CHAPTER 7

Design of Cognitive Work

KEY POINTS:

- Minimize informational workload.
- Limit absolute judgments to 7 ± 2 items.
- Use visual displays for long, complex messages in noise areas.
- Use auditory displays for warnings and short, simple messages.
- Use color, symbols, and alphanumerics in visual displays.
- Use color and flashing lights to get attention.

The design of cognitive work has not been traditionally included as part of methods engineering. However, with ongoing changes in jobs and the working environment, it is becoming increasingly important to study not only the manual components of work but also the cognitive aspects of work. Machines and equipment are becoming increasingly complex and semi, if not, fully automated. The operator must be able to perceive and interpret large amounts of information, make critical decisions, and be able to control these machines quickly and accurately. Furthermore, there has been a gradual shift of jobs from manufacturing to the service sector. In either case, there typically will be less emphasis on gross physical activity and a greater emphasis on information processing and decision making, especially via computers and associated modern technology. Thus, Chapter 7 explains information theory, presents a basic conceptual model of the human as an information processor, and details how best to code and display information for maximum effectiveness, especially with auditory and visual displays. Also, a final section outlines both software and hardware considerations of the human interacting with computers.

INFORMATION THEORY

Information, in the everyday sense of the word, is knowledge received regarding a particular fact. In the technical sense, information is the reduction of uncertainty about that fact. For example, the fact that the engine (oil) light comes on when a car is started provides very little information (other than that the lightbulb is functioning) because it is expected. On the other hand, when that same light comes on when you are driving down a road, it conveys considerable information about the status of the engine because it is unexpected and a very unlikely event. Thus, there is a relationship between the likelihood of an event and the amount of information it conveys, which can be quantified through the mathematical definition of information. Note that this concept is irrespective of the importance of the information; that is, the status of the engine is quite a bit more important than whether the windshield-washer container is empty.

Information theory measures information in bits, where a *bit* is the amount of information required to decide between two equally likely alternatives. The term "bit" came from the first and last part of the words *b*inary dig*it* used in computer and communication theory to express the on/off state of a chip or the polarized/reverse polarized position of small pieces of ferromagnetic core used in archaic computer memory. Mathematically this can be expressed as:

$$H = \log_2 n$$

where: H = The amount of information.
n = The number of equally likely alternatives.

With only two alternatives, such as the on/off state of a chip or the toss of an unweighted coin, there is one bit of information presented. With ten equally likely alternatives, such as the numbers from 0 to 9, 3.322 bits of information can be conveyed ($\log_2 10 = 3.322$). An easy way of calculating $\log_2$ is to use the following formula:

$$\log_2 n = 1.4427 \times \ln n$$

When the alternatives are not equally likely, the information conveyed is determined by:

$$H = \Sigma p_i \times \log_2 (1/p_i)$$

where: p_i = The probability of the ith event.
i = Alternatives from 1 to n.

As an example, consider a coin weighted so that heads come up 90 percent of the time and tails only 10 percent of time. The amount of information conveyed in a coin toss becomes:

$$H = 0.9 \times \log_2 (1/0.9) + 0.1 \times \log_2 (1/0.1) = 0.9 \times 0.152 + 0.1 \times 3.32$$
$$= 0.469 \text{ bits}$$

Note, that the amount of information (0.469) conveyed by a weighted coin is less than the amount of information conveyed by an unweighted coin (1.0). The maximum amount of information is always obtained when the probabilities are equally likely. This is because the more likely an alternative becomes, the less information is being conveyed (i.e., consider the engine light upon starting a car). This leads to the concept of *redundancy* and the reduction of information from the maximum possible due to unequal probabilities of occurrence. Redundancy can be expressed as:

$$\%\ \text{redundancy} = (1 - H/H_{max}) \times 100$$

For the case of the weighted coin, the redundancy is:

$$\%\ \text{redundancy} = (1 - .469/1) \times 100 = 53.1\%$$

An interesting example relates to the use of the English language. There are 26 letters in the alphabet (A through Z) with a theoretical informational content for a randomly chosen letter of 4.7 bits ($\log_2 26 = 4.7$). Obviously, with the combinations of letters into words, considerably more information can be presented. However, there is a considerable reduction in the amount of information that can be actually presented due to the unequal probabilities of occurrence. For example, letters s, t, and e are much more common than q, x, and z. It has been estimated that the redundancy in the English language amounts to 68 percent (Sanders and McCormick, 1993). On the other hand, redundancy has some important advantages that will be discussed later with respect to designing displays and presenting information to users.

One final related concept is the *bandwidth* or *channel capacity,* the maximum information processing speed of a given communication channel. In terms of the human operator, the bandwidth for motor-processing tasks could be as low as 6–7 bits/sec or as high as 50 bits/sec for speech communication. For purely sensory storage of the ear (i.e., information not reaching the decision-making stage), the bandwidth approaches 10,000 bits/sec (Sanders and McCormick, 1993). The latter value is much higher than the actual amount of information that is processed by the brain in that time because most of the information received by our senses is filtered out before it reaches the brain.

HUMAN INFORMATION PROCESSING MODEL

Numerous models have been put forward to explain how people process information. Most of these models consist of black boxes (because of relatively incomplete information) representing various processing stages. Figure 7–1 presents one such generic model consisting of four major stages or components: perception, decision and response selection, response execution, memory, and attentional resources distributed over various stages. The decision-making component, when combined with working memory and long-term memory, can be considered as the central processing unit while the sensory store is a very transient memory, located at the input stage (Wickens, Gordon, and Liu, 1997).

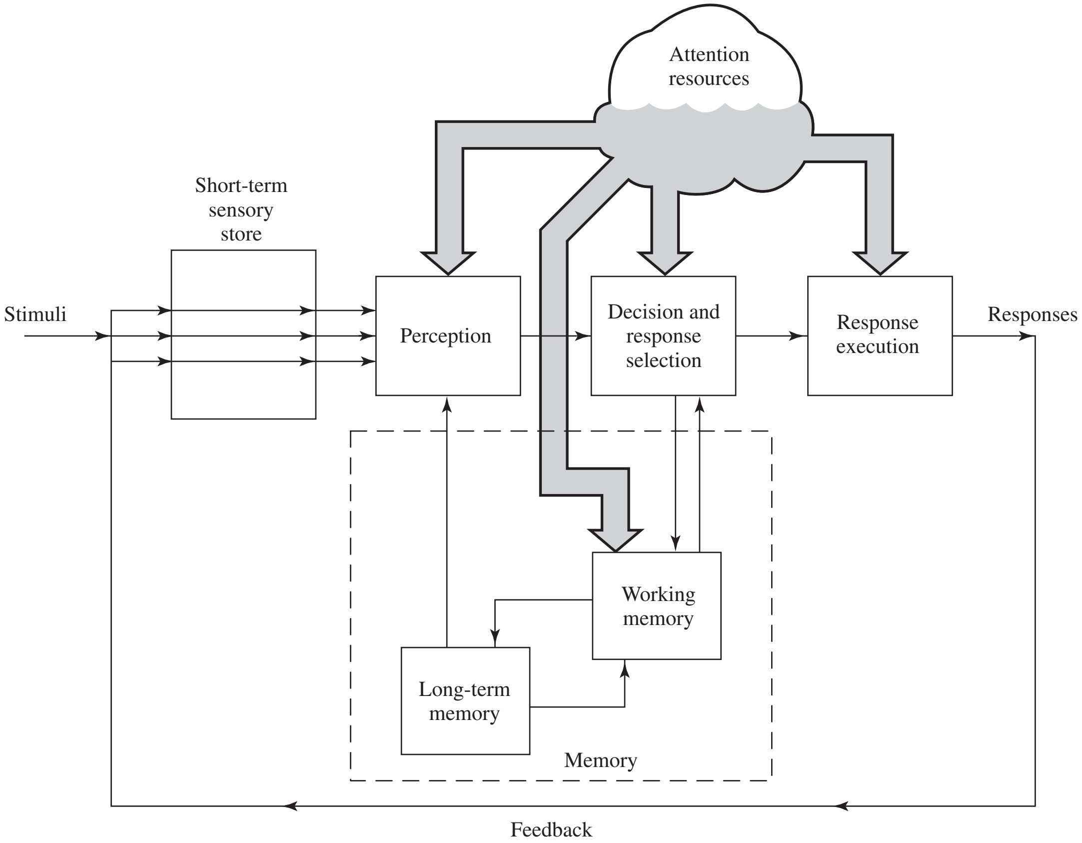


Figure 7–1 | A model of human information processing.
(*From:* Sanders and McCormick, 1993. Reproduced with permission of the McGraw-Hill Companies.)

PERCEPTION AND SIGNAL DETECTION THEORY

Perception is the comparison of incoming stimulus information with stored knowledge to categorize the information. The most basic form of perception is simple *detection,* that is, determining whether the stimulus is actually present. It becomes more complicated if the person is asked to indicate the type of stimulus or the stimulus class to which it belongs and then gets into the realm of identification and recognition with the use of prior experiences and learned associations. The consequent linkage between long-term memory and perceptual encoding is shown in Figure 7–1. This latter more complex perception can be explained in terms of feature analysis, breaking down objects into component geometric shapes or text into words and character strings, and, simultaneously, of top-down or bottom-up processing to reduce the amount of information entering central processing. Top-down processing is conceptually driven using high-level concepts to process low-level perceptual features, while bottom-up processing is data driven and guided by sensory features.

The detection part of perceptual encoding can be modeled or, in fairly simple tasks, even quantified through *signal detection theory* (SDT). The basic concept of SDT is that in any situation, an observer needs to identify a signal (i.e., whether it is present or absent) from confounding noise. For example, a quality inspector in an electronics operation must identify and remove defective chip capacitors from the good capacitors being used in the assembly of printed circuit boards. The defective chip capacitor is the signal, which could be identified by excessive solder on the capacitor that shorts out the capacitor. The good capacitors, in this case, would be considered noise. Note that one could just as easily reverse the decision process and consider good capacitors the signal and defective capacitors noise. This would probably depend on the relative proportions of each.

Given that the observer must identify whether the signal is present or not and that only two possible states exist (i.e., the signal is either there or not there), there is a total of four possible outcomes:

1. *Hit*—saying there is a signal when the signal is present
2. *Correction rejection*—saying there is no signal when no signal is present
3. *False alarm*—saying there is a signal when no signal is present
4. *Miss*—saying there is no signal when the signal is present

Both the signal and noise can vary over time, as is the case with most industrial processes. For example, the soldering machine may warm up and, initially, expel a larger drop of solder on the capacitors, or there may be simply "random" variation in the capacitors with no cause yet determined. Therefore both the signal and noise form distributions of varying solder quantity from low to high, which typically are modeled as overlapping normal distributions (Figure 7–2). Note, the distributions overlap because excessive solder on the body of the capacitor would cause it to short out causing a defective product (in this case a signal). However, if there is excessive solder, but primarily on the leads, it may not short out and thus is still a good capacitor (in this case noise). With ever-shrinking electronic products, chip capacitors are smaller than pinheads, and the visual inspection of these is not a trivial task.

When a capacitor appears, the inspector needs to decide if the quantity of solder is excessive or not and whether to reject the capacitor or not. Either through instructions and/or sufficient practice, the inspector has made a mental standard of judgment, which is depicted as the vertical line in Figure 7–2 and termed the *response criterion.* If the detected quantity of the solder, which enters the visual system as a high level of sensory stimulation, exceeds the criterion, the inspector will say there is a signal. On the other hand, if the detected quantity is small, a smaller level of sensory stimulation is received, landing below the criterion, and the inspector will say there is no signal.

Related to the response criterion is the quantity *beta.* Numerically beta is the ratio of the height of the two curves (signal to noise) in Figure 7–2 at the given

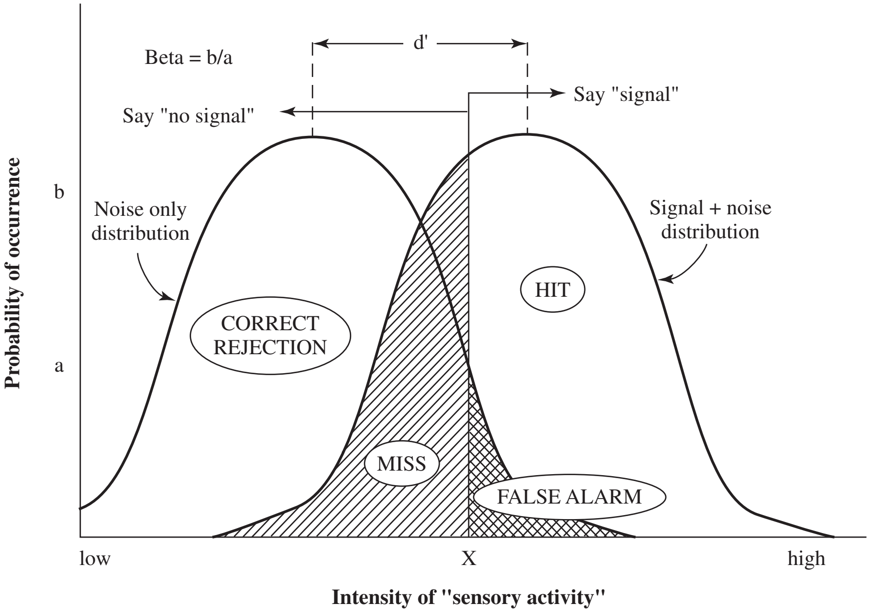


Figure 7–2 | Conceptual illustration of signal detection theory.
(*From:* Sanders and McCormick, 1993. Reproduced with permission of the McGraw-Hill Companies.)

criterion point. If the criterion shifts to the left, beta decreases with an increase of hits but at the cost of a corresponding increase of false alarms. This behavior on the part of the observer is termed *risky.* If the criterion were at the point where the two curves intersect, beta would be 1.0. On the other hand, if the criterion shifts to the right, beta increases with a decrease of both hits and false alarms. This behavior on the part of the observer would be termed *conservative.*

The response criterion (and beta) can easily change depending on the mood or fatigue of the visual inspector. It would not be unexpected for the criterion to shift to the right and the miss rate to increase dramatically late Friday afternoons shortly before quitting times. Note, that there will be a corresponding decrease in the hit rate because the two probabilities sum to one. Similarly, the probabilities of a correct rejection and false alarms also sum to one. The change in the response criterion is termed response bias and could also change with prior knowledge or changes in expectancy. If it was known that the soldering machine was malfunctioning, the inspector would most likely shift the criterion to the left, increasing the number of hits. The criterion could also change due the costs or benefits associated with the four outcomes. If a particular batch of capacitors were being sent to NASA for use in the space shuttle, the costs of having a defect would be very high, and the inspector would set a very low criterion producing many hits but also many false alarms with corresponding increased costs (e.g., losing good products). On the other had, if the capacitors were being used in cheap give-away cell phones, the inspector may set a very high criterion, allowing many defective capacitors to pass through the checkpoint as misses.

