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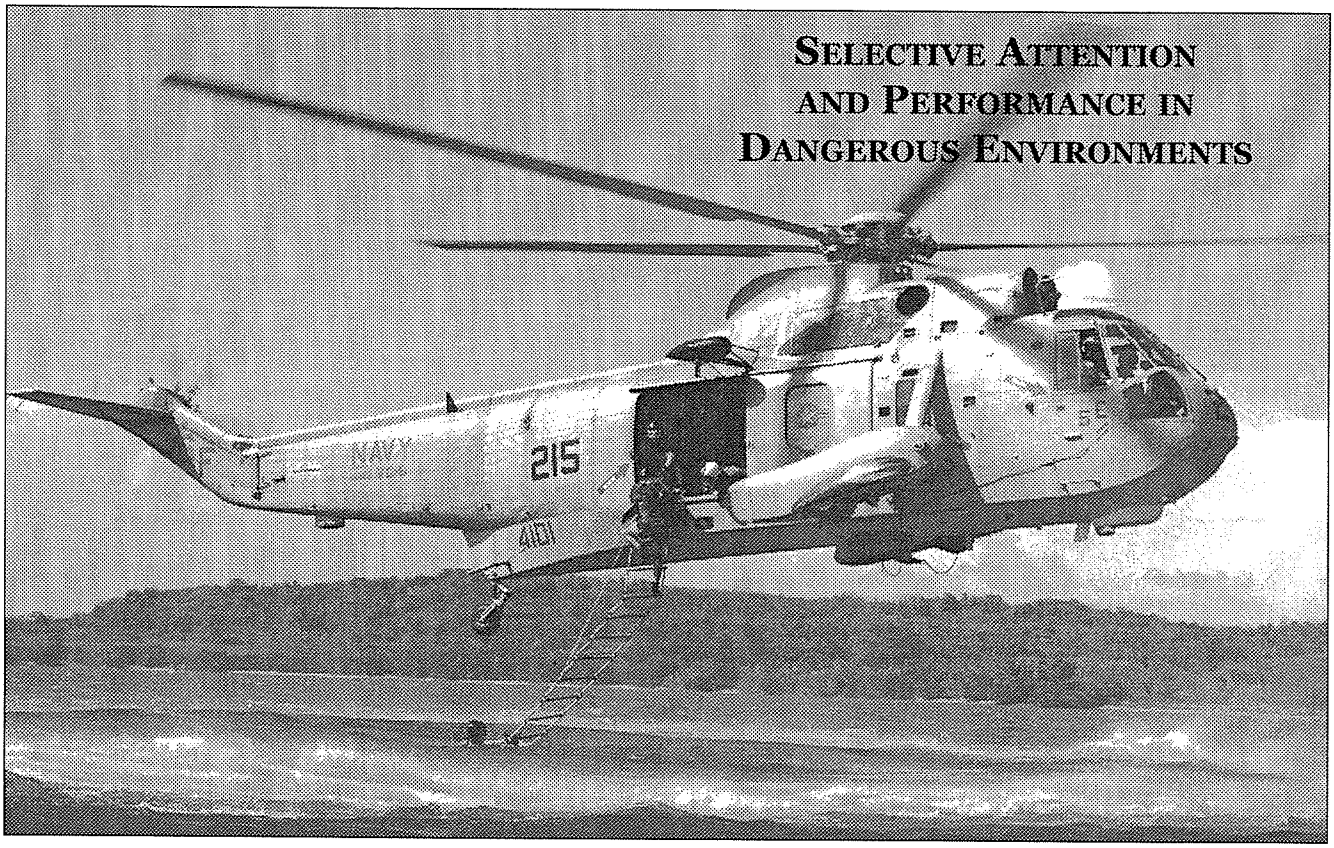
SELECTIVE ATTENTION AND PERFORMANCE IN DANGEROUS ENVIRONMENTS



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Evidence on human performance in dangerous environments is reviewed and suggests that danger reduces efficiency, except in the case of experienced subjects. Perceptual narrowing is shown to be one source of decrement. It is suggested that danger increased the subject's arousal level which influenced performance by producing a narrowing of attention. The nature of the performance decrement and of adaptation to danger are discussed in this context.

