (Szalma, 2002).

Specifically, in a monitoring task requiring information integration, Szalma (2002) reported that object displays were more effective in reducing the perceived workload than were bar graph displays configured to produce an emergent feature representing global system state. It is our contention that these design preferences adhere to the tenets of ecological interface design (EID), which we see as appropriate for the support of stressed and overloaded operators (and see Vicente, 1999). Experimental work is still needed to fully establish exactly how workload and stress states are moderated by use of these displays. Szalma's (2002) recent results suggest that these effects are task and context dependent.

If distortions of spatial and temporal perception resulting from attentional narrowing represent a central characteristic of the stressed operator, displays should be designed to simplify the perception of these dimensions. Integrated displays accomplish this for spatial distortions by centralizing information in a single figure in an easily perceived format. To compensate for temporal distortion, these displays, like trend displays, should incorporate changes in system state as a function of time as a part of the collective integration process. Capture of the temporal dimension into an integrated display can permit the extraction of information regarding system state over specified time intervals (see Figure 2).

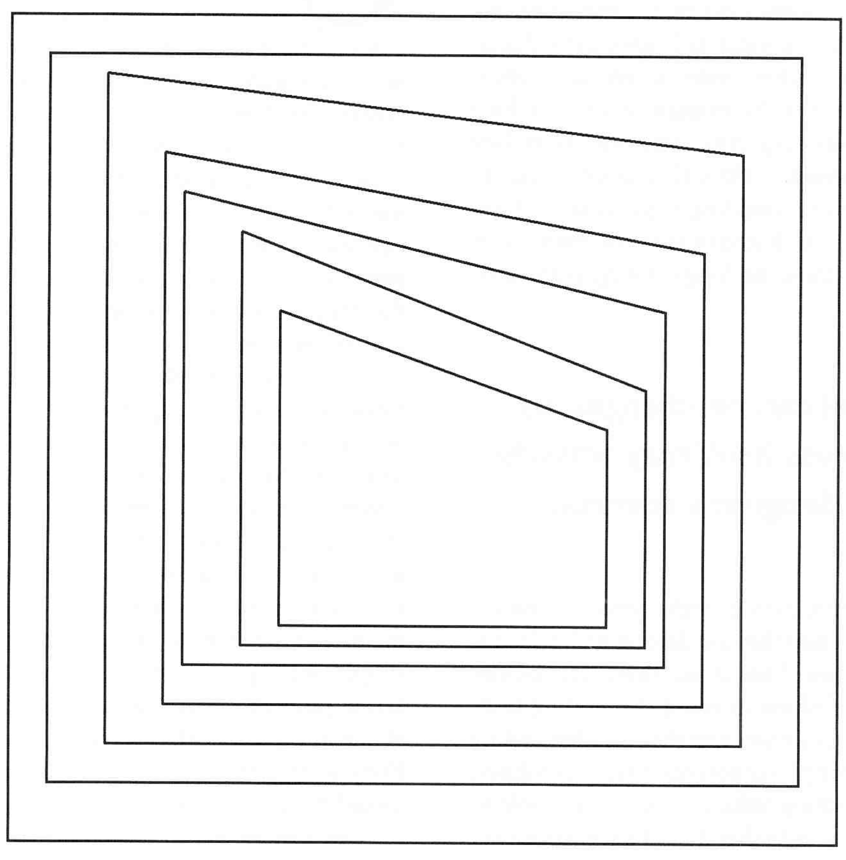

Figure 2. An integrated display organized in a time tunnel format. The successive changes in the size of the polygon represent the state of the system at different points in time. Variations, including confidence intervals, can be developed from this basic illustration.

Fortunately, data support the design use of this approach. For example, Hansen (1995) investigated the efficacy of incorporating temporal information into integrated process control displays. He reported that despite the contextual dependence of performance with configural displays, incorporating a temporal component into an integrated display can improve the ability of operators to perceive trends in the presence of display disturbances.

Designers should use integrated displays in which different facets of system information are brought into a coherent whole.

Given the finding that this display format aided performance under degraded viewing conditions, it is reasonable to infer that it will also support performance under high-stress conditions. Hence, it is possible to develop integrated displays with both spatial and temporal elements in a simplified arrangement that will mitigate the combined effects of distortions of perceptual space-time. However, as in the case of configural and integrated displays generally, it is crucial that the temporal changes represented in the display possess good semantic mapping to the temporal component of system states if such display formats are to be effective (Bennett & Flach, 1992).

Design Guidelines

Although operators in general do not face the problem of decisions under the extreme stress of crises such as the Three Mile Island and Blackhawk down incidents, they often experience periods of particularly high demand combined with limited time for response. In contrast, many workers suffer under the "hurry up and wait" situation in which prolonged periods of underload are followed by moments of mayhem (Hancock, 1997a). In addition, some military and emergency response personnel have to operate under conditions of ultimate threat.

In all these circumstances, effective display design can support performance, but poor displays can hamper and distract an already taxed individual. As a consequence, we have distilled the following guidelines to support display design for operations under stress.

- If at all possible, designers should minimize information dispersal over multiple sources for work under stress. This is because high-stress and high-workload conditions inhibit operator search for novel sources of information. This applies especially to situations in which task resolution requires information integration.
- New information should be linked to data currently being processed, given that operators under stress and high workload tend to discount new information.
- Whenever possible, designers should employ integrated information formats to present an overall "picture" on a single display. This also facilitates the integration of new or contradictory information. When appropriate, display elements should also capture temporal change to mitigate potential deleterious effects of temporal distortion.
- When integrated displays (e.g., object displays) are not practical, use separable configural displays (e.g., bar graph displays) whose elements (both spatial and temporal) form emergent features that are mapped to system dynamics (i.e., displays with good semantic mapping).
- The principles of ecological interface design facilitate implementation of the aforementioned principles. Thus, designers should explore further applications of EID to highly demanding operational conditions.
- When operators are faced with the most extreme conditions, designers should avoid presenting displays that require data transformation. The use of simple graphic displays to convey low-level, direct instructions is recommended because stress depletes resource-based processing of higher-level functions (e.g., problem solving).
- When possible, designers should first prevent direct structural interference to highly stressed and loaded operators. For example, when auditory information is masked by noise and visual displays are obscured by glare, failure to address these simple structural forms of interference obviates any subsequent improvement regardless of the level of sophistication of the design.

Conclusion

Designing for stressful and high-workload situations is becoming increasingly important with the continuing growth of the human as a system monitor and overseer. Specifying crucial information during violent swings between extremes of underload and overload is a vital concern because temporal distortion and time criticality characterize these life-altering events (Huey & Wickens, 1993).

Designers also have to be concerned with person-centered issues. Designing displays for the presentation of information may seem to be a task-driven endeavor, but in reality it is concerned with individual human intention and purpose (Hancock, 1997b; Oborne, Branton, Leal, Shipley, & Stewart, 1993). Indeed, the experience of stress and overload is directly contingent on the understanding of the exposed individual and the way he or she appraises the work environment in the first place (see also Lazarus & Folkman, 1984).

In giving the current recommendations, we acknowledge that much remains to be accomplished to refine the present guidelines and to integrate them with the few extant theories of interface structure and function. However, the move toward context-specific design is an important development, and we see this work as one step in that direction.

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