A second important concept in SDT is that of *sensitivity* or the resolution of the sensory system. In SDT, sensitivity is measured as the separation between the two distributions shown in Figure 7–2 and labeled as d'. The greater the separation, the greater the observer's sensitivity and the more correct responses (more hits and more correct rejections) and fewer errors (fewer false alarms and misses) are made. Usually sensitivity will improve with greater training and alertness (e.g., through more frequent rest breaks) on the part of the inspector, better illumination at the workstation, and slowing the rate of signal presentation (which has the trade-off of decreasing productivity). Other factors that may help increase sensitivity are supplying visual templates of the defective parts, providing redundant representations or clues for the defective parts, and providing knowledge of results. Note that providing incentives will help increase hit rates. However, this is typically due to a shift of the response bias (not an increase in sensitivity) with a corresponding increase in false alarm rates. Similarly introducing "false signals" to increase alertness will again have a greater tendency to shift the response bias. More information on signal detection theory can be found in Green and Swets (1988).

Signal Detection Theory as Applied to the Inspection of Glass

EXAMPLE 7.1

A good application of signal detection theory was detailed by Drury and Addison (1973) in the visual inspection of glass. The inspection was in two stages: (1) 100 percent general inspection in which each item was either accepted or rejected and (2) a sample inspection by special examiners who reexamined the previous results and provided feedback to the general inspectors. Considering the quality of the items being inspected, a proportion was good and the rest was bad. The general inspector could only make two decisions: accept or reject. The proper responses would be the acceptance of a good item (hit) and the rejection of a bad item (correct rejection). However, some good items could be rejected (misses) and some bad items could be accepted (false alarms). Consider four different cases of varying conditions.

Case #1—Conservative Inspector A conservative inspector sets the criterion far to the right (Figure 7–3a). In such a situation, the probability of hits (saying "yes" to the signal of good glass) is low (e.g., 0.30). The probability of false alarms (saying "yes" to the noise of bad glass) is even lower (e.g., 0.05). Beta is determined by the ratio of the ordinates of the signal curve over the noise curve at the criterion. The ordinate for a standard normal curve is:

$$y = \frac{e^{-z^2/2}}{\sqrt{2\pi}}$$

For the signal curve, a probability of 0.30 yields a z of 0.594 and an ordinate of 0.348. For the noise curve, a probability of 0.05 yields a z of 1.645 and an ordinate of 0.103. Beta then becomes 3.38 (0.348/0.103). Note that the probability of hits and misses

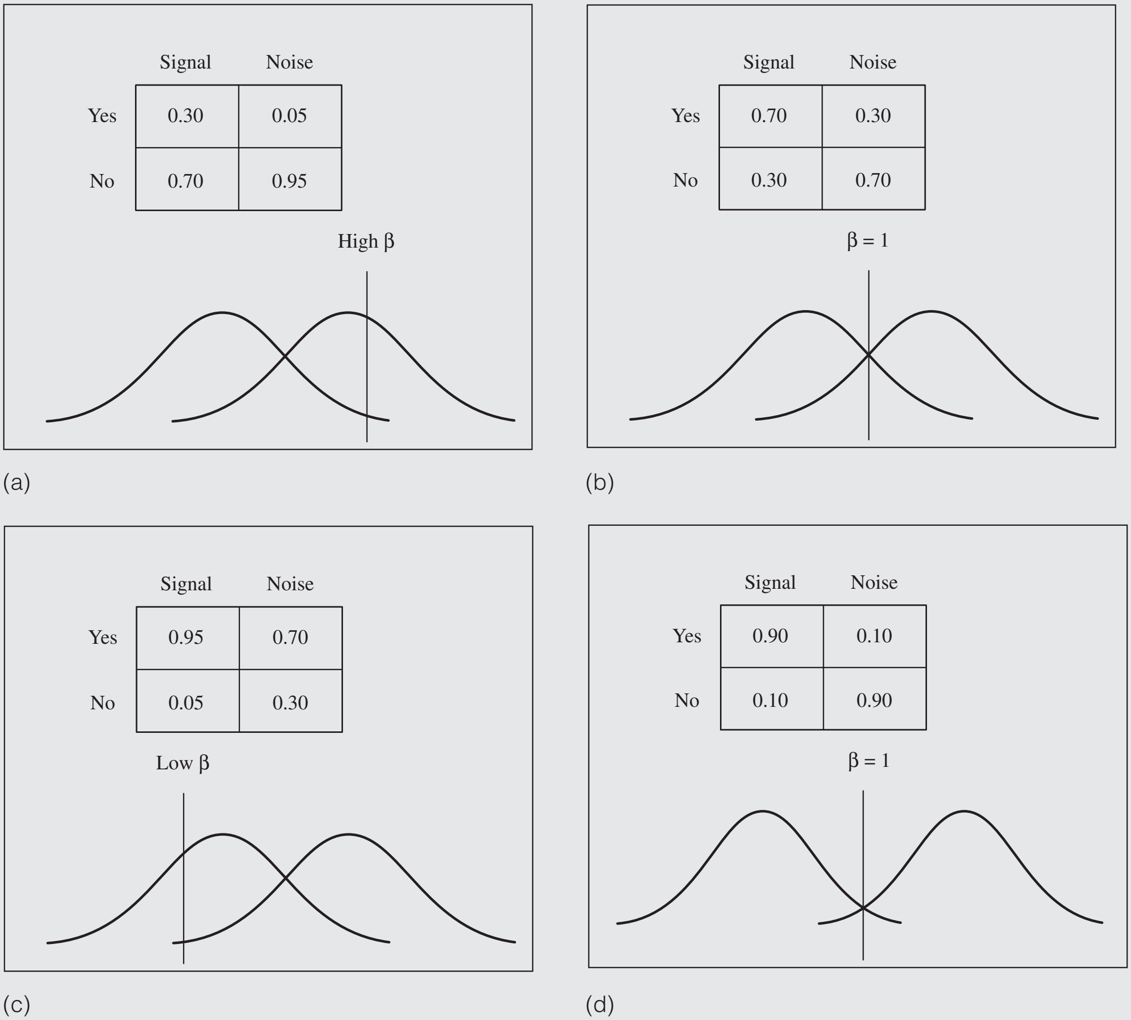


Figure 7–3 | Signal detection theory as applied to inspection: (a) conservative inspector, (b) average inspector, (c) risky inspector, and (d) increased sensitivity

equals 1.0 (i.e., 0.30 + 0.70 = 1.0). The same is true for false alarms and correct rejections.

Case #2—Average Inspector If the inspector is average— neither conservative nor risky—the probability of hits roughly equals the probability of correct rejections (Figure 7–3b). The curves intersect symmetrically, resulting in the same ordinate values and a value of 1.0 for beta.

Case #3—Risky Inspector A risky inspector (Figure 7–3c) sets the criterion far to the left, increasing the probability of hits (e.g., 0.95) at the cost of a high probability of false alarms (e.g., 0.70). In this case, for the signal curve, a probability of 0.95 yields a z of -1.645 and an ordinate of 0.103. For the noise curve, a probability of 0.70 yields a z of -0.594 and an ordinate of 0.348. Beta then becomes 0.296 (0.103/0.348).

Case #4—Increased Sensitivity Sensitivity can be calculated as the difference of the z values for the same abscissa for both signal and noise curves (Figure 7–3d):

$$d' = z(\text{false alarms}) - z(\text{hits})$$

Using the criterion of Case #1:

$$d' = 1.645 - 0.594 = 1.111$$

The same is found from the criterion in Case #3:

$$d' = -0.594 - (-1.645) = 1.111$$

If the signal can be better separated from the noise, the probability of hits will increase (e.g., up to 0.90), while the probability of false alarms will remain fairly low (e.g., 0.10). Using the criterion as the comparison point, the probability of hits is 0.90 with a corresponding z value of -1.283 and an ordinate of 0.175. The probability of false alarms is 0.10, with a corresponding z value of 1.283 and an ordinate of 0.175. The sensitivity then becomes:

$$d' = 1.283 - (-1.283) = 2.566$$

With increased sensitivity there is better performance in identifying defective parts. Sometimes, the hit rate is plotted against the false alarm rate to yield a receiver operator characteristic curve in which the deviation of the curve from the 45 degree slope indicates sensitivity.

In the Drury and Addison (1973) case study, weekly data on glass inspection were collected from which the value d' was calculated. A change in inspection policy of providing more rapid feedback to the general inspector resulted in d' increasing from a mean value of 2.5 to a mean value of 3.16, a 26 percent increase in sensitivity over the course of 10 weeks (see Figure 7–4). This represented a 60 percent increase in the signal to noise ratio (i.e., beta) and a 50 percent decrease in the probability of missing a defect.

MEMORY

Once the stimulus has been perceptually encoded, it goes into *working memory,* one of the three components of the human memory system. The other two are sensory store and long-term memory. Each sensory channel has a temporary storage mechanism that prolongs the stimulus for it to be properly encoded. This storage is very short, on the order of one or two seconds depending on the sensory channel, before the stimulus representation disappears. It is also fairly automatic, in that it doesn’t require much attention to maintain it. On the other hand, there is very little that can be done to maintain this storage or increase the length

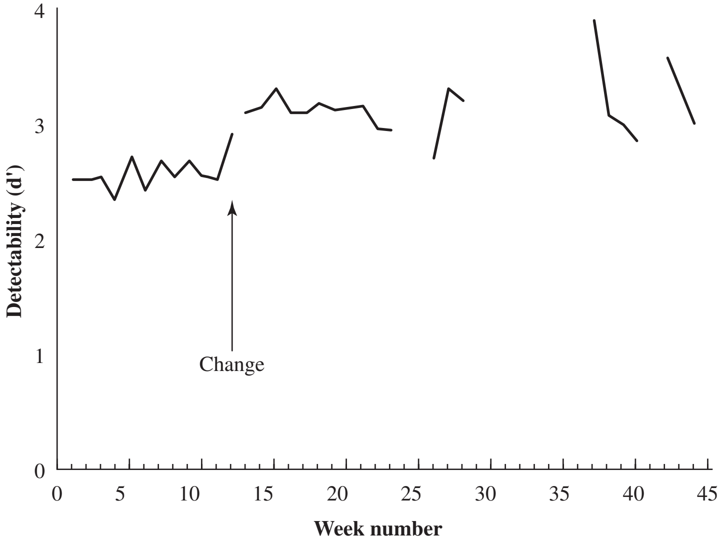


Figure 7–4 | Change in sensitivity with time for glass inspection. (*From:* Drury and Addison, 1973; Taylor & Francis, Philadelphia, PA.)

of the time period. Note also from Figure 7–1, that, although there may be a vast amount of stimuli, which could be represented on the order of millions of bits of information entering the sensory storage, only a very small portion of that information is actually encoded and sent on to working memory.

As opposed to long-term memory, working memory is a means of temporarily storing information or keeping it active while it is being processed for a response. Thus, it sometimes is termed *short-term memory.* Looking up a phone number and retaining it until the number has been dialed and finding a processing code from a list and entering it into the control pad of a machine are good examples of working memory. Working memory is limited both in the amount of information and the length of time that information can be maintained.

The upper limit for the capacity of working memory is approximately 7 ± 2 items, sometimes known as *Miller's rule* after the psychologist who defined it (Miller, 1956). For example, the 11 digits, 12125551212 would be very difficult, if not impossible, to recall. Recall can be improved by the use of *chunking,* or the grouping of similar items. The above numbers, when properly grouped as 1-212-555-1212 are much easier remembered as three chunks (the 1 is the obvious standard for long distance). Similarly, *rehearsal,* or mentally repeating the numbers, which shifts additional attentional resources (see Figure 7–1) to working memory can improve recall.

Working memory also decays quickly, in spite of rehearsing or serially cycling through the items being actively maintained. The more items in working memory the longer it takes to cycle through and the greater likelihood of one or more of the items being lost. It is estimated that the half-life for a memory store of three items is seven seconds. This can be easily demonstrated by presenting a subject three random numbers (e.g., 5 3 6). After seven seconds counting backward to prevent rehearsal, most individuals would have forgotten at least one number, if not two numbers.

Some recommendations for minimizing errors on tasks requiring the use of working memory are (Wickets, Gordon, and Liu, 1997):

- minimize the memory load, both in terms of capacity and time to maintain recall
- utilize chunking, especially in terms of meaningful sequences and use of letters over numbers (e.g., the use of words or acronyms instead numbers for toll-free telephone numbers, such as 1-800-CTD-HELP)
- keep chunks small, no more than three or four items of arbitrary nature
- keep numbers separate from letters (e.g., chunks should contain similar entities)
- minimize confusion of similar sounding items (e.g., letters D, P, and T are easily confused, as opposed to letters J, F, and R)

Information from working memory may be transferred to *long-term memory i*f it will be needed for later use. This could be information related to general knowledge in semantic memory or information on specific events in one's life in the form of event memory. This transfer must be done in an orderly manner so as to be able to easily retrieve it at a later time in a process we know as learning. The process of retrieving the information is the weak link and can be facilitated by frequent activation of that memory trace (e.g., a social security or phone number used every day) and the use of *associations* with previous knowledge. These associations should be concrete rather than abstract and be meaningful to the user, utilizing the user's expectations and stereotypes. For example, the name John Brown can be associated with the image of a brown outhouse.