The present review was stimulated by a series of experiments on the performance of divers at depth in the open sea. The original aim of these experiments was to study the effects on diver performance of nitrogen narcosis, the intoxication which occurs when air is breathed at high pressure. Discrepancies between open sea results and pressure chamber simulation occurred (Baddeley, 1966; Baddeley & Flemming, 1967), and it subsequently became apparent that degree of danger was a crucial variable (Baddeley, 1967, 1971; Baddeley *et al.*, 1968). What follows attempts to review the literature on performance in danger and to suggest one way in which a subject's information processing capacity may be impaired by fear.

EVIDENCE

Anecdotal

Evidence about the effect of danger on human performance is of three main types: anecdotal, observational and experimental. These will be considered in turn. Perhaps the most abundant source of evidence is from first-hand accounts of behaviour in danger. Unfortunately such evidence is very difficult to evaluate since it is generally highly subjective, liable to forgetting and distortion during recall and by its very nature not replicable. Nevertheless, anecdotal evidence may prove useful both as a source of hypotheses to be tested by more rigorous means and as a concrete illustration of independently established principles. A good example of this is found in the work of Radloff & Helmreich (1968) on Sealab II, the U.S. Navy underwater living project. They use verbatim quotes from interviews with divers to illustrate and amplify conclusions based on more objective procedures, and in doing so give a clearer and more vivid picture. Although useful as an expository device, anecdotes are obviously a dubious source of evidence since they depend on selection by the writer.

Observational

The performance of a soldier in combat is another source of evidence of the effects of danger. It has long been known that the probability that a soldier will use his rifle effectively in the heat of battle is considerably less than in training. For example, after the battle of Gettysburg in the American Civil War, over 200 of the muzzle-loading rifles used were found to have been loaded five or more times without being fired, and one had been loaded 21 times without being fired once (Walker & Burkhardt, 1965). In this case inadequate training was blamed, but more recent reports based, for example, on the Korean war suggest that even with fully trained troops performance in action is much worse than performance in training (Egbert *et al.*, 1957, 1958).

Perhaps the most useful combat information, however, comes from the quantitative evaluation of performance on a complex weapon system in training and under varying degrees of danger. Such an analysis is performed by Walker & Burkhardt (1965) who

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relate performance to degree of combat stress for aircraft weapons involving various types of control. Their results are shown in Fig. 1.

E_S is the ratio of error in combat to error during training, and A, B, C, and D represent different degrees of combat severity, namely: *A,* No losses whatever in combat. B, Consistent losses of 2 per cent of aircraft per raid. C, Consistent losses of 5 per cent of aircraft per raid, the limit of attrition warfare accepted by night-bombing forces in World War II. D, Consistent losses of 10 per cent of aircraft per raid, the limit of heavy combat which is not exceeded lightly for long periods. This was about the average loss rate of the German air force in the Battle of Britain.

The three lines represent different control systems. Line X represents acceleration control with about 1.25 sec. lag. The points come from a number of guided bomb systems, both U.S. and German used in World War II. The results show a decrement of up to 900 per cent as the combat situation becomes more and more dangerous, followed eventually by abandonment of the control. Line Y represents an acceleration control with negligible lag. While there is only one point, the Henschel glide bomb used in the Mediterranean, it appears that eliminating the lag from an acceleration control system greatly reduces its susceptibility to degradation under stress. Line Z represents a velocity control with a short lag, a task which Walker & Burkhardt (1965) suggest is like that of pointing a high-speed aircraft. The points are based on air-to-ground gunnery, air-to-ground rocket fire and dive bombing. Again there is some degradation in performance with increasing stress, but this is very much less than is found with systems involving lagged acceleration control.

As Walker & Burkhardt point out, however, degree of danger is by no means the only determinant of operational effectiveness. Level of motivation is clearly an important factor, a point which is illustrated by Walker & Burkhardt as follows. During World War II, public recognition (being awarded a medal) was usually determined on the basis of tonnage of bombs dropped in enemy territory. In the case of one system, the aircraft could carry only two-thirds the normal load, and in addition bombadiers were instructed to bring the bombs home if target visibility was poor, rather than drop them on alternative targets as was normally the case. Consequently the chance of receiving a medal with this system was only one-third the normal chance, a factor which it is claimed reduced enthusiasm and doubled the error rate. In contrast to this Walker & Burkhardt cite the case of dive bombing in Korea, where the results in 1953 were considerably better than in the previous year despite much stronger oppostiton. They attribute this to the order that in view of the serious military situation, planes were instructed that if they missed the target on the first pass they must continue with second and third passes until the target was destroyed. Since their only chance of survival against really strong opposition was to hit the target on the first pass, they were very strongly motivated to make an accurate first shot. Combat data is inevitably difficult to interpret because of the many complicating factors of this type; nevertheless, in view of the paucity of quantitative data from really dangerous environments it provides valuable evidence.

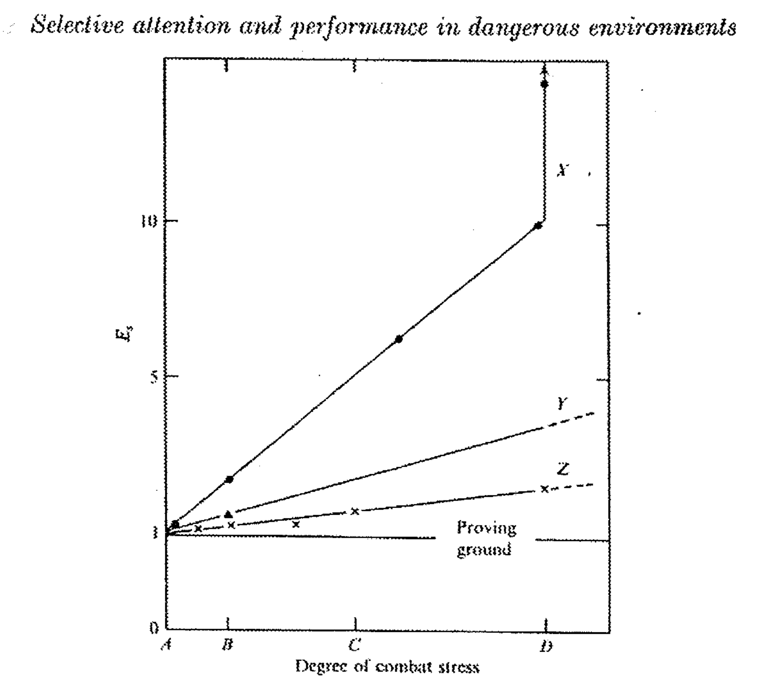

Fig. 1. Performance decrement as a function of degree of combat stress (see text for details): from Walker & Burkhardt (1965).

Experimental

If we are to understand the effects of stress on performance fully, however, it is obviously desirable to carry out controlled experiments. A battlefield, however, is hardly an ideal place for experimentation. This has led to attempts to simulate the battlefield environment, and, provided one is prepared to go to sufficient lengths to deceive the subject, Berkun *et al* (1962) have shown that it is possible to produce a simulated danger situation which will impair performance. They performed two experiments; in the first of these their subjects, servicemen, were taken on a plane flight during which an emergency was simulated. One of the engines stopped and subjects were then told that the plane's landing gear was faulty so that an emergency crash landing in the sea was probable. At this stage they were required to fill in two forms, one about disposition of their private belongings, the other a test of retention of emergency instructions, which it was explained was necessary to convince the insurance company in due course that the appropriate precautions had been taken. The forms were intentionally badly designed to allow scoring in terms of errors. Not surprisingly these subjects made more errors than unstressed controls. The second experiment involved army recruits on a simulated tactical exercise. The subject was isolated except for a telephone link, and was subsequently led to believe that he was either in the path of a forest fire, in an area subject to intense accidental atomic radiation, was being shelled with live ammunition by mistake or that he had inadvertently blown up one of his comrades. All these situations required him to contact headquarters by radio. His radio, however, would not transmit. In order to repair it he had to follow certain instructions each requiring him to perform some task which was automatically timed and led on to another instruction. Physiological and self-rating measures of anxiety were subsequently taken. It was found that the simulated danger situations did produce anxiety and also tended to impair performance. Although these studies show that it is possible to simulate danger successfully, the problems raised by this type of experiment on both moral and practical grounds are considerable, and this does not seem to be a very promising line of development.