If there is the lack of clear or organized associations, the process can be done artificially in the form of mnemonics—an acronym or phrase—the letters of which represent a series of items. For example, the resistor color code (black, brown, red, orange, yellow, green, blue, violet, gray, white) can be remembered from the first letters of each word from the expression "big brown rabbits often yield great big vocal groans when gingerly slapped." Standardization of procedures or use of memory aids (signs or notes) for complicated procedures also help by decreasing the load on long-term memory. Unfortunately, long-term memory decays exponentially with the most rapid decline in the first few days. Because of this, the effectiveness of training programs should not be evaluated immediately after the program.

DECISION MAKING AND RESPONSE SELECTION

Decision making is really the core of information processing, in which people evaluate alternatives and select an appropriate response. This is a relatively long-term process and should be distinguished from short-term processing as in choice reaction time. Unfortunately people are not optimal decision makers and frequently do not make rational decisions based on objective numbers or hard information. The rational approach in classical decision theory would be to calculate an expected value based on the sum of products of each outcome multiplied by its expected probability:

$$E = \Sigma\, p_i v_i$$

where: E = Expected value.
p_i = Probability of the ith outcome.
v_i = Value of the ith outcome.

Unfortunately, people typically use a variety of heuristics to make decisions, in which case, a variety of biases may influence the way they seek information, attach values to outcomes, and make overall decisions. A short list of such biases is derived from Wickens, Gordon, and Liu (1997):

- A limited number of *cues* or pieces of information are used.
- Undue weight is given to early cues.
- Inattention is given to later cues.
- Prominent cues are given more weight.
- All information is weighted equally regardless of true weight.
- A limited number of hypotheses are generated.
- Once a hypothesis has been selected, later cues are omitted.
- Only confirming information is sought for the chosen hypothesis.
- Only a small number of responses are chosen.
- Potential losses are weighted more heavily than comparable potential gains.

By understanding these biases, the industrial engineer may be able to better present information and better set up the overall process to improve the quality of decision making and minimize errors.

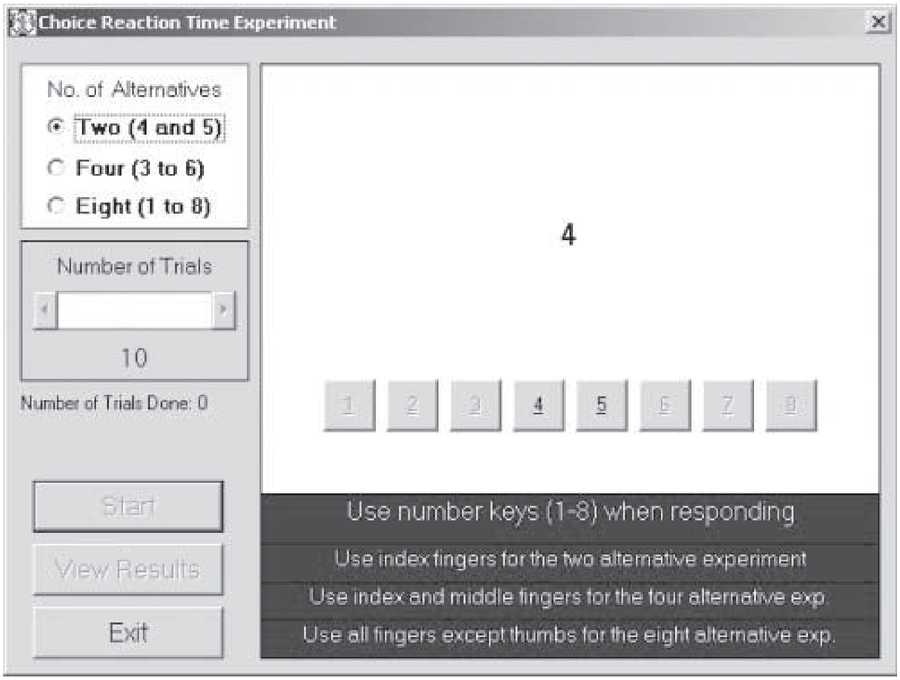
In addition, current theories on decision making center around *situational awareness,* which is an evaluation of all the cues received from the surrounding environment. It requires the integration of cues or information into mental representations, ranging from simple schemata to complex mental models. To improve situational awareness, operators need to be trained to recognize and consider appropriate cues, to check the situation for consistency within the cues, and to analyze and resolve any conflicts in the cues or the situation. Decision aides, such as simple decision tables (discussed in Chapter 8) or more complex expert systems may assist in the decision-making process. Also, the display of key cues, the filtering out of undesirable cues, and the use of spatial techniques and display integration can also assist in this process. Some of these will be discussed further in the section below on display modality.

The speed and difficulty of decision making and response selection, as discussed above, is influenced by many factors. One attempt at quantifying this process is typically performed through a *choice-reaction time* experiment, in which the operator will respond to several stimuli with several appropriate responses (see Figure 7–5a). This can be considered as simple decision making and, based on the human information processing system, the response time should increase as the number of alternative stimuli increases. The response is nonlinear (see Figure 7–5b) but, when decision complexity is quantified in terms of the amount of information conveyed in bits, then the response becomes linear and is referred to as the *Hick-Hyman Law* (Hick, 1952; Hyman, 1953; see Figure 7-5c):

$$RT = a + bH$$

where: RT = Response time (sec).
H = Amount of information (bits).
a = Intercept.
b = Slope, sometimes referred to as the information processing rate.

Note that when there is only one choice (e.g., when the light appears, press the button), H equals zero and the response time is equal to the intercept. This is



Choice Reaction Time Experiment

No. of Alternatives
● Two (4 and 5)
○ Four (3 to 6)
○ Eight (1 to 8)

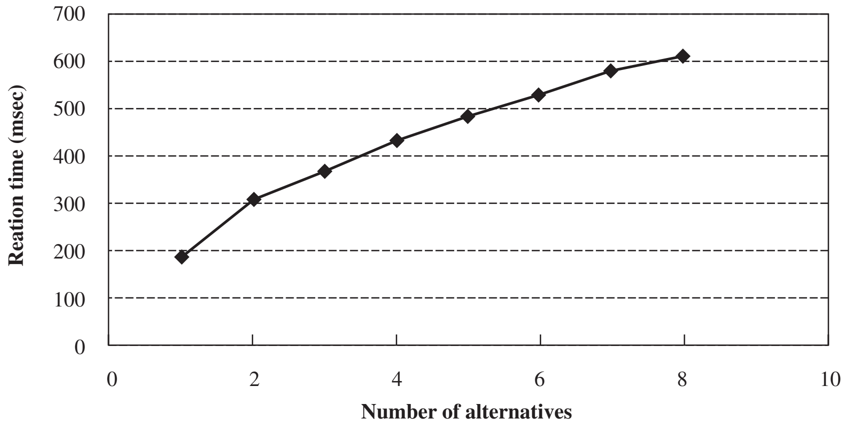
Number of Trials
10

Number of Trials Done: 0

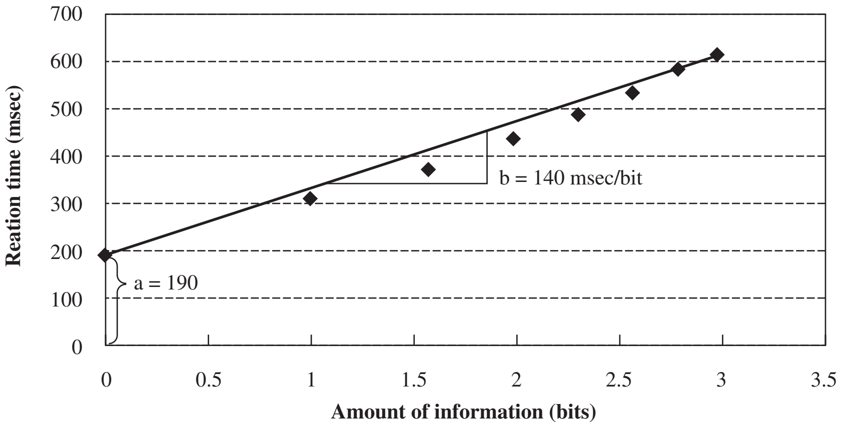
Use number keys (1-8) when responding
Use index fingers for the two alternative experiment
Use index and middle fingers for the four alternative exp.
Use all fingers except thumbs for the eight alternative exp.

(a)

Figure 7–5 |
Hick-Hyman Law illustrated in a choice-reaction time experiment: (a) choice-reaction time experiment from DesignTools, (b) raw data, (c) information expressed in bits.



(b)



(c)

Figure 7–5 | (continued)

known as *simple reaction time.* It can vary depending on the type of stimulus (auditory reaction times are about 40 msec faster than visual reaction times), the intensity of the stimulus, and preparedness for the signal.

Overall choice reaction times also vary considerably due a variety of factors. The greater the compatibility (see also Chapter 5) between the stimulus and the response, the faster the response. The more practice, the faster the response. However, the faster the operator tries to respond, the greater the number of errors. Similarly, if there is a requirement for very high accuracy (e.g., air-traffic control), the response time will become slower. This inverse relationship is known as the *speed-accuracy trade-off.*

The use of multiple dimensions, in another form of redundancy, can also decrease response time in decision making, or, conversely, if there is conflicting information, response time will be slowed. A classic example is the *Stroop Color-Word Task* (Stroop, 1935), in which the subject is asked to read a series of words expressing colors as rapidly as possible. In the control redundant case, having red ink spell out the word "red" will result in a fast response. In the conflict case, red ink letters spelling out "blue" will slow response time due to the semantic and visual conflicts.

Human Information Processing in a Wiring Task

EXAMPLE 7.2

A good example of quantifying the amount of information processed in an industrial task was presented by Bishu and Drury (1988). In a simulated wiring task, industrial operators moved a stylus to the proper terminal or location on a control panel, which consisted of four different plates, each having eight possible components. Each component area was divided into 128 terminals in an array of eight columns and 16 rows. The most complex task involved all four plates ($\log_2 4 = 2$ bits of information), all eight components (3 bits), eight columns (3 bits), and 16 rows (4 bits) for a total complexity of 12 bits (sum of 2, 3, 3, and 4). From this control panel, others of less complexity could be produced by reducing the number of plates, components, columns, and rows. A low-complexity task involved only two plates (1 bit), four components (2 bits), four columns (2 bits), and 8 rows (3 bits) for a total complexity of 8 bits (sum of 1, 2, 2, and 3). Other intermediate-complexity tasks were also utilized.

The final results showed a linear relationship between information processing (simulated wiring or placement) time and the information complexity of the input (see Figure 7–6). Using the Hick-Hyman Law, this relationship can be expressed as:

$$\text{IP} = -2.328 + 0.7325\ \text{H}$$

where: IP = Information processing time (sec).
H = the amount of information (bits).

Thus, as the number of alternatives in performing the task increased, so also increased the informational loading on the central processing unit of the human operator, and the corresponding time for task performance. Note that in this relatively real-world case of a complex task, the intercept may not always be a positive value corresponding to simple reaction time.

Fitts' Law and Information Processing of Movement

EXAMPLE 7.3

Information theory was applied to the modeling of human movement by Fitts (1954) who developed the *index of difficulty* to predict movement time. The index of difficulty was defined as a function of the distance of movement and target size in a series of positioning movements to and from identical targets:

$$\text{ID} = \log_2 (2\text{D}/\text{W})$$

where: ID = Index of difficulty (bits).
D = Distance between target centers.
W = Target width.

Movement time was found to follow the Hick-Hyman Law, now termed *Fitts' Law:*

$$MT = a + b\,ID$$

where: MT = Movement time (sec).
a = Intercept.
b = Slope.

In a particularly successful application of Fitts' Law, Langolf, Chaffin, and Foulke (1976) modeled human movement by different limbs across a wide range of distances, including very small targets visible only with the assistance of a microscope. Their results (see Figure 4–14) yielded slopes of 105 msec/bit for the arm, 45 msec/bit for the wrist, and 26 msec/bit for the finger. The inverse of the slope is interpreted, according to information theory, as the motor system bandwidth. In this case, the bandwidths were 38 bits/sec for the finger, 23 bits/sec for the wrist, and 10 bits/sec for the arm. This decrease in information processing rates was explained as the result of added processing for the additional joints, muscles, and motor units. Interestingly, these results are identical to Gilbreth's classification of movements (see Chapter 4).

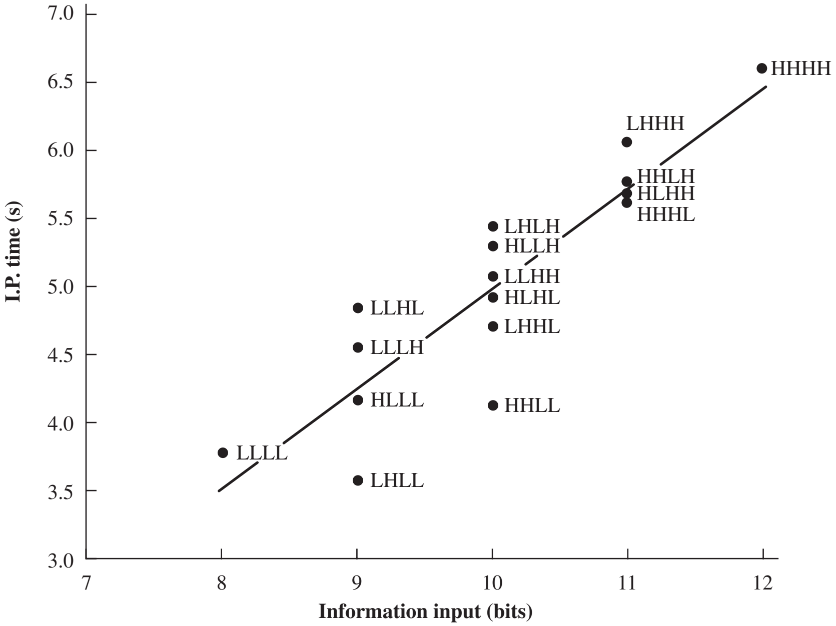


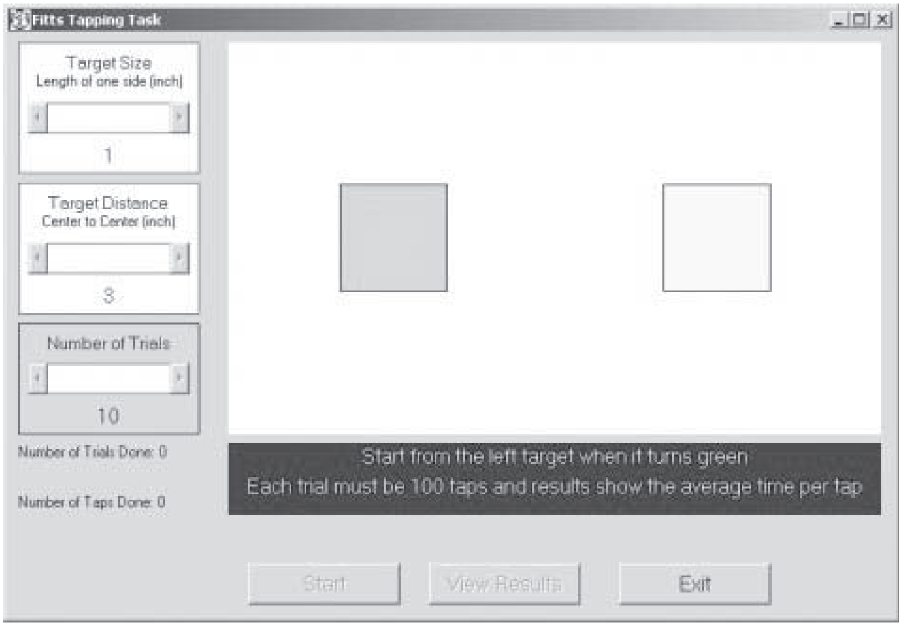
Figure 7–6 | Hick-Hyman Law illustrated in a wiring task.
(Reprinted from *Applied Ergonomics,* Vol. 19, Bishu and Drury, Information Processing in Assembly Tasks—A Case Study, pp. 90–98, 1988, with permission from Elsevier Science.)