A second experimental approach is to take advantage of the fact that people do voluntarily subject themselves to real danger in such activities as parachute jumping, rock climbing, and deep sea diving. A recent study by Hammerton & Tickner (1967) required army parachutists at three levels of practice to perform a tracking task involving velocity control well before, immediately before and immediately after jumping. They found no change in performance for experienced parachutists, but found a significant drop in pre-jump tracking efficiency for regular army trainees and an even greater decrement in the case of territorial army trainees, civilians who train on a part-time basis.

A further source of evidence comes from a series of studies of the performance of divers in the open sea. The first of these (Baddeley, 1966) was concerned with studying the effects of nitrogen narcosis on manual dexterity, and in particular in comparing performance in the open sea with performance in a pressure chamber simulation of depth. The task comprised a 6 x 12 in. brass plate with 32 holes, 16 of which contained nuts and bolts. The diver was required to transfer the 16 nuts and bolts from one end of the plate to the 16 holes at the other end. He was scored in terms of the time taken. In the open sea condition, divers performed the task three times in counterbalanced order, on dry land, and on the sea bed at depths of 10 ft. and 100 ft. The dry condition involved tests at comparable pressures in a dry chamber. Pressure chamber performance showed a significant but small effect of pressure (6 percent), which is comparable in size to that shown in previous pressure chamber studies (Kiessling & Maag, 1962). In the open sea condition, however, the picture was quite different. Performing underwater caused a 28 per cent drop in efficiency, which when combined with the effect of pressure gave a drop of 49 per cent, considerably more than the 34 per cent which would be predicted by simply adding the pressure effect to that of being under water.

A similar exaggerated narcosis effect was found later in a study which compared the performance of divers breathing air with the performance breathing and oxy-helium mixture at a depth of 200 ft. both in the open sea and in a dry pressure chamber (Baddeley & Flemming, 1967). Similar results were obtained by Bowen *et al.* (1966) who studied the performance of divers participating in Sealab II, the U.S. Navy underwater living project. Their divers were also working at a depth of 200 ft. and breathing an oxy-helium mixture. They showed no impairment in performance in a dry test performed inside the underwater house, but showed markedly poorer performance in the open sea than they had shown during prior shallow water tests.

THEORETICAL ISSUES

In general then, those studies agreed in suggesting that a diver in the open sea will show a greater impairment in efficiency at depth than would be expected on the basis of pressure chamber experiments. While it is clearly of practical importance to know this, the possibility of explaining the effect theoretically seemed remote since the observed interaction might be due to any one or more of the many additional stresses that face a diver in the open sea. These include weightlessness, narrowed vision, cumbersome equipment, and possibly anxiety, cold and reduced illumination. An attempt to isolate the cause of the interaction by systematically manipulating these various factors did not seem very feasible. The picture changed dramatically, however, when a subsequent study under almost identical conditions failed to allow the expected interaction (Baddeley *et al.*, 1968). Careful comparison of this with previous studies (Baddeley, 1967) suggested only one major difference, namely the apparent risk involved. This study involved diving from the shore under ideal conditions in a sheltered inlet with clear calm water, and with the sea bed sloping gently down to a sandy plain at 100 ft. The deep condition in the previous studies, however, had always involved diving from a boat in the open sea down into 'the blue', under conditions which were riskier than shore diving, and almost certainly provoked considerably more anxiety. In the case of the study by Bowen *et al.* we know from the work of Radloff & Helmreich (1968) that the divers involved in the project consistently reported being afraid, as indeed they should in view of the enormously hostile environment in which they lived and worked. Further evidence that the interaction effect depends on danger comes from the work of Adolfson (1967) who found no such exaggerated depth effect when divers were tested underwater in the well of a wet-and-dry pressure chamber, a situation involving many of the stresses of actual diving, but with little real danger.