RESPONSE EXECUTION

Response execution depends primarily on human movement. More details on the musculoskeletal system, motor control, and manual work can be found in Chapter 4. Note that the *Fitts' Tapping Task* (see Figure 7–7) is a simple extension of the Hick-Hyman Law with respect to movement and also an example of a speed-accuracy trade-off with respect to the size of the target and movement time. Specific applications of responses with respect to controls and to the operation of machines and other equipment is discussed in Chapter 5.

ATTENTION RESOURCES

Attention resources, or more simply, *attention,* refers to the amount of cognitive capacity devoted to a particular task or processing stage. This amount could vary considerably from very routine, well-practiced assembly tasks with low attentional demands to air-traffic controllers with very high attentional demands. Furthermore, this cognitive capacity can be applied in a very directed manner, such as a spotlight on a particular part of the human information processing system, termed focused attention. Or it can be applied in a much more diffuse manner to various parts or even all of the human information processing system, termed divided attention. An example of focused attention on working memory would occur while an operator was trying to remember a looked-up processing code while



Target Size
Length of one side (inch)
1

Target Distance
Center to Center (inch)
3

Number of Trials
10

Number of Trials Done: 0

Number of Taps Done: 0

Start from the left target when it turns green
Each trial must be 100 taps and results show the average time per tap

Figure 7–7 | Fitts' Tapping Task from DesignTools.

entering it into a computer-controlled machine tool. Focused attention can be improved by reducing the number of competing sources of information or demands on the human information processing system or separating these sources in as distinct a manner as possible.

On the other hand, an inspector, sorting apples on a conveyor line, divides his attention between visual perception of blemishes and apple sizes, decision making on the nature of the blemish and the size of the apple, with reference to memory and the images stored there from training, and hand movements to remove the damaged apples and sort the good ones into appropriate bins by size. This latter case of performing various tasks simultaneously is also termed *multitasking* or *time-sharing*. Because our cognitive resources for attention are relatively limited, time-sharing between several tasks will probably result in a decrease in performance for one or more of these tasks as compared to a single task baseline. Again, it can be difficult to improve task performance in such situations, but similar strategies as discussed for focused attention are also utilized. The number and difficulty of tasks should be minimized. The tasks should be made as dissimilar as possible in terms of the demands placed on a processing stage of Figure 7–1. Whereas a purely manual assembly task with auditory instructions can be managed, a musician tuning an instrument would have a much more difficult time listening to verbal comments. One approach that is fairly successful in explaining time-sharing performance with multiple tasks is the multiple resource model of Wickens (1984).

An extension of multiple resource modes of attention relates to the measurement of *mental workload* or the demands placed on the human information processor. One definition uses the ratio of resources required to the resources available, where time is one of the more important of a number of required resources. In the examples mentioned above, simple assembly may be time-consuming, but is not especially demanding of cognitive resources. On the other hand, air-traffic control, at peak times, can be very demanding. It can be very difficult to actually quantify these demands placed on the operator. Some of the approaches used to do so include:

- *Primary task* measures such as time required to perform the task divided by total time available or the number of items completed per unit time; the problem with this approach is that some tasks are better time-shared than others.
- *Secondary task* measures utilize the concept of a reserve capacity, that, if not being directed to the performance of the primary task, will be used by a secondary task (choice reaction time), which can be controlled and more easily measured; the problem with this approach is that the secondary task typically seems artificial and intrusive and it is difficult to identify how the operator prioritizes the performance of both tasks.
- *Physiological measures* (e.g., heart rate variability, eye movement, pupil diameter, electroencephalograms) are thought to respond to the stress imposed by mental workload; although, they typically don't interfere with

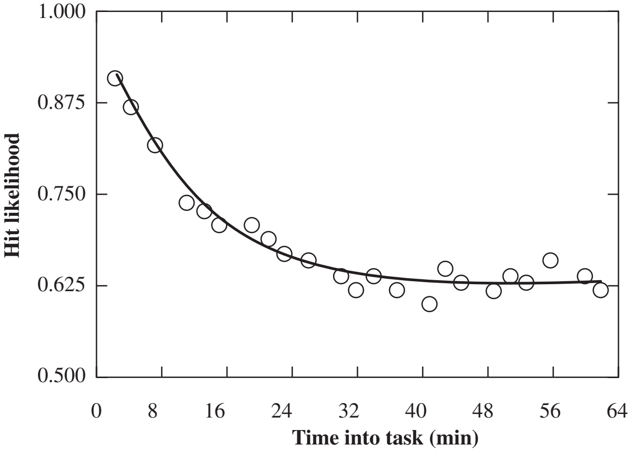


Figure 7–8 | Vigilance decrement over time.
(*From:* Giambra and Quilter, 1987. Reprinted with permission from *Human Factors,* Vol. 29, No. 6, 1987. Copyright 1987 by the Human Factors and Ergonomics Society. All rights reserved.)

the primary task performance, the equipment needed to measure them may do so.

- *Subjective measures* are thought to aggregate all aspects of mental workload in a simple overall rating (or a weighted average of several scales); unfortunately subjective reports don't always accurately reflect true performance; also, motivation may strongly affect the ratings.

For a more detailed discussion of mental workload and the advantages and disadvantages of various means to measure it, see Wickens (1984), Eggemeier (1988), and Sanders and McCormick (1993).

A final example of attentional resources relates to the ability of an operator (e.g., a visual inspector) to maintain attention and remain alert over prolonged periods of time. Termed *sustained attention* or *vigilance,* the concern is how to minimize the vigilance decrement that occurs after as little as 30 minutes and increases up to 50 percent with increasing time (Giambra and Quilter, 1987; see Figure 7–8). Unfortunately, there are few documented countermeasures that work well for industrial tasks. The basic approach is to try to maintain a high level of arousal, which then maintains performance, following the *Yerkes-Dodson (1908) inverted-U* curve (see Figure 7–9). This can be done by providing more frequent rest breaks, providing task variation, providing operators with more feedback on their detection performance, and using appropriate levels of stimulation, either internal (e.g., caffeine) or external (e.g., music or white noise), or even through the introduction of false signals. However, the latter change of detection criteria will also increase the rate of false alarms (see page 291, in the discussion of signal detection theory) with consequent costs. Increasing the

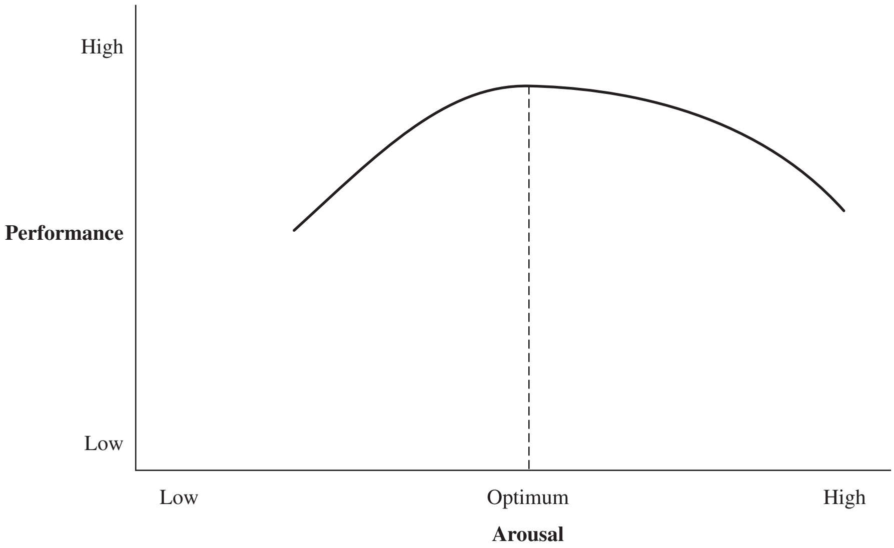


Figure 7–9 | The Yerkes-Dodson Law showing the inverted-U relationship between performance and the level of arousal.

prominence of the signal will assist in the detection performance (e.g., making the signal brighter, larger, or with greater contrast through special illumination). Overlays that act as special patterns to enhance differences between the defective part and the rest of the object may also be useful. Finally, selecting inspectors with faster eye fixation time and better peripheral vision will also help in inspection performance (Drury, 1982).

To assist the industrial engineer in evaluating and redesigning cognitive tasks, the above details on the human information processing system have been summarized in the Cognitive Work Evaluation Checklist (see Figure 7–10).

CODING OF INFORMATION: GENERAL DESIGN PRINCIPLES

As mentioned in the introduction to Chapter 4, many, if not most, industrial functions or operations will be performed by machines, because of the greater force, accuracy, and repeatability considerations. However, to insure that these machines are performing satisfactorily at the desired specifications, there will always be the need for a human monitor. This operator will then receive a variety of information input (e.g., pressure, speed, temperature, etc.) that has to be presented in a manner or form that will be both readily interpretable and unlikely to result in an error. Therefore, there are a number of design principles that will assist the industrial engineer in providing the appropriate information to the operator.

Perception Considerations	**Yes**	**No**
1. Are key signals enhanced?	☐	☐
2. Are overlays, special patterns, or grazing light used to enhance defects?	☐	☐
Are both top-down and bottom-up processing used simultaneously?	☐	☐
a. Are high-level concepts used to process low-level features?	☐	☐
b. Is data-driven information used to identify sensory features?	☐	☐
4. Is better training used to increase sensitivity of signal detection?	☐	☐
5. Are incentives provided to change the response bias and increase hits?	☐	☐

Memory Considerations	**Yes**	**No**
1. Is short-term memory load limited to 7±2 items?	☐	☐
2. Is chunking utilized to decrease memory load?	☐	☐
3. Is rehearsal utilized to enhance recall?	☐	☐
4. Are numbers separated from letters in lists or chunks?	☐	☐
5. Are similar-sounding items separated?	☐	☐
6. Are mnemonics and associations used to enhance long-term memory?	☐	☐

Decision and Response Selection	**Yes**	**No**
1. Are a sufficient number of hypotheses examined?	☐	☐
2. Are a sufficient number of cues utilized?	☐	☐
3. Are later cues given equal weight to early cues?	☐	☐
4. Are undesirable cues filtered out?	☐	☐
5. Are decision aids utilized to assist in the process?	☐	☐
6. Are a sufficient number of responses evaluated?	☐	☐
7. Are potential losses and gains weighted appropriately?	☐	☐
8. Are speed-accuracy trade-offs considered?	☐	☐
9. Are the stimuli and responses compatible?	☐	☐

Attentional Resource Considerations	**Yes**	**No**
1. Is there task variety?	☐	☐
2. Is performance feedback provided to the operator?	☐	☐
3. Does the operator have internal stimulation (e.g., caffeine)?	☐	☐
4. Does the operator have external stimulation (e.g., music, incentives)?	☐	☐
5. Are rest breaks provided?	☐	☐

Figure 7–10 | Cognitive work evaluation checklist.

TYPE OF INFORMATION TO BE PRESENTED

Information to be presented can be either static or dynamic, depending on whether it changes over time. The former includes any printed text (even scrolling text on a computer screen), plots, charts, labels, or diagrams that are unchanging. The latter is any information that is continually updated such as pressure, speed, temperature, or status lights. Either of the two categories can also be classified as:

- quantitative—presenting specific numerical values (e.g., 50°F, 60 rpm)
- qualitative—indicating general values or trends (e.g., up, down, hot, cold)

- status—reflecting one of a limited number of conditions (e.g., on/off, stop/caution/go)
- warnings—indicating emergencies or unsafe conditions (e.g., fire alarm)
- alphanumeric—using letters and numbers (e.g., signs, labels)
- representational—using pictures, symbols, and color to code information (e.g., "wastebasket" for deleted files)
- time-phased—using pulsed signals, varying in duration and intersignal interval (e.g., Morse code or blinking lights)

Note that one informational display may incorporate several of these types of information simultaneously. For example, a stop sign is a static warning using both alphanumeric letters and an octagonal shape and the red color as representations of information.

DISPLAY MODALITY

Since there are five different senses (vision, hearing, touch, taste, smell), there could be five different *display modalities* for information to be perceived by the human operator. However, given that vision and hearing are by far the most developed senses and most used for receiving information, the choice is generally limited to those two. The choice of which of the two to use depends on a variety of factors, with each sense having certain advantages as well as certain disadvantages. The detailed comparisons given in Table 7–1 may aid the industrial engineer in selecting the appropriate modality for the given circumstances.

Touch or tactile stimulation is useful primarily in the design of controls, which is discussed further in Chapter 5. Taste has been used in a very limited range of circumstances, primarily added to give medicine a "bad" taste and prevent children from accidentally swallowing it. Similarly, odors have been used in the ventilation system of mines to warn miners of emergencies or in natural gas to warn the homeowner of a leaking stove.

SELECTION OF APPROPRIATE DIMENSION

Information can be coded in a variety of dimensions. Select a dimension appropriate for the given conditions. For example, if lights are to be used, one can then

Table 7–1 | When to Use Visual or Auditory Forms of Presentation

Use visual forms if:	Use auditory forms if:
The message is long and complex	The message is short and simple
The message deals with spatial references	The message deals with events in time
The message needs to be referred to later	The message is transient
No immediate action is needed	Immediate action is needed
Hearing is difficult (noise) or overburdened	Vision is difficult or overburdened
The operator can be stationary	The operator is moving about

Adapted from Deatherage, 1972.

select brightness, color, and frequency of pulsing, as dimensions to code information. Similarly, if sound is to be used, one can select dimensions such as loudness, pitch, and modulation.

LIMITING ABSOLUTE JUDGMENTS

The task of differentiating between two stimuli along a particular dimension depends on either a *relative judgment,* if a direct comparison can be made of the two stimuli, or an *absolute judgment,* if no direct comparison can be made. In the latter case the operator must utilize working memory to hold one stimulus and make the comparison. As discussed previously, the capacity of working memory is limited to approximately 7 ± 2 items by Miller's rule. Therefore, an individual will be able to identify, at most, five to nine items based on absolute judgment. Research has shown that this holds true for a variety of dimensions: five levels for pure tones, five levels for loudness, seven levels for size of the object, five levels for brightness, and up to a dozen colors. On the other hand, individuals have been able to identify up to 300,000 different colors on relative basis, when comparing them two at a time. If multiple dimensions are used (e.g., brightness and color), then the range can be increased to some degree, but less than would be expected from the combination (direct product) of the two coding dimensions (Sanders and McCormick, 1993).

INCREASING DISCRIMINABILITY OF CODES

When selecting a coding scheme, consider that with regards to relative judgment, it is apparent that there has to be some minimum difference between the two codes or stimuli before they can be distinguished as different. This difference is termed the *just noticeable difference* (JND) and is found to vary depending on the level of the stimuli. For example (see Figure 7–11), if an individual is given a 10- ounce weight (0.283 kg), the JND is roughly 0.2 ounces (0.056 kg). If the weight is increased to 20 ounces (0.566 kg), the JND increases to 0.4 ounces (0.113 kg), and so on. This relationship is termed *Weber's Law* and can be expressed as:

$$k = JND/S$$

where: k = Weber's fraction or slope.
S = Standard stimulus.

The application of this law is quite evident in an industrial setting. Consider a lighting source with a three-way bulb (100-200-300 watts). The brightness change from 100 to 200 watts is quite noticeable, whereas, the change from 200 to 300 watts is much less noticeable. Thus, for a change in a high-intensity signal to be noticeable, the change must be quite large. Although, Weber's Law was formulated for relative thresholds, Fechner (1860) extended it to develop psychological scales for measuring a wide range of sensory experiences to form the basis for the science of psychophysics.

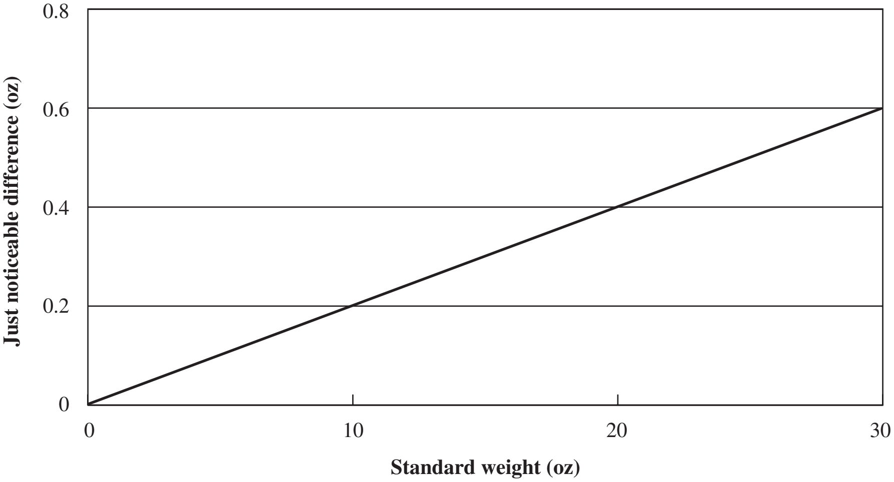


Figure 7–11 | Weber's Law showing the relationship between just noticeable difference and the level of stimuli which, for this example, is standard weight.

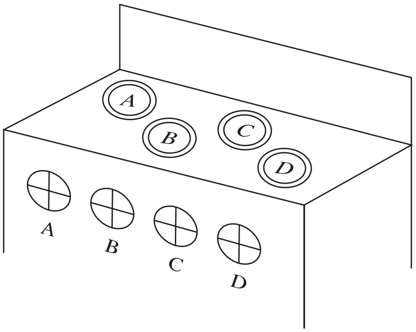


Figure 7–12 | Spatial compatibility of controls and burners on a stove top.

COMPATIBILITY OF CODING SCHEMES

Compatibility refers to the relationship of stimuli and responses that are consistent with human expectations, resulting in decreased errors and faster response time. This can occur at several levels: conceptual, movement, spatial, and modality. Conceptual compatibility refers to how meaningful the codes are to the individuals using them. Red is an almost universal code for danger or stop. Similarly pictorial realism is very useful, for example, a symbol for a female on a door indicating women's toilets. Movement compatibility refers to the relationship between the movement of controls and displays and is discussed further in Chapter 5. Spatial compatibility refers to the physical arrangement of controls and displays. The classic example (see Figure 7–12) is the optimum arrangement of knobs to control the burners on a stove from Chapanis and Lindenbaum (1959). Modality compatibility refers to using the same stimulus modality for both the signal and response. For example, verbal tasks (responses to verbal commands) are performed best with auditory signals and spoken responses. Spatial tasks (moving a cursor to a target) are performed best with a visual display and a manual response.

REDUNDANCY FOR CRITICAL SITUATIONS

When several dimensions are combined in a redundant manner, the stimulus or code will be more likely to be interpreted correctly and fewer errors will be made. The stop sign is a good example with three redundant codes: the words "stop," the universal red color, and the unique (among traffic signs) octagonal shape. Note that these dimensions are all in the visual modality. Using two different modalities will improve the response as compared to two different dimensions within a modality. Thus, for an emergency evacuation of a plant in case of a fire, using both an auditory signal (a siren) and a visual signal (flashing red lights) will be more effective than either modality alone. The trade-off, as discussed earlier in this chapter, is a reduction in the number of potential codes available and a reduction in the amount of information that can be presented.

MAINTAINING CONSISTENCY

When coding systems have been developed by different people in different situations, it is important to maintain consistency. Otherwise, especially under times of stress, it is likely that operators will respond instinctively to previous habits and errors will occur. Therefore, as new warnings are added to a factory having an existing warning system, it is important that the coding system duplicate the existing scheme when the same information is being transmitted, even though the old system might not have had the most optimum design in the first place. For example, the color yellow, typically meaning proceed with caution, should have the same meaning for all displays.

DISPLAY OF VISUAL INFORMATION: SPECIFIC DESIGN PRINCIPLES

FIXED SCALE, MOVING POINTER DESIGN

There are two major alternative analog display designs: a fixed scale with a moving pointer and a moving scale with a fixed pointer (see Figure 7–13). The first is the preferred design because all major compatibility principles (as discussed in Chapter 5) are maintained: increasing values on the scale go from left to right and a clockwise (or left to right) movement of the pointer indicates increasing values. With a moving scale and fixed pointer, one of these two compatibility principles will always be violated. Note that the display itself can be circular, semicircular, a vertical bar, a horizontal bar, or an open window. The only situation in which the moving scale and fixed pointer design has an advantage is for very large scales, which cannot be fully shown on the fixed scale display. In that

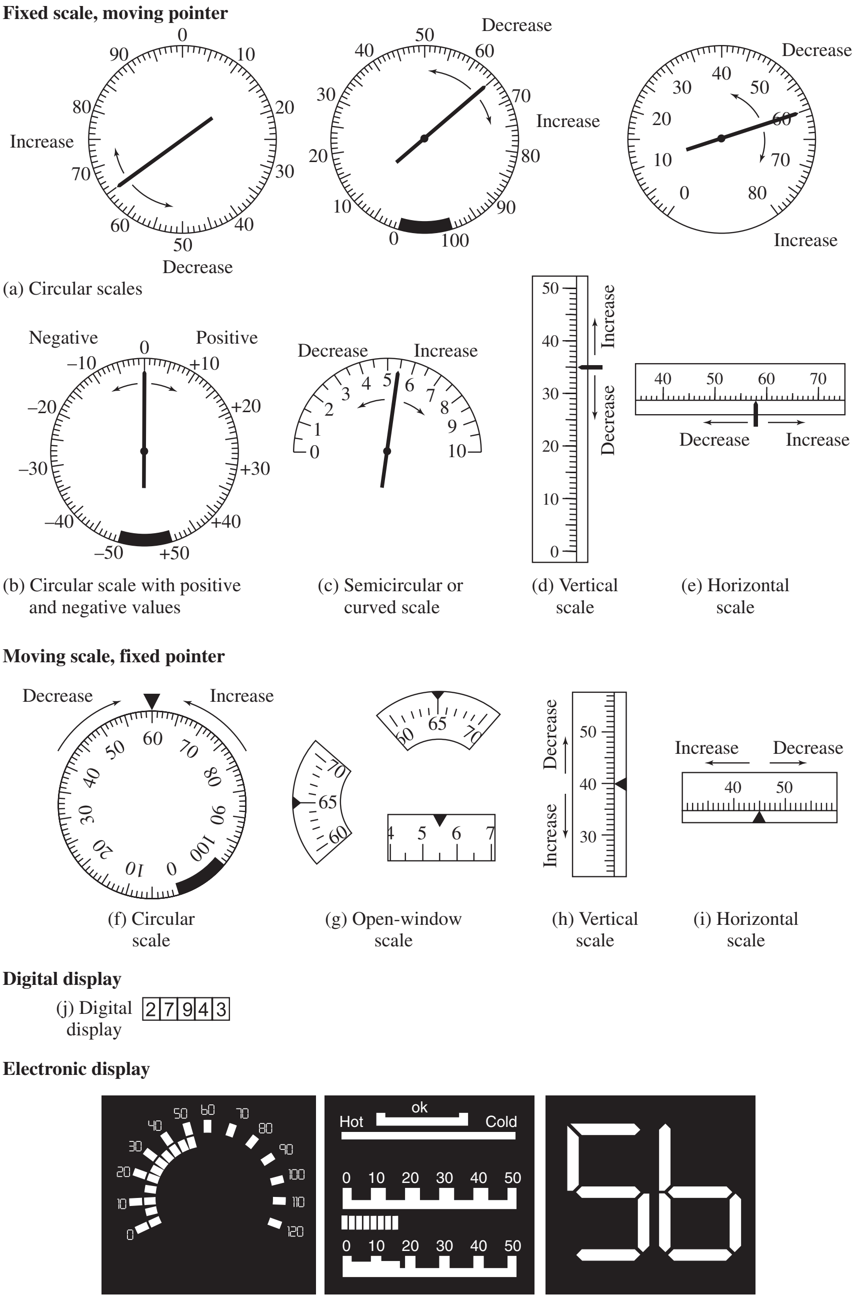


Figure 7–13 | Types of displays for presenting quantitative information. (*From:* Sanders and McCormick, 1993. Reproduced with permission of the McGraw-Hill Companies.)

Table 7–2 | Comparison of Pointers, Scales, and Counters

	Service rendered			
Indicator	**Quantitative reading**	**Qualitative reading**	**Setting**	**Tracking**
Moving pointer . . .	Fair	Good (changes are easily detected)	Good (easily discernible relation between setting knob and pointer)	Good (pointer position is easily controlled and monitored)
Moving scale	Fair	Poor (may be difficult to identify direction and magnitude)	Fair (may be difficult to identify relation between setting and motion)	Fair (may have ambiguous relationship to manual-control motion)
Counter	Good (minimum time to read and results in minimum error)	Poor (position change may not indicate qualitative change)	Good (accurate method to monitor numerical setting)	Poor (not readily monitored)

case an open window display can accommodate a very large scale in back of the display with only the relevant portion showing. Note that the fixed scale and moving pointer design can display very nicely quantitative information as well as general trends in the readings. Also, the same displays can be generated with computer graphics or electronics without a need for traditional mechanical scales.

DIGITAL DISPLAYS FOR PRECISION

When precise numeric values are required and the values remain relatively static (at least long enough to be able to be read), then a digital display or *counter* should be utilized (see Figure 7–12). However, once the display changes rapidly, then counters become difficult to use. Also, counters are not good for identifying trends. Thus, digital counters were never very successful as a “high-tech” feature for automobile speedometers. A more detailed comparison in Table 7–2 shows the advantages and disadvantages of using moving pointers, moving scales and counters.

DISPLAY BASIC FEATURES

Figure 7–14 illustrates some of the basic features utilized in a dial design. The scale range is clearly depicted with an orderly numerical progression with numbered major markers at 0, 10, 20, and so on, and minor markers at every unit. An intermediate marker at 5, 15, 25, and so on, helps identify readings better. A progression by 5s is less good but still satisfactory. The pointer has a pointed tip just meeting, but not overlapping, the smallest scale markers. Also, the pointer should be close to the surface of the scale to avoid parallax and erroneous readings.