Circumstantial evidence therefore points to anxiety as a crucial factor in the open sea performance of divers and points to the need for a more direct investigation which should include both physiological and performance measures. A recent study by Davis & Osborne (1970) has studied diver performance under relatively stressful conditions off Western Scotland, with simultaneous recording of a number of physiological measures of anxiety. It gave clear evidence of both diver anxiety and of the exaggerated drop in performance found previously under what were subsequently assumed to be stressful open sea conditions. They also noted that the most anxious divers tended to allow the greatest impairment but unfortunately they did not have enough complete data for a correlational analysis.

On the basis of the data so far considered, it seems reasonable to suppose that danger may impair performance. This leads on to the question of how the impairment occurs, and in what way impairment can be minimized. There is very little direct evidence available on this question. We are therefore left with two possible strategies, to wait until more empirical data has accumulated before attempting to theorize, or else to use data from related areas to produce a tentative theory which can then be used in designing further experiments. Research on performance in dangerous environments will almost inevitably involve working outside the laboratory, and as Radloff &, Helmreich (1968, p. 210) point out, in field research, 'A researcher without a model will inevitably become lost in the frustrating complexities of the natural environment. The speculations which follow represent an attempt to provide a partial model, and as such they are presented not as a final answer, but as a tool to assist further research.

There already exists a considerable literature on the effects of physiological arousal on performance, much of which suggests that they are related by a function resembling an inverted U, that is, as arousal increases, performance improves up to a maximum beyond which further increments in level of arousal lead to poorer and poorer performance (Hebb, 1955; Malmo, 1959). A good deal of experimental data can be accounted for in terms of the inverted U function, indeed one of its weaknesses as a theory rests on its ability to account for almost any result so long as the exact location on the inverted U of the task in question is not specified in advance. However, it is possible, as, for example, Corcoran (1965) has shown, to test the assumed function relatively rigorously, provided enough points along the arousal dimension are sampled. The situation is further complicated, however, by the fact that the peak of the inverted U occurs at quite different levels of arousal for different tasks (Corcoran, 1965). This is intuitively reasonable; it seems likely that level of arousal at which a man will run fastest will not be that at which he will, for example, be best at threading a needle. However, unless one has an objective means of assessing a task in advance, prediction of performance under stress becomes even more difficult. It seems unlikely that such an assessment can be made until we know what causes the inverted U relationship.

One possible explanation of the relationship lies in the suggestion made by a number of workers that an increase in arousal produces a narrowing of attention, with the subject concentrating more and more on the central features of the task and paying less and less attention to more peripheral ones (Easterbrook, 1959; Teichner, 1968). Perhaps the strongest experimental evidence for such a view comes from recent work by Hockey (1969, 1970 *a, b*) on the effects of loud noise on performance. In one of his experiments, Hockey (1970*a*) required his subjects to perform a centrally located tracking task, while at the same time monitoring a series of six small lights, distributed on either side of the central task at varying distances from the centre. Occasionally one of these lights would be briefly illuminated; if the subject detected this he pressed an appropriate response button. Subjects were tested both in continuous loud noise and in a quieter condition. Overall tracking performance was significantly higher in the noise condition than in the control condition which allowed a decrement during the session. Detection scores on the peripheral task tended to deteriorate with increasing distance from the centre. Noise exaggerated this bias by improving performance on the central lights at the expense of peripheral lights. When no central task was required, noise improved detection performance (Hockey, 1969), suggesting noise does not impair peripheral vision.

In a subsequent experiment, Hockey (1970*b*) showed that subjects missed more peripheral signals in noise because they regarded them as less probable than central signals, not simply because of their peripheral location. A comparable result was recently reported by Cornsweet (1969) who used threat of electric shock to increase level of arousal. The point is made particularly clearly in a further experiment by Hockey (1969) in which the subject was required to monitor three sources for occasional signals. Each source was checked by pressing one of three buttons and a signal comprised a dim light at the relevant source. The subject could check only one source at a time and the number of checks allowed was limited by the experimenter. Under those conditions, differences in signal probability between the sources tend to be reflected in the frequency of checking, with the sources bearing the greatest number of signals being checked most often. As predicted from the previous studies, when this task is performed in noise, there is an increase in the bias towards sampling the most probable source. Furthermore, when level of arousal is decreased by depriving subjects of a night's sleep the opposite effect occurs; tendency to sample the most probable source is reduced.

Although Hockey's results show a clear effect on breadth of attention of stresses that may reasonably be assumed to influence the subject's level of arousal, we have no direct evidence that danger will have such an effect. Evidence that this is in fact the case comes from a study by Weltman & Egstrom (1967) in which novice divers were required to perform a central task while monitoring a faint peripheral light. While the central task did not affect peripheral vigilance on the surface, during diving a distinct subgroup of the subjects emerged showing much slower responding to the peripheral lights, while showing no impairment on the central task. These subjects appeared to be more anxious than the other subgroup which showed no deterioration under water, but unfortunately no objective measure of anxiety was available. This defect was remedied in a subsequent study (Weltman *et al.*, 1971) in which a similar dual task was performed by naive subjects during a simulated 60 ft. dive in a pressure chamber. After an explanation of the potential dangers and emergency procedures, the door of the pressure chamber was bolted and a rise inpressure simulated, although actual pressure did not change. Experimental subjects showed a clear anxiety response in terms of both increased heart rate and subjective ratings. They also showed a clear decrement in detection of peripheral light signals but no drop in performance on the central task, relative to an unstressed control group.

It seems plausible to assume then that an increase in arousal will focus the subject's attention more and more narrowly on that aspect of the situation that is of greatest immediate importance to him. If this happens to be the task he is required to perform, then his efficiency will be increased. If not, however, his performance will deteriorate until he abandons the task.

Fortunately, however, response to a dangerous environment may be much more adaptive than this, especially as the Hammerton & Tickner (1967) parachutist study showed, if the subject has had considerable prior experience of the danger situation. Why should this be so? Common sense suggests that an experienced parachutist is less anxious because he is more competent and more confident in his ability. Some recent work by Epstein & Fenz (1965), however, suggests a more interesting answer.

ADAPTATION TO DANGER

Epstein & Fenz were interested in parachute jumping as an approach-avoidance conflict: the parachutist wishes to jump and yet he is afraid. In order to examine this they asked their subjects to rate both their keenness and their aversion to jumping at various points during the sequence of events leading to and following a jump. The novice parachutist became less and less eager to jump as jumping time approached, his reluctance reaching a maximum with the ready signal. From then on he showed increasing enthusiasm up to and including landing. Experienced parachutists gave an almost inverse picture with maximal avoidance ratings occurring on the morning of the jump and actually on landing, whereas their points of maximum approach occurred at the point of jumping. Physiological measures based on the galvanic skin response (GSR) supported the self-rating data, with novice parachutists showing a high response before jumping which fell to a more normal level on landing while the experienced parachutists showed completely the reverse effect. Unpublished work of my own has shown a similar effect on heart rate in divers, with novices showing a high pulse rate before the dive, which drops after the dive, whereas experienced divers tend to have a higher pulse rate after the dive.