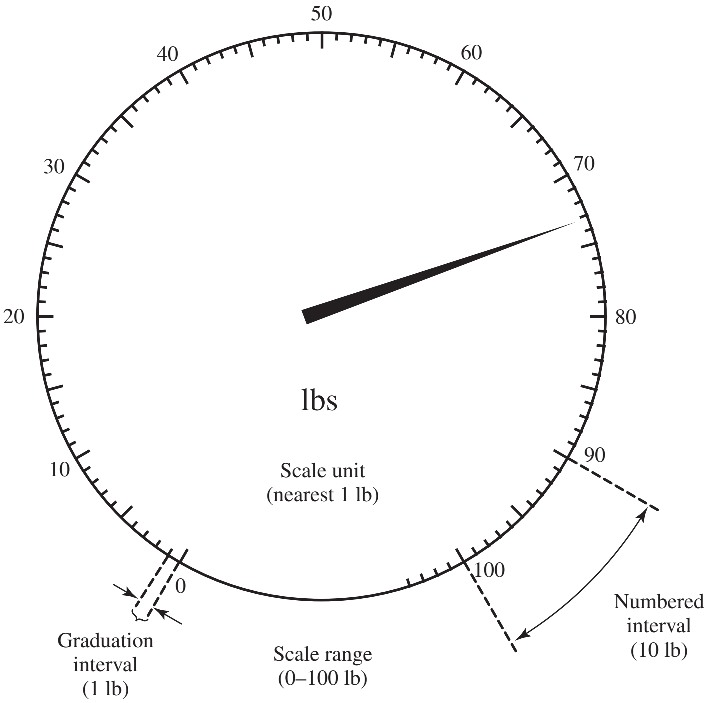


Figure 7–14 | Basic features in the design of a dial.

PATTERNS FOR A PANEL OF DIALS

Usually a panel of dials is used to indicate the status of a series of pressure lines or valves as in the control room of a power plant. In such cases, the operator is primarily a monitor, performing check readings to ascertain whether readings (and the status of the system) are normal. Although the actual dials may be quantitative, the operator is primarily determining whether any one dial is indicating a condition out of a normal range. Thus, the key design aspect is to align all normal states and all dial pointers in the same direction, such that any change or deviant reading will stand out from the others. This pattern is accentuated by having extended lines between dials (see Figure 7–15).

MINIMIZING INFORMATIONAL LOADING ON THE WORKER

Human error in reading display information increases as the amount of information per unit area increases. Always consider Miller's rule in limiting the amount of information presented. Proper coding of the information improves readability of the displays and decreases the number of errors. In general, color, symbols or

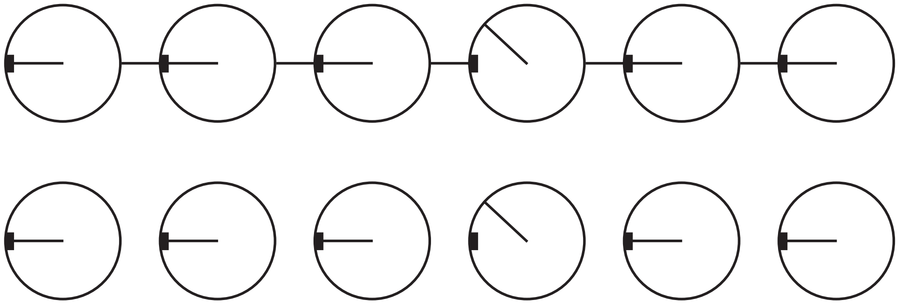


Figure 7–15 | Panel of dials designed for check reading.
(*From:* Sanders and McCormick, 1993. Reproduced with permission of the McGraw-Hill Companies.)

Table 7–3 | Recommended Coding of Indicator Lights

		Color			
Diameter	**State**	**Red**	**Yellow**	**Green**	**White**
12.5 mm	Steady	Failure; Stop action; Malfunction	Delay; Inspect	Circuit energized; Go ahead: Ready; Producing	Functional; In position; Normal (on)
25 mm or larger	Steady	System or subsystem in stop action	Caution	System or subsystem in go-ahead state	
25 mm or larger	Flashing	Emergency condition			

geometric figures, and alphanumerics are the best coding methods. These require little space and allow easy identification of information.

INDICATOR LIGHTS TO GET THE ATTENTION OF THE WORKER

Indicator or warning lights are especially good in attracting attention to potentially dangerous situations. Several basic requirements should be incorporated into their use. They should indicate to the operator what is wrong and what action should be taken. In poor background conditions with poor contrasts, a red (typically a serious situation), a green, and a yellow (less-serious condition) light have advantages over a white light. In terms of size and intensity, a good rule is to make it twice the size (at least 1 degree of visual arc) and brightness of other panel indicators, and place it not more than 30 degrees off the operator's line of sight. A flashing light, with a flash rate between 1 to 10 per second, will especially attract attention. Immediately after the operator takes action, the flashing should stop, but the light should remain on until the improper condition has been completely remedied. Further details on the coding of indicator lights are given in Table 7–3.

PROPER SIZE ALPHANUMERIC CHARACTERS FOR LABELS

For the most effective alphanumeric coding use recommended illumination levels (see Chapter 6) and consider the following information on letter height, stroke width, width-height ratio, and font. Based on a viewing distance of 20 inches (51 cm), the letter or numeral height should be at least 0.13 inches (0.325 cm) and the stroke width at least 0.02 inches (0.055 cm), to give a stroke width-height ratio of 1:6. This creates a preferred visual angle (see Chapter 6) of 22 arc minutes as recommended by ANSI/HFS 100 (1988) or a point size of 10 as typically found in newspapers (one point equals 1/72 inch or 0.035 mm). For distances other than 20 inches (51 cm), the value can be scaled so as to yield a comparable visual angle (e.g., for a distance of 40 inches, sizes would be doubled).

The above recommendations refer to dark letters on a white background, the preferred format for reading for well-illuminated areas (e.g., typical work areas with windows or good lighting). White letters on a dark background are more appropriate for dark areas (e.g., nighttime conditions) and have a narrower stroke width (1:8 to 1:10 ratio) due to a spreading effect of the white letters. The font refers to the style of type such as Roman, with serifs or the special embellishments on the ends of the strokes, or Gothic, without serifs. In general, a mix of uppercase and lowercase letters is easier for extended reading. However, for special emphasis and attracting attention, as in labels, boldface or uppercase letters with a width-height ratio of about 3:5 are useful (Sanders and McCormick, 1993).

DISPLAY OF AUDITORY INFORMATION: SPECIFIC DESIGN PRINCIPLES

AUDITORY SIGNALS FOR WARNINGS

As discussed previously, there are special characteristics of the auditory system that warrant using an auditory signal for warnings. Simple reaction time is considerably quicker to auditory than visual signals (e.g., consider the starter pistol to start races). An auditory signal places much higher attentional demands on the worker than a visual signal. Since hearing is omnidirectional and sound waves penetrate barriers (to some degree, depending on thickness and material properties), auditory signals are especially useful if workers are at an unknown location and moving about.

TWO-STAGE AUDITORY SIGNALS

Since the auditory system is limited to short and simple messages, a two-stage signal should be considered when complex information is to be presented. The first stage should be an attention-demanding signal to attract attention, while the second stage would be used to present more precise information.

HUMAN ABILITIES AND LIMITATIONS

Since human auditory sensitivity is best at approximately 1,000 Hz, use auditory signals with frequencies in the range of 500 and 3,000 Hz. Increasing signal intensity will serve two purposes. First it will increase the attention-demanding quality of the signal and decrease response time. Second, it will tend to better differentiate the signal from background noise. On the other hand, one should avoid excessive levels (e.g., well above 100 dB) as these will tend to cause a startle response and perhaps disrupt performance. Where feasible, avoid steady-state signals so as to avoid adaption to the signal. Thus, *modulation* of the signal (i.e., turning the signal on and off in a regular cycle), in the frequency range of 1 to 3 Hz will tend to increase the attention-demanding quality of the signal.

ENVIRONMENTAL FACTORS

Since sound waves can be dispersed or attenuated by the working environment, it is important to take environmental factors into account. Use signal frequencies below 1,000 Hz when the signals need to travel long distances (i.e., more than 1,000 ft), because higher frequencies tend to be absorbed or dispersed more easily. Use frequencies below 500 Hz when signals need to bend around obstacles or pass through partitions. The lower the signal frequency the more similar sound waves become to vibrations in solid objects, again with lower absorption characteristics.

DISSOCIATING THE SIGNAL FROM NOISE

Auditory signals should be as separate as possible from other sounds, whether useful auditory signals or unneeded noise. This means the desired signal should be as different as possible from other signals in terms of frequency, intensity, and modulation. If possible, warnings should be placed on a separate communication channel to increase the sense of *dissociability* and increase the attention-demanding qualities of the warning.

The above principles for designing displays, both auditory and visual, are summarized as an evaluative checklist in Figure 7–16. If purchased equipment has dials or other displays that don’t correspond to these design guidelines, then there is the possibility for operator error and potential loss. If at all possible, those problems should be corrected or the displays replaced.

HUMAN COMPUTER INTERACTION: HARDWARE CONSIDERATIONS

KEYBOARDS

The standard computer keyboard used today is based on the typewriter key layout patented by C. L. Sholes in 1878. Termed a *QWERTY keyboard,* because of the sequence of the first six leftmost keys in the third row, it has the distinction of allocating some of the most common English letters to the weakest fingers.

General Principles	Yes	No
1. Is the number of absolute judgments limited to 7±2 items?	☐	☐
2. Is the difference between coding levels well above the JND?	☐	☐
3. Is the coding scheme compatible with human expectations?	☐	☐
4. Is the coding scheme consistent with existing schemes?	☐	☐
5. Is redundancy utilized for critical situations?	☐	☐

Visual Displays		
1. Is the message long and complex?	☐	☐
2. Does the message deal with spatial information?	☐	☐
3. Does one need to refer to the message later?	☐	☐
4. Is hearing overburdened or is noise present?	☐	☐
5. Is the operator in a stationary location?	☐	☐
6. For general purpose and trends, is a fixed-scale, moving-pointer display being used?	☐	☐
a. Do scale values increase from left to right?	☐	☐
b. Does a clockwise movement indicate increasing values?	☐	☐
c. Is there an orderly numerical progression with major markers at 0, 10, 20, etc.?	☐	☐
d. Are there intermediate markers at 5, 15, 25, etc. and minor markers at each unit?	☐	☐
e. Does the pointer have a pointed tip just meeting the smallest scale markers?	☐	☐
f. Is the pointer close to the surface of the scale to avoid parallax?	☐	☐
7. For a very large scale, is an open-window display being used?	☐	☐
8. For precise readings, is a digital counter being used?	☐	☐
9. For check reading of a panel of dials, are pointers aligned and a pattern utilized?	☐	☐
10. For attentional purposes, are indicator lights being used?	☐	☐
a. Do the lights flash (1 to 10/sec) to attract attention?	☐	☐
b. Are the lights large (1 degree of visual arc) and bright?	☐	☐
c. Does the light remain on until the improper condition has been remedied?	☐	☐
11. Are alphanumeric characters of proper size?	☐	☐
a. Are they at least a 10 point font at a distance of 20 inches (22 min of visual arc)?	☐	☐
b. In a well-illuminated area, are the letters dark on a light background? Do they have a stroke width-to-height ratio of approximately 1:6?	☐	☐
c. In a dark area, are the letters white on a dark background?	☐	☐
Do they have a stroke width-to-height ratio of approximately 1:8 for nighttime use?	☐	☐
d. Are both uppercase and lowercase letters utilized?	☐	☐
e. For special emphasis, are capitals or boldface utilized?	☐	☐

Auditory Displays	Yes	No
1. Is the message short and simple?	☐	☐
2. Does the message deal with events in time?	☐	☐

Figure 7–16 | Display design checklist.

3. Is the message a warning or is immediate action required? ☐ ☐
4. Is vision difficult or overburdened? ☐ ☐
5. Is the operator moving about? ☐ ☐
6. Is a two-stage signal being utilized? ☐ ☐
7. Is the frequency of the signal in the range of 500 to 3,000 Hz for best auditory sensitivity? ☐ ☐
8. Is the sound level of the signal well above background noise? ☐ ☐
9. Is the signal being modulated (1 to 3 Hz) to attract attention? ☐ ☐
10. If the signal is traveling over 1,000 ft or around obstacles, is the frequency below 500 Hz? ☐ ☐
11. If a warning, is a separate communication channel being used? ☐ ☐

Figure 7–16 | (continued)

One potential explanation is that the most commonly used keys were separated from each other so that they would not jam upon rapid sequential activation. Other more scientifically based alternative layouts, which allocate the letters more proportionately, have been developed, with the 1936 Dvorak keyboard being the most notable. However, scientific studies have shown the Dvorak layout to achieve at most a 5 percent improvement over the QWERTY layout, which is probably not a large enough improvement to justify switching and retraining millions of operators.

In certain special circumstances such as stenotyping and mail sorting, a *chord keyboard* may be more appropriate. Whereas in a standard keyboard, individual characters are keyed in sequentially, a chord keyboard requires the simultaneous activation of two or more keys. The basic trade-off is that with such activation, fewer keys are required and considerably more (estimates of 50 percent to 100 percent) information can be entered. It also has the distinct advantage of small size and one-handed operation, allowing the other hand to perform other tasks. However, for general use, the standard keyboard is more than sufficient without the need for additional specialized training.

Many keyboards will have a separate numeric keypad. Early research on telephones established that users preferred that numerals increased from left to right and then from top to bottom, which resulted in the standard layout for telephones. An alternate layout was developed for calculators, in which the numbers increased from the bottom to the top. Most research has shown that the telephone layout is slightly but significantly faster and more accurate than the calculator layout. Unfortunately, the difference was not large enough for the ANSI/HFS 100 standard (Human Factors Society, 1988) to favor one over the other, resulting in, perhaps, the worst situation in performance, with an operator having to alternate between both layouts in an office environment (e.g., a telephone next to a computer keyboard).

For any keyboard the keys should be relatively large, spaced center to center 0.71–0.75 inches (18-19 mm) horizontally and 0.71–0.82 inches (18–21 mm) vertically. Smaller keys, which are becoming more common as PCs become smaller and smaller, become a disadvantage to individuals with large fingers with a definite decrease in speed and an increase in errors. The keys will have a preferred displacement between 0.08–0.16 inches (2.0–4.0 mm) with the key force not to exceed 0.33 lb (1.5 N). Actuation of a key should be accompanied by either tactile or auditory feedback. Traditionally, a slight upward slope (0–15°) has been advocated. However, more recent research shows that a slight downward slope of −10° may actually provide a more neutral and favorable wrist posture. Also split keyboards have been shown to reduce the ulnar deviation commonly found while using traditional one-piece keyboards. As mentioned in Chapter 5, armrests provide shoulder/arm support and reduce the shoulder muscle activity. These are recommended in place of the more commonly seen wrist rest, which may actually increase the pressure in the carpal tunnel and increase operator discomfort.