Epstein & Fenz suggest that the experienced parachutist learns to inhibit anxiety since it tends to disrupt performance. They suggest that both the fear and the inhibition focus on the jump but generalize both temporally, to prior and later aspects of the jumping situation, and to other stimuli associated more or less closely with jumping. If one assumes the generalization gradient associated with the inhibition of fear to be steeper than that associated with fear itself, then the point of maximum emotional response will tend to be displaced away from the danger stimulus; the greater the degree of inhibition, the further away will be the displacement (see Epstein, 1962, for a more detailed discussion of this point). Further evidence in support of such a hypothesis comes from a study in which the GSR of parachutists was recorded on the day of a jump while they produced associations to various words, some of which were related more or less remotely to jumping (examples of words in increasing order of relevance are 'music', 'sky', 'fall' and 'ripcord'). For novices, magnitude of GSR increased monotonically with stimulus relevance, while experienced parachutists give their maximum GSR to remotely relevant stimulus words. Similar results were obtained when subjects were featured to make up stories about pictures which varied in how closely relevant they were to the act of jumping (Epstein, 1962).

It seems then that subjects who are repeatedly exposed to a dangerous situation can in some as yet unspecified way learn to inhibit their anxiety and displace it away from the point of maximum danger. This is likely to be useful for two reasons, first because it prevents performance being impaired at a crucial time, and secondly because the displaced anxiety will tend to act as a warning of impending danger. Much of the process of training a diver seems to consist of exposing him to increasingly stressful exercises within the safety of a swimming pool. In the case of the British Sub-Aqua Club, this culminates in a test in which the diver's equipment is thrown into the pool and he is required to dive in, turn on the air in his aqualung and put all his equipment on without surfacing. The actual motor skills required by this are relatively simple but the emotional control necessary to perform the task is quite considerable. In short it seems likely that such a course is mainly concerned, quite rightly, with teaching the diver an emotional skill. How this skill is achieved is far from clear. Subjectively, the feeling is one of focusing attention firmly on the matter in hand, possibly taking advantage of any narrowing of attention to shut out peripheral fears. Testing such a hypothesis, though not easy, should not prove impossible.

To return to the original problem, can the impaired performance of divers in the open sea be entirely attributed to an arousal-produced narrowing of attention? Such an explanation is adequate only on the assumption that nitrogen narcosis somehow increases level of arousal. This seems unlikely since at depths in excess of 300 ft. subjects are liable to become drowsy and lose consciousness, suggesting, if anything, a reduction in arousal. Subjects in the study by Baddeley & Flemming (1967) all rated themselves as more 'comfortable' at 200 ft. than at 10 ft., which does not suggest a simple increase in arousal due to fear. The same subjects when breathing oxy-helium at 200 ft. made the more rational judgment that they were less comfortable. It seems likely then that nitrogen narcosis has effects other than those due to a change in arousal. One of these is probably a general reduction in information-processing capacity. A similar effect is probably also responsible for the complex interaction of alcohol with other stresses noted by Wilkinson & Colquhoun (1968) and is discussed in a recent paper by Hamilton & Copeman (1970). Using the analogy of a searchlight, level of arousal will determine the breadth of the beam, while stresses such as nitrogen narcosis and alcohol may reduce the total power available.

CONCLUSION

To sum up then, it appears that one way in which danger affects performance is through its influence on the subject's breadth of attention. A dangerous situation will tend to increase level of arousal which in turn will focus the subject's attention more narrowly on those aspects of the situation he considers most important. If the task he is performing is regarded by him as most important, then performance will tend to improve; if on the other hand it is regarded as peripheral to some other activity, such as avoiding danger, then performance will deteriorate. With experience, subjects appear to inhibit anxiety in the danger situation and hence reduce the degree of impairment. We still do not know what mechanisms mediate the effect of arousal on the distribution of attention, or what is involved in the process of adaptation to fear. When we can answer these questions we shall be much closer to understanding human performance in dangerous environments.

I am grateful to N. K. Walker for permission to reproduce Fig. 1.

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