POINTING DEVICES

The primary device for data entry is the keyboard. However, with the growing ubiquitousness of graphical user interfaces and depending on the task performed, the operator may actually spend less than half the time using the keyboard. Especially for window and menu-based systems, some type of a cursor-positioning or a pointing device better than the cursor keys on a keyboard is needed. A wide variety of devices has been developed and tested. The *touch screen* uses either a touch-sensitive overlay on the screen or senses the interruption of an infrared beam across the screen as the finger approaches the screen. This approach is quite natural with the user simply touching the target directly on the screen. However, the finger can obscure the target and, in spite of the fairly large targets required, accuracy can be poor. The *light pen* is a special stylus linked to the computer by an electrical cable that senses the electron scanning beam at the particular location on the screen. The user has a similar natural pointing response as with a touch screen, but usually with more accuracy.

A *digitizing tablet* is a flat pad placed on the desktop, again linked to the computer. Movement of a stylus is sensed at the appropriate position on the tablet, which can either be absolute (i.e., the tablet is a representation of the screen) or relative (i.e., only direct movement across the tablet is shown). Further complications are tablet size versus accuracy trade-offs and optimum control-response ratios. Also, the user needs to look back at the screen to receive feedback. Both displacement and force joysticks (currently termed track sticks or *track points*) can be used to control the cursor and have a considerable background of research on types of control systems, types of displays, control-response ratios, and tracking performance. The *mouse* is a hand-held device with a roller ball in the base to control position and one or more buttons for other inputs. It is a relative positioning device and requires a clear space next to the keyboard for operation. The *trackball,* an upside-down mouse without the mouse pad, is a good alternative for work surfaces with limited space. More recently, *touchpads,* a form of digitizing tablets integrated into the keyboard, have become popular especially for notebook PCs.

A number of studies have compared these pointing devices, showing clear speed-accuracy trade-offs, i.e. the fastest devices (touch screens and light pens) being quite inaccurate. Keyboard cursor keys were very slow and probably not acceptable. Touch pads were a bit faster than joysticks, but were less preferred by users. Mice and trackballs were generally similarly good both in speed and accuracy and, probably, indicate, why mice are so ubiquitous. However, there is a tendency for users to overgrip a mouse by a factor of two to three (i.e., use two to three times more than the minimum force required), with potential risk of incurring an injury. Use of a drag-lock, similar to what is found on trackballs, would reduce this risk. For a more detailed review of cursor-positioning devices, please refer to Greenstein and Arnaut (1988) or Sanders and McCormick (1993).

MONITOR SCREENS

The center of the monitor screen should be placed at the normal line of sight, which is roughly about 15 degrees below the horizontal. For a 15-inch screen, at a typical 16-inch reading distance, the edges are only slightly beyond the recommended ±15 degree cone of primary visual field. The implication is that within this optimal cone, no head movements are needed and eye fatigue is minimized. Thus, the top of the screen should not be above the horizontal plane through the eyes.

A 16-inch reading distance, however, may not be optimal. A comfortable reading distance is a function not only of the size of the displayed characters, but also of the person's ability to maintain focus and alignment of the eyes. The mean resting focus (measured in the dark or in the absence of a stimulus with a laser optometer) is roughly 24 inches. The implication is that the eye may be under greater stress when viewing characters at distances larger or smaller than 24 inches, because then there will be compromise between the "pull" of the stimulus and the tendency of the eye to regress toward the individual's resting position. However, there is a large variation in individual resting focus distances. Therefore, office workers that view computer screens for extended periods of time may wish to have their eyes measured for their resting focus. Then if they are not able to set the monitor screen at the appropriate distance (e.g., excessive short or long distances), they can have their eyes fitted with special "computer-viewing" lenses (Harpster et al., 1989).

The monitor, preferably tiltable, should be placed relatively vertical such that the angle formed by the line of sight and the line normal to surface of the display is relatively small, but definitely less than 40 degrees. Tilting the screen upward should be avoided due to an increased likelihood of developing specular reflections from overhead lighting leading to glare and decreased visibility. The screen should have minimum flicker, uniform luminance, and glare control if needed (polarizing or micromesh filters). Further details on hardware and furniture requirements for computer workstations can be found in the ANSI/HFS 100 standard (Human Factors Society, 1988).

NOTEBOOKS AND HAND-HELD PCS

Portable PCs, or laptop or notebook computers are becoming very popular, accounting for 34 percent of the U.S. PC market in 2000. Their main advantage over a desktop is reduced size (and weight) and portability. However, with the smaller size, there are distinct disadvantages; smaller keys and keyboard, keyboard attached to screen, and lack of a peripheral cursor-positioning devices. The lack of adjustability in placing the screen has been found to give rise to excessive neck flexion (much beyond the recommended 15 degrees), increased shoulder flexion, and elbow angles greater than 90 degrees, which has accelerated feelings of discomfort as compared to using a desktop PC. Adding an external keyboard and raising the notebook computer or adding an external monitor helps alleviate the situation.

Even smaller handheld computers, termed *personal digital assistants,* have been developed but are too new to have had detailed scientific evaluations performed. Being pocket-sized, they offer much greater portability and flexibility, but at an even greater disadvantage for data entry. Decrements in accuracy and speed, when entering text via the touchscreen, have been found. Alternate input methods such as handwriting or voice input may be better.

HUMAN COMPUTER INTERACTION: SOFTWARE CONSIDERATIONS

The typical industrial or methods engineer will not be developing programs but will, most likely, be using a variety of existing software. Therefore that person should be aware of current software features or standards that allow best human interaction with the computer and minimize the number of errors that could occur through poor design.

Most current interactive computing software utilizes the *graphical user interface* (GUI), identified by four main elements: windows, icons, menus, and pointers (sometimes collectively termed WIMP). *Windows* are the areas of the screen that behave as if they were independent screens in their own right. They typically contain text or graphics and can be moved around or resized. More than one window can be on a screen at once, allowing users to switch back and forth between various tasks or information sources. This leads to a potential problem of windows overlapping each other and obscuring vital information. Consequently, there needs to be a layout policy with windows being tiled, cascaded, or picture-in-a-picture (PIP). Usually windows have features that increase their usefulness such as scrollbars, allowing the user to move the contents of the window up and down or from left to right. This makes the window behave as if it were a real window onto a much larger world, where new information is brought into view by manipulating the scrollbars. There is usually a title bar attached to the top of the window, identifying it to the user, and there may be special boxes in the corners of the window to aid in resizing, and closing.

Icons are small or reduced representations of windows or other entities within the interface. By allowing icons, many windows can be available on the screen at the same time, ready to be expanded to a useful size by clicking on the icon with a pointer (typically a mouse). The icon saves space on the screen and serves as a reminder containing the dialog. Other useful entities represented by icons include a wastebasket for deleting unwanted files, programs, applications, or files accessible to the user. Icons can take many forms: they can be realistic representations of the objects they stand for or they can be highly stylized, but with appropriate reference to the entity (known as compatibility) so that users can easily interpret them.

The *pointer* is an important component of the WIMP interface, since the selection of an appropriate icon requires a quick and efficient means of directly manipulating it. Currently the mouse is the most common pointing device, although joysticks and trackballs can serve as useful alternatives. A touch screen, with the finger serving as a pointer, can serve as very quick alternative and even redundant backup/safety measure in emergency situations. Different shapes of the cursor are often used to distinguish different modes of the pointer, such as, an arrow for simple pointing, cross-hairs for drawing lines, and a paintbrush for filling in outlines. Pointing cursors are essentially icons or images and thus should have a hot spot that indicates the active pointing location. For an arrow, the tip is the obvious hot spot. However, cutesy images (e.g., dogs and cats) should be avoided because they have no obvious hot spot.

Menus present an ordered list of operations, services, or information that is available to the user. This implies that the names used for the commands in the menu should be meaningful and informative. The pointing device is used to indicate the desired option, with possible or reasonable options highlighted and impossible or unreasonable actions dimmed. Selection usually requires an additional action by the user, usually clicking a button on a mouse or touching the screen with the finger or a pointer. When the number of possible menu items increases beyond a reasonable limit (typically 7 to 10), the items need to be grouped in separate windows with only the title or a label appearing on a menu bar. When the title is clicked, the underlying items pop up in a separate window known as a pull-down menu. To facilitate finding the desired item, it is important to group menu items by functionality or similarity. Within a given window or menu, the items should be ordered by importance and frequency of use. Opposite functions, such as SAVE and DELETE, should be clearly kept apart to prevent accidental misselection.

Other menulike features include buttons, isolated picture-in-picture windows within a display that can be selected by the user to invoke specific actions, toolbars, a collection of buttons or icons, and dialog boxes that pop up to bring important information to the user's attention such as possible errors, problems, or emergencies.

Other principles in screen design include simple usability considerations: orderly, clean, clutter-free appearance, expected information located where it should be consistently from screen to screen for similar functions or information. Eye-tracking studies indicate that the user's eyes typically move first to the upper left center of the display and then move quickly in a clockwise direction. Therefore, an obvious starting point should be located in the left upper corner of the screen, permitted the standard left-to-right and top-to-bottom reading pattern found in Western cultures. The composition of the display should be visually pleasing with balance, symmetry, regularity, predictability, proportion, and sequentiality. Density and grouping are also important features.

The appropriate use of uppercase and mixed-case fonts is important, with special symbols thrown in as necessary. Any text should be brief and concise with familiar words with minimal jargon. Simple action terms expressed in a positive mode are much more effective than some negative statements or standard military jargon. Color is appropriate to draw attention but should be used sparingly and limited to no more than eight colors. Note that a relatively high proportion of the population suffers from deficiencies in color vision.

The user should always feel under control and have the ability to easily exit screens or modules and undo previous actions. Feedback should appear for any actions and the progress indicated for any long transactions. Above all, the main consideration in any display should be simplicity. The simpler the design, the quicker the response. Further information on software interface design can be found in Mayhew (1992), Galitz (1993), and Dix et al. (1998). As a convenience to the purchaser or user of software, the above desired features have been summarized in the Graphical User Interface Features Checklist (see Figure 7-17).

SUMMARY

Chapter 7 presented a conceptual model of the human as an information processor along with the capacities and limitations of such a system. Specific details were given for properly designing cognitive work so as not to overload the human with regard to information presented through auditory and visual displays, to information being stored in various memories, and to information being processed as part of the final decision-making and response-selection step. Also, since the computer is the common tool associated with information processing, issues and design features with regard to the computer workstation were also addressed. With manual work activities, the physical aspects of the workplace and tools, and the working environment having been addressed in Chapters 4, 5, and 6, the cognitive element is the final aspect of the human operator at work and the analyst is now ready to implement the new method.

QUESTIONS

1. How can the informational content of a task be quantified?
2. What is redundancy? Give a good everyday example of redundancy.

Windows Features	Yes	No
1. Does the software use movable areas of the screen termed windows?	☐	☐
2. Is there a layout policy for the windows (i.e., are they tiled, cascaded, or picture-in-picture)?	☐	☐
3. Are there scrollbars to allow the contents of windows to be moved up or down?	☐	☐
4. Are there meaningful titles identifying the windows?	☐	☐
5. Are there special boxes in the corners of the windows to resize or close them?	☐	☐

Icon Features	Yes	No
1. Are reduced versions of frequently used windows, termed icons, utilized?	☐	☐
2. Are the icons easily interpretable or realistic representations of the given feature?	☐	☐

Pointer Features	Yes	No
1. Is a pointing device (mouse, joystick, touch screen) utilized to move icons?	☐	☐
2. Is the pointer or cursor easily identifiable with an obvious active area or hot spot?	☐	☐

Menu Features	Yes	No
1. Are meaningful menus (list of operations) with descriptive titles provided?	☐	☐
2. Are menu items functionally grouped?	☐	☐
3. Are menu items limited to a reasonable number (7 to 10)?	☐	☐
4. Are buttons available for specific common actions?	☐	☐
5. Are toolbars with a collection of buttons or icons used?	☐	☐
6. Are dialog boxes used to notify the user of potential problems?	☐	☐

Other Usability Considerations	Yes	No
1. Is the screen design simple, orderly, and clutter free?	☐	☐
2. Are similar functions located consistently from screen to screen?	☐	☐
3. Is the starting point for the screen action the upper left-hand corner?	☐	☐
4. Does the screen action proceed left to right and top to bottom?	☐	☐
5. Is any text brief and concise and does it use both uppercase and lowercase fonts?	☐	☐
6. Is color used sparingly for attention (i.e., limited to eight colors)?	☐	☐
7. Does the user have control over exiting screens and undoing actions?	☐	☐
Is feedback provided for any action?	☐	☐

Figure 7–17 | Graphical user interface features checklist.

3. Explain the five stages of the human information processing model.
4. How do information processing stages act to prevent an information overload of the human operator?
5. What are the four possible outcomes explained by signal detection theory?
6. Give an example of a task to which signal detection theory can be applied. What effect would a shift in the criterion have on task performance?

7. What is the meaning of sensitivity in signal detection theory? What techniques can be used to increase sensitivity in an inspection task?
8. What techniques can be used to improve memory?
9. What are some of the biases that may negatively affect a person's decision making?
10. What is compatibility? Give two everyday examples of compatibility.
11. Compare and contrast the different types of attention.
12. What is the inverted-U curve in attention?
13. Under what conditions are auditory displays best used?
14. What is the difference between absolute and relative judgment? What is the limitation in absolute judgment?
15. What is the just noticeable difference and how does it relate to the level of the stimulus?
16. Why is redundancy utilized for critical stimuli?
17. Why is a fixed-scale, moving-pointer display preferred?
18. What is the purpose of using patterns for a set of dials in a control room?
19. What key features are used to increase attention in a visual display?
20. What key features are used to increase attention in an auditory display?
21. What are the trade-offs between the different types of pointing devices?
22. What are the main components of a good graphical user interface?

PROBLEMS

1. *a.* What is the amount of information in a set of eight signal lights if each light has an equal probability of occurrence?

   b. The probabilities of the lights are changed as shown below. Calculate the amount of information and the redundancy in this configuration.

Stimulus	1	2	3	4	5	6	7	8
Probability	0.08	0.25	0.12	0.08	0.08	0.05	0.12	0.22

2. A large state university uses three-digit mail stops to code mail on campus. The initial step in sorting this mail is to sort according to the first digit (there are 10 possible), which signifies a general campus zone. This step is accomplished by pushing a key with corresponding number, which dumps the letter in an appropriate bin. A typical mail sorter can sort 60 envelopes per minute and it takes a minimum of 0.3 seconds to just push the key with cognitive processing involved.

   a. Assuming that the mail is distributed evenly over the campus zones, what is the mail sorter's bandwidth?

   b. After a while the sorter notices that campus mail is distributed as follows. If the mail sorter used this information, how many pieces of mail could the sorter possibly handle in one minute?

Zone	% Distribution
0	25
1	15
2	25
3–9	5

3. Bob and Bill are two weather forecasters for AccurateWeather. Bob is a veteran forecaster, while Bill is fresh out of school. The following are the records (in number of predictions) on both forecasters' ability to predict whether it will rain in the next 24 hours.

a. Which forecaster would you hire? Why?

b. Who is a more conservative forecaster? Why?

c. How would a conservative versus a risky forecaster be beneficial for different geographic regions?

	True result	
Bob said:	**Rain**	**No rain**
Rain	268	56
No rain	320	5,318

	True result	
Bill said:	**Rain**	**No rain**
Rain	100	138
No rain	21	349

4. The Dorben Electronics Co., manufacturer of resistors, screens potential quality control inspectors before they are hired. Dorben has developed the following preemployment test. Each potential employee is presented with the same set of 1,000 resistors of which 500 are defective. The results for two applicants are as follows: (1) of the 500 good resistors, applicant #1 labeled 100 as defective, and of the 500 bad resistors, applicant #1 labeled 200 as defective; (2) of the 500 good resistors, applicant #2 labeled 50 as defective, and of the 500 bad resistors, applicant #2 labeled 300 as defective.

a. Treat picking a defective resistor as defective as a hit. Fill in the following table.

	Applicant #1	**Applicant #2**
Hit rate		
False alarm rate		
Miss rate		
Correct rejection rate		
d'		

b. Given that Dorben places a very large emphasis on quality control (i.e., they don't wish to sell a defective product at any cost), which applicant would better fulfill its goal? Why?

c. Given that Dorben wishes to hire the most efficient inspector (i.e., most correct), which applicant would the company hire?

5. The following performance data were collected under similar conditions on two inspectors removing defective products from the assembly line. Comment on the relative performance of the two inspectors. Which one is better at finding defects? Which would you hire if the cost of releasing a defective product would be high? Which does an overall better job? (Hint, consider d′.)

		Case #1	**Case #2**
JRS	Hit rate	0.81	0.41
	False alarm rate	0.21	0.15
ABD	Hit rate	0.84	0.55
	False alarm rate	0.44	0.31

6. The following data *response-time* data (in msec) were obtained on Farmer Brown and his son Big John while operating a tractor using the right foot to control the clutch, brake, and accelerator. The foot is normally kept on the rest position. The location and sizes of the pedals are shown below as well as some sample response times (in msec) for activating a given control from the rest position.

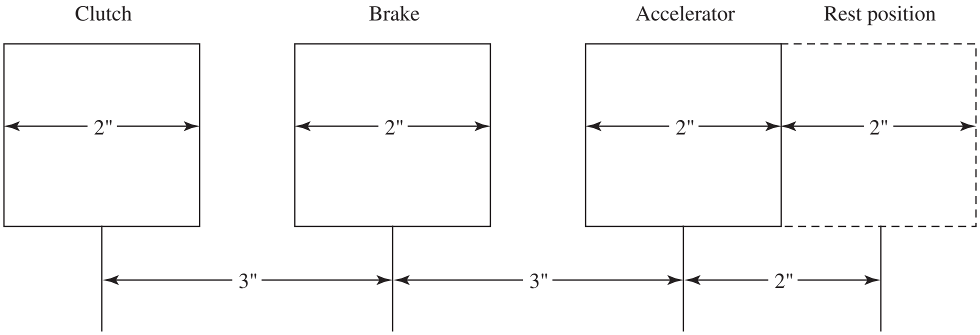
a. What is the index of difficulty value for each pedal?

b. Plot the response times. What law can be used to explain the relationship between response times and the difficulty in activating a given control?

c. What is the simple reaction time for Farmer Brown?

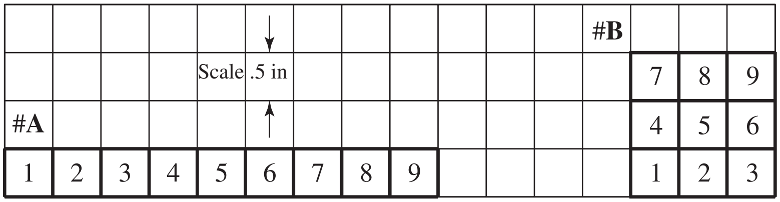
d. What is the bandwidth for Big John?

e. Which farmer is the better tractor operator? Why?



	Accelerator	Brake	Clutch
Farmer Brown	300	432	510
Big John	270	428	480

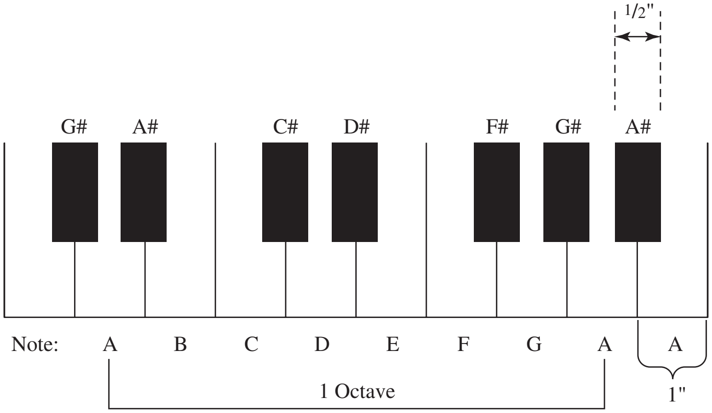
7. Disregarding the digit 0, which keyboard is fastest for entering digits using one finger? Assume that the home position is digit 5. (Hint: Calculate the index of difficulty.)



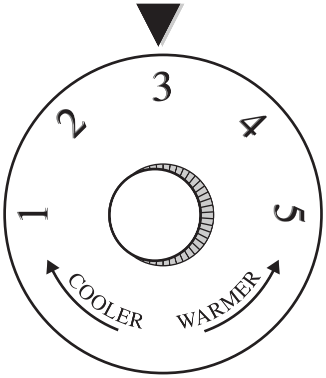
8. Pianists must often hit keys in very quick succession. The figure below displays a typical piano keyboard.

a. Compare the index of difficulty for striking C, C#, F, and F#. Assume one is starting from the A key and distances are measured center to center.

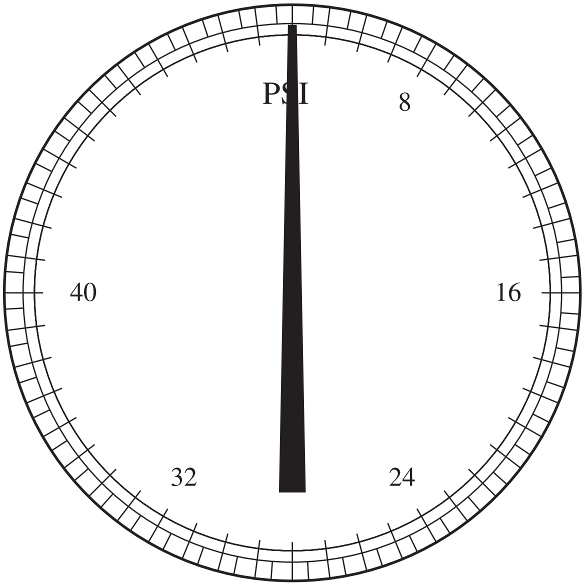
b. If starting from the A key, it takes 200 msec to strike the C key and 500 msec to strike the F key, what is the bandwidth of a typical pianist?



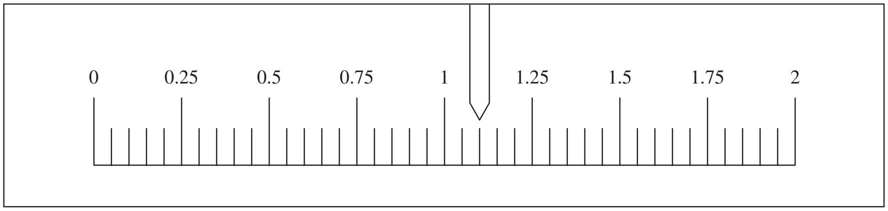
9. The knob with numbers and directional arrows on it shown below is used on refrigerators to control temperature. In which direction, clockwise or counterclockwise, would you turn the knob to make the refrigerator cooler? Why? How would you improve the control to avoid confusion?



10. The dial shown below represents a pressure gage. The operational range is 50 psi. The operator must read the scale to the nearest 1 psi. Critically evaluate the dial indicating the poor design practices. Then redesign the dial following recommended design practices.



11. The scale shown below represents a scale used to measure weight. The maximum weight possible is 2 pounds and the scale must be read to the nearest 0.1 pound. Critically evaluate the dial indicating the poor design practices. Then redesign the dial following recommended design practices.



12. Design an EXIT sign which is to be displayed in a public auditorium. Explain the ergonomics principles that need to be considered for this sign.

REFERENCES

ANSI (American National Standards Institute). *ANSI Standard for Human Factors Engineering of Visual Display Terminal Workstations.* ANSI/HFS 100-1988. Santa Monica, CA: Human Factors Society, 1988.

Bishu, R. R., and C. G. Drury. "Information Processing in Assembly Tasks—A Case Study," *Applied Ergonomics,* 19 (1988), pp. 90–98.

Chapanis, A., and L. Lindenbaum. "A Reaction Time Study of Four Control-Display Linkages," *Human Factors,* 1 (1959), pp. 1–7.

Deatherage, B. H. "Auditory and Other Sensory Forms of Information Presentation," In H. P. Van Cott and R. Kinkade (eds.) *Human Engineering Guide to Equipment Design.* Washington DC: Government Printing Office, 1972.

Dix, A., J. Finlay, G. Abowd, and R. Beale. *Human-Computer Interaction.* 2nd ed. London: Prentice Hall, 1998.

Drury, C. "Improving Inspection Performance." In *Handbook of Industrial Engineering.* Ed. G. Salvendy. New York: Wiley, 1982.

Dury, C. G. and J. L. Addison. "An Industrial Study on the Effects of Feedback and Fault Density on Inspection Performance." *Ergonomics,* 16 (1973), pp. 159–169.

Eggemeier, F. T. "Properties of Workload Assessment Techniques," In *Human Mental Workload.* Ed. P. Hancock and N. Meshkati. Amsterdam: North-Holland, 1988.

Fechner, G. *Elements of Psychophysics.* New York: Holt, Rinehart and Winston, 1860.

Fitts, P. "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement." *Journal of Experimental Psychology,* 47 (1954), pp: 381–391.

Galitz, W. O. *User-Interface Screen Design.* New York: John Wiley & Sons, 1993.

Giambra, L. and R. Quilter. "A Two-Term Exponential Description of the Time Course of Sustained Attention." *Human Factors,* 29, (1987), pp. 635–644.

Green, D. and J. Swets. *Signal Detection Theory and Psychophysics.* Los Altos, CA: Peninsula Publishing, 1988.

Greenstein, J. S. and L. Y. Arnaut. 1988, "Input Devices." In *Handbook of Human-Computer Interaction.* Ed. M. Helander. Amsterdam: Elsevier/North-Holland.

Harpster, J .L., A. Freivalds, G. Shulman, and H. Leibowitz, "Visual Performance on CRT Screens and Hard-Copy Displays, *Human Factors,* 31 (1989), pp. 247–257.

Helander, J. G., T. K. Landauer, and P. V. Prabhu, Eds. *Handbook of Human-Computer Interaction,* 2d ed. Amsterdam: Elsevier, 1997.

Hick, W. E. "On the Rate of Gain of Information". *Quarterly Journal of Experimental Psychology,* 4 (1952), pp. 11–26.

Human Factors Society, 1988, *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations, ANSI/HFS 100-1988.* Santa Monica, CA: Human Factors Society.

Hyman, R. "Stimulus Information as a Determinant of Reaction Time." *Journal of Experimental Psychology,* 45 (1953), pp. 423–432.

Langolf, G., D. Chaffin, and J. Foulke, "An Investigation of Fitts' Law Using a Wide Range of Movement Amplitudes." *Journal of Motor Behavior,* 8, No. 2 (June 1976), pp. 113–128.

Mayhew, D. J. *Principles and Guidelines in Software User Interface Design.* Englewood Cliffs, NJ: Prentice Hall, 1992.

Miller, G. "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information." *Psychological Review,* 63 (1956), pp. 81–97.

Sanders, M. S. and E. J. McCormick, *Human Factors in Engineering and Design.* 7th ed. New York: McGraw-Hill, 1993.

Stroop, J. R. "Studies of Interference in Serial Verbal Reactions." *Journal of Experimental Psychology,* 18 (1935), pp. 643–662.

Wickens, C. D. "Processing Resources in Attention." In *Varieties of Attention.* Ed. R. Parasuraman and R. Davies. New York: Academic Press, 1984.

Wickens, C. D., S. E. Gordon, and Y. Liu, *An Introduction to Human Factors Engineering.* New York: Longman, 1997.

Yerkes, R. M. and J. D. Dodson, "The Relation of Strength of Stimulus to Rapidity of Habit Formation." *Journal of Comparative Neurological Psychology,* 18 (1908), pp. 459–482.

SELECTED SOFTWARE

DesignTools (included with textbook), New York: McGraw-Hill, 2002.

WEBSITES

Examples of bad ergonomic design—http://www.baddesigns.com/